Long-Term Studies of Ecosystem Response to Disturbance Along Environmental Gradients at Coweeta Hydrologic Laboratory

Renewal Proposal Submitted to
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Athens GA 30602

Principal Investigators

Judy L. Meyer	Wayne T. Swank
Institute of Ecology and	Botany Department, UGA and
Zoology Department	Coweeta Hydrologic Laboratory
Athens, Georgia	Otto, North Carolina

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List of Co-Principal Investigators

Benfield, Ernest F., Department of Biology, Virginia Tech, Blacksburg, Virginia 24061

Boring, Lindsay R., School of Forest Resources, University of Georgia, Athens, Georgia 30602

Coleman, David C., Department of Entomology, University of Georgia, Athens, Georgia 30602

Crossley, Jr., D. A., Department of Entomology, University of Georgia, Athens, Georgia 30602

Donaldson, Jennifer, Coweeta Hydrologic Laboratory, USDA Forest Service, 999 Coweeta Lab Road, Otto, North Carolina 28763

Dowd, John, School of Forest Resources, University of Georgia, Athens, Georgia 30602

Fitzgerald, John, Department of Microbiology, University of Georgia, Athens, Georgia 30602

Grossman, Gary, School of Forest Resources, University of Georgia, Athens, Georgia 30602

Haines, Bruce L., Department of Botany, University of Georgia, Athens, Georgia 30602

Huston, Michael, Environmental Sciences Division, Oak Ridge National Lab, Oak Ridge, Tennessee 37831

Meyer, Judy L. Department of Zoology and Institute of Ecology, University of Georgia, Athens, Georgia 30602

Swank, Wayne T., Coweeta Hydrologic Laboratory, USDA Forest Service, 999 Coweeta Lab Road, Otto, North Carolina 28763

Swift, Jr., Lloyd W., Coweeta Hydrologic Laboratory, USDA Forest Service, 999 Coweeta Lab Road, Otto, North Carolina 28763

Vose, James M., Coweeta Hydrologic Laboratory, USDA Forest Service, 999 Coweeta Lab Road, Otto, North Carolina 28763

Wallace, J. Bruce, Department of Entomology, University of Georgia, Athens, Georgia 30602

Webster, Jackson R., Department of Biology, Virginia Tech, Blacksburg, Virginia 24061

Project Summary

Coweeta Hydrologic Laboratory has been the site of interdisciplinary ecological research using experimental watersheds for over twenty years. We propose to continue these long-term studies of response and recovery of Southern Appalachian forested ecosystems to disturbance and to concentrate on current disturbances that are of major consequence. To understand and predict responses to current and emerging environmental problems (e.g., global climate change) requires an expansion of our research perspective from a watershed to a landscape; hence we propose new studies along a complex environmental gradient with a continued emphasis on use of experimental manipulation to examine ecosystem response to disturbance. The elevational gradient we propose to study represents a gradient in external driving variables (e.g. temperature, precipitation) as well as a gradient in ecosystem response. Three interconnected ecosystems are arrayed along this response gradient at Coweeta: forested slopes, riparian zone, and stream. We propose to test the following ideas in these landscape components: (1) Forest structure and processes in the Southern Appalachians are currently changing as a result of both historic factors and recent drought-induced tree mortality. (2) Differences in structural and functional characteristics of stream ecosystems along elevational and longitudinal gradients are a consequence of changes in the relative abundance of geomorphic patch types along the stream. (3) *Rhododendron maximum* is a keystone species in the Southern Appalachian landscape, regulating the rates of soluble and particulate element export from the forest and reducing stream productivity.

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I. Results from Prior NSF Support

This is the second five-year funding period for the Coweeta LTER with a focus on long-term recovery from disturbance in Southern Appalachian forested ecosystems. Additions in senior personnel during the past five years have strengthened our research program: Dr. David C. Coleman and Dr. Jennifer M. Donaldson in soil process areas, and Dr. James Vose in forest ecology and modeling. We have added two additional senior personnel for the next six-year period: Dr. Michael Huston in vegetation modeling and Dr. Ernest F. Benfield in stream ecology. In 1990 Drs. Judy L. Meyer and Wayne T. Swank assumed leadership as Principal Investigators.

The publication of a Coweeta synthesis volume in 1988 ("Forest Hydrology and Ecology at Coweeta") provided an opportunity to analyze and integrate long-term data sets. Projects initiated in the late 1960's in forest ecology (and even earlier for climatology and hydrology) were summarized in this volume. Because of space limitations, we have not included citations in this brief description, and instead refer the reviewer to the list of publications from the last five years of this project in Section V.1.

The single, major event during the current funding cycle was a prolonged drought. Rainfall deficits in late 1985 escalated into major precipitation shortfalls by 1986 (Figure 1). The drought did not end until June 1989 when record precipitation occurred. Phenomena in all core research areas were impacted by the drought. Since response to disturbance has been an organizing theme of our LTER research, the drought presented a welcome opportunity to test our ideas.

Climatology, Hydrology, Precipitation and Stream Chemistry

Analysis of drought patterns during the 55-year record at Coweeta revealed that the drought was the most severe in the Coweeta record with a recurrence interval ranging from 90-250 years, depending on the data set (Table 1). This analysis was accomplished with a new technique, which considers simultaneously both magnitude and duration of extreme events. Analysis of a longer-term precipitation record from Highlands, N.C. reveals 5 severe drought periods in the 56 years preceding initiation of Coweeta records (Table 1). These analyses also indicate the period from the late 1960's to the mid 1970's was relatively moist and essentially free of droughts of even modest severity. This is significant because it was during this period that numerous baseline ecological studies were performed at Coweeta.

Recent analyses of trends in solution chemistry within the Coweeta Basin continue to support the conclusion that Coweeta watersheds are exhibiting delayed response to atmospheric deposition. Several significant facts emerged from the analyses. First, bulk precipitation at Coweeta is a weak solution of sulfuric and nitric acids buffered by cations to a mean pH of 4.5. Sulfate is the dominant anion and H^+ is the dominant cation. Over the 20-year period of record, no significant temporal trends in SO_4^{2-} or H^+ concentrations are apparent. However, NO_3^- concentrations have increased (ca. 50 percent), whereas concentrations of Ca^{2+} and summed cations have declined (ca. 30 percent). Second, in contrast to precipitation, Coweeta streamflow at low elevations is a highly buffered cation-bicarbonate solution with a mean pH of 6.8. Highly significant trends in stream chemistry are apparent in the Coweeta record: concentrations of SO_4^{2-} are increasing while cations and SiO_2 are decreasing. These trends are consistent across all reference watersheds in the Coweeta Basin (Figure 2). Third, substantial differences in stream chemistry exist between low- and high-elevation watersheds within the basin. These differences appear to result from differences in hydrologic characteristics of watersheds, particularly related to interactions between pathways of soil water flux and soil biogeochemical processes. At higher elevations, SO_4^{2-} has replaced HCO_3^- as the dominant anion in streamflow, whereas HCO_3^- is the dominant anion in

TABLE 1. SUMMARY OF MAJOR DROUGHTS (ANNUAL ANALYSIS)

1) CHL WS 08

Time Period	Deficit (in)	Return Period (yrs)
1940-42	45.07	130
1985-86	39.51	97
1981-82	28.72	63
1953-56	22.94	56
1944-45	19.62	54

2) CHL Rain gauge 19 (low elevation)

Time Period	Deficit (in)	Return Period (yrs)
1985-86	45.25	205
1940-42	36.09	110
1981-82	22.76	58
1977-78	14.57	53
1963	12.52	52

3) CHL Rain gauge 31 (high elevation)

Time Period	Deficit (in)	Return Period (yrs)
1984-86	47.06	98
1938-41	46.33	95
1980-81	21.83	52
1978	17.98	51
1943-45	16.62	50

4) Highlands Biological Station

Time Period	Deficit (in)	Return Period (yrs)
1894-97	72.34	320
1925-27	47.56	130
1883-85	44.11	120
1930-31	39.01	115
1878-79	37.20	113
1950-54	34.75	111
1985-86	28.00	109

low-elevation streams. Temporal trends in stream H^+ concentrations also differ: stream H^+ is increasing (pH is declining) at higher elevations, but not at lower elevations.

High ozone levels (> 85 ppb for 12 hours or longer in three separate periods) during the 1984 growing season at Coweeta caused extensive damage to the white pine plantation (WS 17). Ozone stress included premature senescence and loss of foliage, stimulation of pine seedling germination, reduced basal area increment (Figure 3), and small but measurable increases in NO_3-N and K concentrations in stream water. There were no observable effects of O_3 damage on nutrient concentrations of stemwood and foliage but net nutrient accumulation was reduced because of lower stemwood production. Ozone injury did not predispose trees to root pathogens or bark beetle infestations. There is a wide range of O_3 concentrations over the Coweeta Basin with higher values on ridges than on lower slopes. Analyses are focusing on physical factors that may influence O_3 distribution such as patterns of air mixing and movement.

Long-term research on hydrologic and stream chemistry recovery on WS 7, the clearcut and cable logged watershed, has continued to the present time. By the 7th year after cutting, annual streamflow returned to baseline levels. Hydrologic recovery is attributed to rapid regrowth and the reestablishment of leaf area indices close to values for the original hardwood forest. Concentrations of most dissolved inorganic nutrients have also returned close to baseline levels except for NO_3-N which is still clearly above pretreatment levels. In the first 5 years after cutting, the net increase in nutrient export from WS 7 was 3.2, 8.1, 11.1, and 4.4 kg ha^{-1} for NO_3-N, K, Ca, and Mg, respectively. Elevated exports represent the combined influence of increased discharge and alteration of biological processes which regulate nutrient recycling.

Vegetation studies

This work consists of several components: (1) an intensive, 12-year study of the physical, chemical and biological effects of forest disturbance on terrestrial vegetation and its subsequent recovery; (2) the importance of nitrogen-fixing trees (*Robinia pseudoacacia*) and other early successional species in nutrient dynamics; and (3) long-term vegetation changes in permanent plots. During this 5-year period, extensive effort was devoted to the characterization of canopy gaps, including those created during the most severe part of the drought.

Severe mortality occurred for pines (*Pinus rigida*) in the Coweeta Basin, with the consequent creation of snags and deadfalls in gaps generated by 1-10 or more pine deaths. A consequence of this woody input to the forest floor has been an increase in termite populations, which were previously rare.

An extensive study of canopy gaps concentrated on hardwood tree species, including historical and recent records. The distribution of gap age showed a significant increase in gap formation beginning in the drought year of 1986 (Figure 4). The most common gaps were those created by single and multiple standing dead trees, accounting for 72% of gaps sampled. The most frequent gap-forming species were oaks, with *Quercus coccinea* predominating (Table 2). Canopy gaps were distributed evenly between north and south aspects and between watersheds in the Coweeta Basin. The data indicate that 65% of the gaps sampled were formed within 2 years of the 1986 drought summer and resulted from the root pathogen *Armillaria* killing drought-stressed oaks. This episodic event will likely have long-term effects upon the structure and processes of hardwood forests in the Coweeta basin, which we have proposed to investigate over the next six-year period.

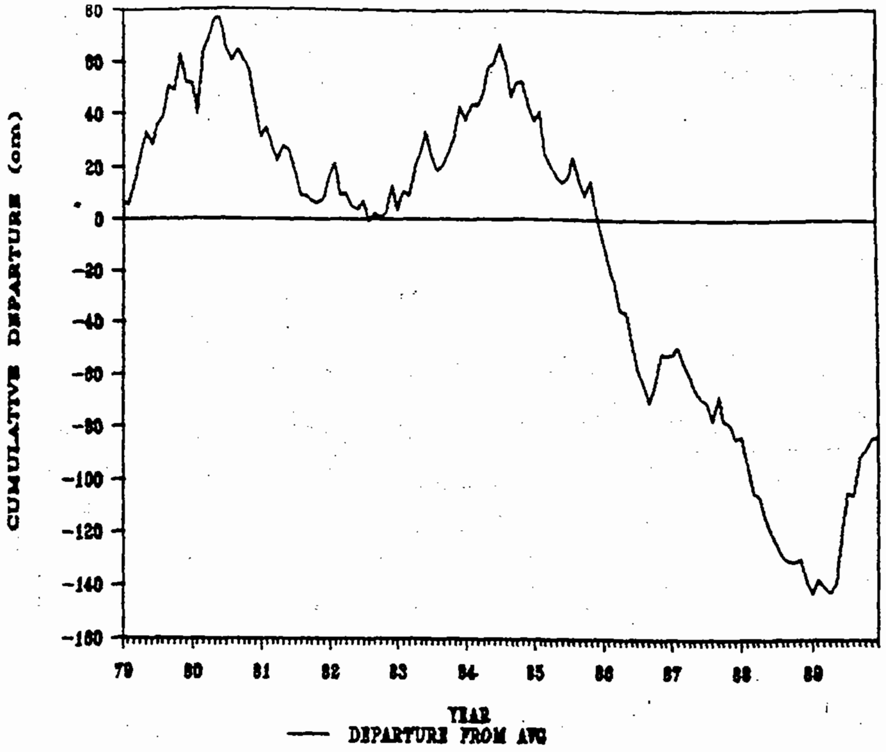


Figure 1: Intensity of drought at Coweeta Hydrologic Laboratory shown by cumulative departure in precipitation from 55-year average during 1979 - 1989.

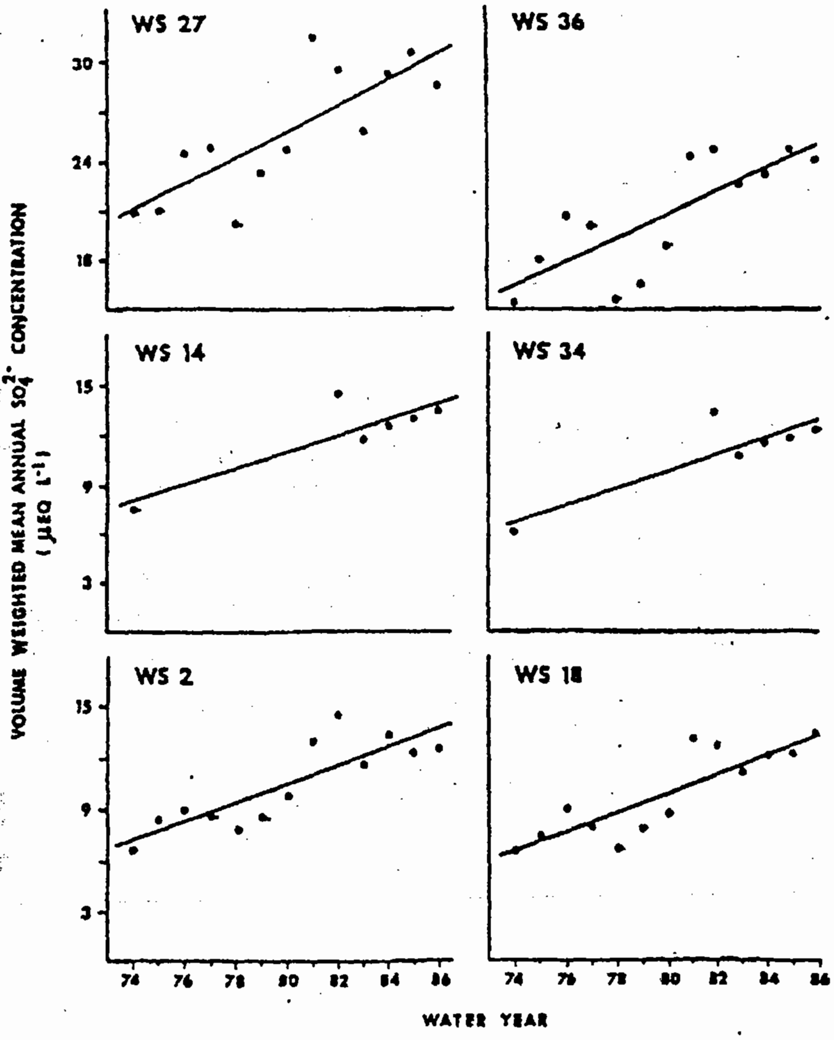


Figure 2: Time trends of volume-weighted mean annual SO_4 concentrations in streams draining high- (WS27, WS 36) and low- (all others) elevation Coweeta reference watersheds (note differences in vertical scales). Partial correlation-multiple regression analysis was used to account for annual vaiability in streamflow amount. Time trends are significant and the slopes of the concentration vs. time regressions are statistically homogeneous across all watersheds

Patterns of Herbivory

Long-term research on canopy arthropods at Coweeta has emphasized the importance of herbivory for nutrient cycling in watersheds. Ten-year data sets include arthropod biomass and measurements of leaf area lost to folivory. The latter measurements provide an estimate of the impact of the entire canopy arthropod community on tree foliage. Together with sampling programs for estimating canopy arthropod densities, these measurements constitute the basic long-term data set for canopy consumers.

In addition, premature leaf abcission (greenfall) as a response to herbivory was measured to estimate leaf litter inputs during the growing season. Greenfall contribution was <5% of total foliar production, but consistent throughout the growing season. Herbivore-caused greenfall was consistently higher than other sources. The influence of herbivory on seasonal leaf fall was similar among watersheds with differing treatment histories or aspects.

Historical patterns of canopy arthropod load indicate responses to drought in 1978, 1981 and 1985, when arthropod mass and numbers decreased on south-facing, more xeric slopes but increased on a north-facing watershed. Relationships of arthropod numbers or feeding to drought depended upon timing of precipitation. The best predictor for decreased canopy arthropod abundance was low dormant-season rainfall; droughts which occurred in summer months had little impact on canopy insects. This finding differs somewhat from predictions offered by current theories of climatic release of insect outbreaks (e.g. Mattson and Haack 1987). However, the drought years did produce mortality of native pine species in which the complex of bark-boring insects evidently played a major role.

Soil microbial and decomposition studies

This research has emphasized microbial and faunal processes controlling the mobility of elements in the forest floor, and biotic controls over decomposition and mineralization. Particular attention has been given to sulfate adsorption and incorporation of S into organic matter. Objectives of the work include evaluating the importance of sulfur adsorption in soils and development of a sulfur cycling model for Coweeta. Experiments are helping to explain the mechanisms by which Coweeta forests accumulate sulfate from precipitation, a phenomenon we have documented with our long-term record of precipitation and streamwater chemistry.

An evaluation of long-term changes in decomposition rates following disturbance showed that leaf litter decomposition rates continue to be reduced 8 years following clearcutting. Decomposition of *Cornus, Acer* and *Quercus* litter was slower in the 8-year-old clearcut, and absolute increases of N (net mobilization) were also lower (Figure 5). Lower levels of net mineralization led to slower increases in N concentration in the decomposing leaf litter on the disturbed watershed. Decay constants for woody debris during the first 7 years after cutting were 0.083 and 0.185 yr^{-1} for coarse and fine debris, respectively. CO_2 efflux accounted for two-thirds of the total mass loss.

Soil and detrital carbon dynamics were examined following clearcutting. CO_2 effluxes were 33% lower than in the reference forest and were associated with higher soil temperatures, smaller live-root masses, and larger forest floor masses. No long-term changes in soil C pools were apparent following cutting. After developing a technique to distinguish between nitrification and denitrification as sources of gaseous nitrogen production in soil, these techniques were used to determine the relative importance of O_2, NO_3, organic C, and acidity on denitrification rates in soils of disturbed and reference watersheds. C limitation is unimportant for denitrification in surface horizons at Coweeta, but C limitation does occur with increasing soil depth. Measures of

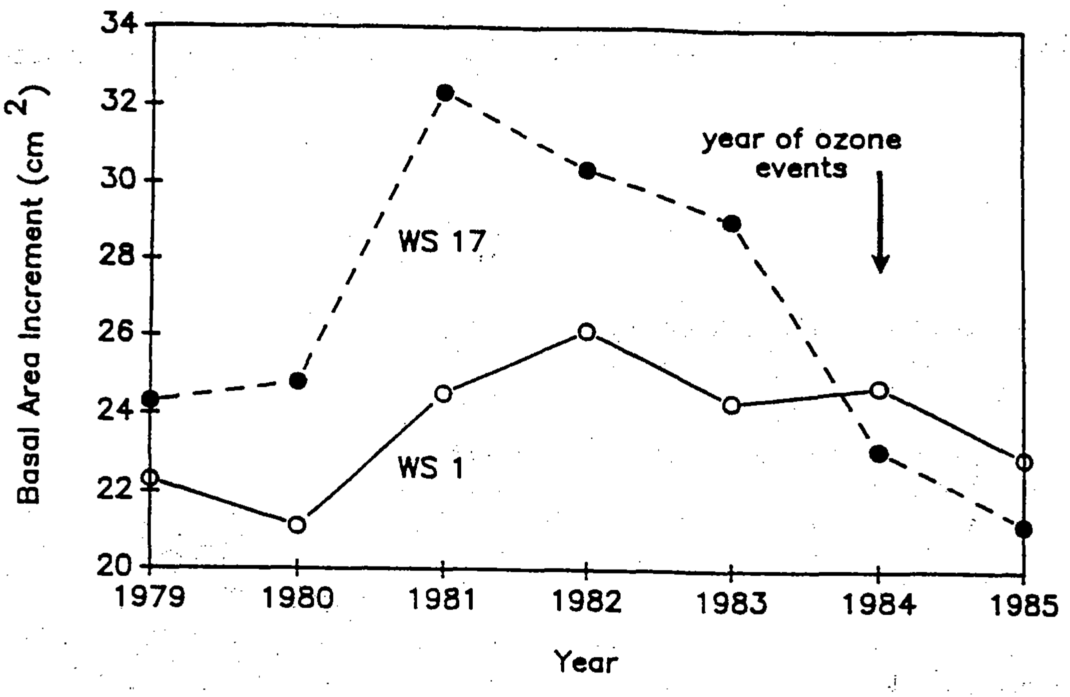


Figure 3: Annual basal area increment (BAI) for dominant and codominant 28-year-old white pine on Coweeta WS 17 (ozone symptomatic in 1984) and WS 1 (ozone asymptomatic) from 1979 to 1985. The BAI of trees on WS 17 decreased dramatically in 1984, whereas BAI of trees on WS 1 was unchanged. BAI on WS 17 in 1984 (23.1 cm^2) was significantly different ($p < 0.05$) from BAI for the preceding 5 years (28.2 cm^2).

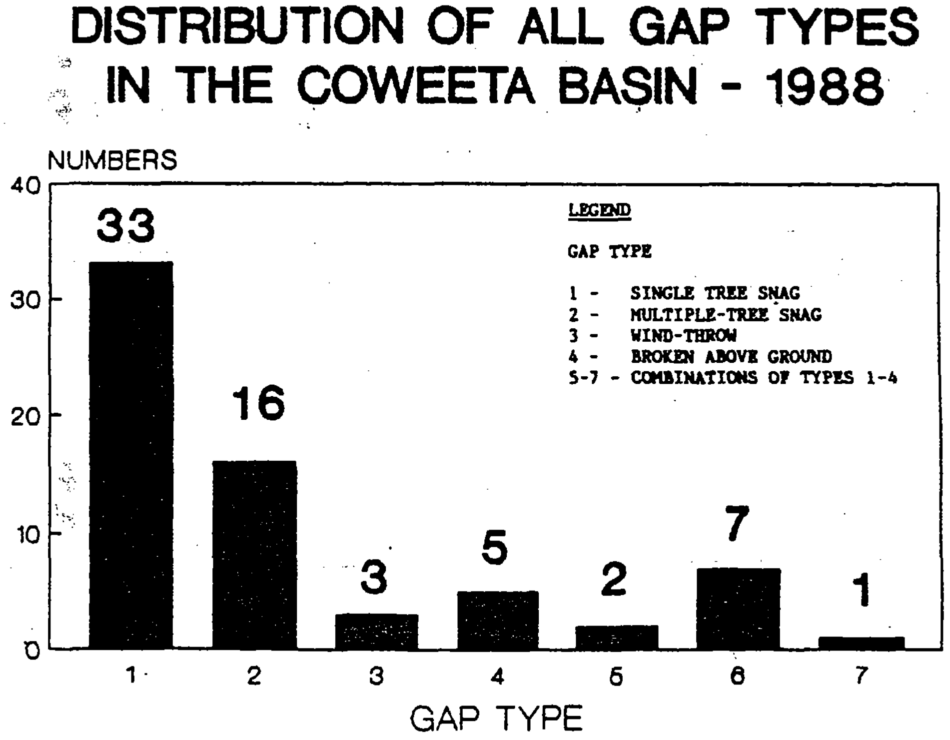


Figure 4: Frequency of different gap types in the Coweeta Basin (from Clinton, 1989).

in situ N2O diffusion demonstrated that gaseous losses from Coweeta soil are minor relative to other N transformations.

Stream ecosystems

During this five-year period, stream studies have had three foci: 1) effect of disturbance on ecosystem structure and function and ecosystem recovery from disturbances (including logging, drought, and macroinvertebrate removal); 2) basic research on previously unstudied components of the stream food web including bacteria, meiofauna, and production studies of crayfish and chironomids; and 3) influence of local geomorphology on structural and function characteristics of streams.

1) Disturbance: Data from a separately funded project on the role of invertebrates in ecosystem processes combined with LTER data have allowed us to compare the effect of drought on organic matter processing in streams with the effect of macroinvertebrate removal. Leaf litter processing rates, seston concentration, and fine particulate organic matter (FPOM) export were significantly reduced by macroinvertebrate removal. The 5-year period of this study encompassed the driest (1986) and the wettest (1989) years during 55 years of record. During this period FPOM export in reference streams varied about 3.5-fold, whereas variation in streams where macroinvertebrates were removed was 7-fold. In other words, variation in FPOM export as a consequence of biotic manipulation was as great as variation produced by a range in discharges encompassing the extremes for a 55-year period.

The impact of the drought on fish populations was examined as part of ongoing research on the relationship between environmental variability and assemblage dynamics. Recruitment and year-class strength for the four dominant species were strongly affected by the drought. In some cases, the drought had a negative impact on species abundances; however for many species, recruitment and year-class strength increased during the drought. This does not appear to be a consequence of positive effects occurring during low water periods, but to the cessation of winter flooding during the drought. The drought may also have contributed to the upstream invasion of sites by two species (Tennessee shiner and river chub). Consequently, the drought appears to have played a strong role in the dynamics of Coweeta fish assemblages.

We have also examined the effect of watershed disturbances on nutrient retention and organic matter processing in streams. Despite major differences in retentive characteristics and dissolved nutrient concentrations, we found no significant differences in phosphate and nitrate uptake in reference and disturbed streams; however the mechanisms of nutrient uptake and retention in the streams may be quite different. Organic matter processes studied include allochthonous inputs, standing crops of fine, coarse, and woody particulate materials, export of organic particles, and wood and leaf breakdown rates. In general, forest disturbance decreases allochthonous inputs, accelerates transport losses, and greatly increases the turnover of material in the stream. As a result, there is a long-term degradation of material from the streambed.

Standing stock of organic matter in stream channels changes in response to watershed disturbance. To investigate how these changes affect the stream microbial community, we measured sediment bacterial biomass in watersheds with different treatment histories. Bacterial biomass varied directly with organic matter content of the sediments, but did not vary with source of organic matter (hardwood vs. pine). Our results were similar when we experimentally altered organic matter content in small plots in the stream bed and followed organic matter and bacteria over time.

Rates of invertebrate recovery from disturbances vary with the nature of the disturbance. Those which produce long-term changes in the physical environment (e.g. logging) appear to require many decades at Coweeta. Our studies show no evidence for functional or taxonomic

Table 2. Species responsible for canopy gap formation in the mid-elevation mixed-oak forest type of the Coweeta Basin.

SPECIES	% OF TOTAL
Quercus coccinea	44
Quercus rubra	16
Quercus velutina	11
Carya spp.	11
Quercus prinus	7
Tilia americana	5
Quercus alba	4
Magnolia fraseri	2
	100 %

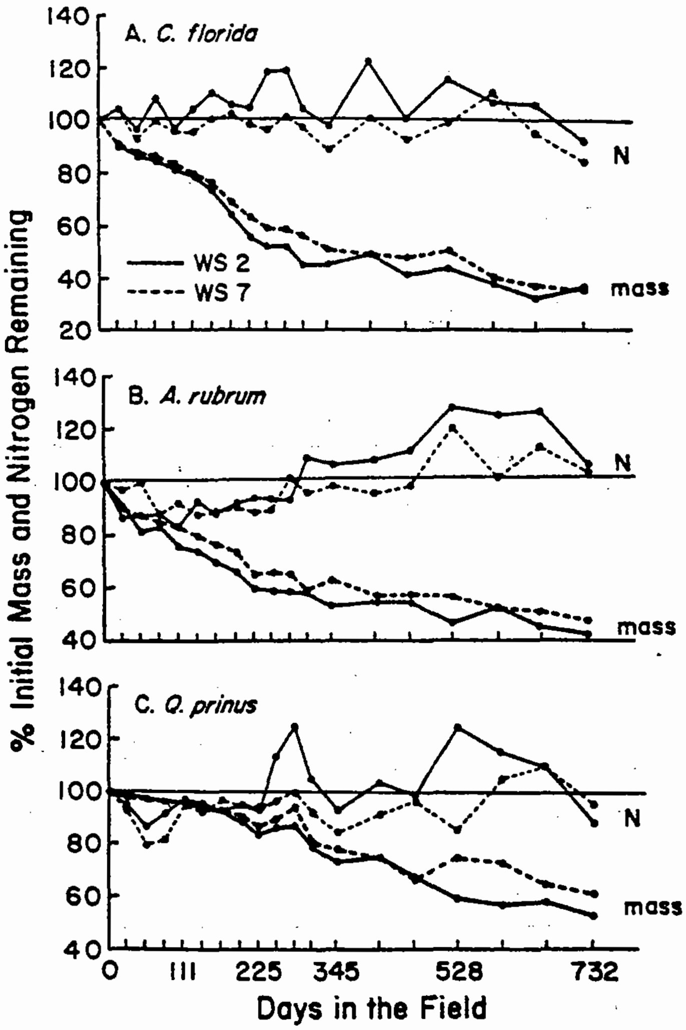


Figure 5: Mean percent of initial mass and nitrogen remaining over time in (A) *C. florida* , (B) *A. rubrum* and (C) *Q. prinus* litter on WS 2 (__) and WS 7 (----) from January 1985 - January 1987 (from Blair and Crossley 1988).

recovery of macroinvertebrate fauna five years after logging. In contrast, recovery from insecticide treatments are relatively rapid with functional group recovery occurring within two years and taxonomic recovery within 5 years.

2) Basic research: Two invertebrate groups -- those with multivoltine life cycles (e.g. copepods and many chironomids) and those that are extremely long-lived (e.g. crayfish) -- have represented the most difficult groups for estimates of secondary production in streams. Field and laboratory studies of copepods and chironomids at Coweeta have indicated high ratios of production to biomass (P/B) in these groups. In contrast, field growth rates for crayfish indicate low P/B ratios. These studies have made it possible to calculate reasonable estimates on secondary production of invertebrates in Coweeta streams. In addition, studies of copepods indicated that these meiofaunal organisms may form important trophic linkages between microbes associated with detritus and macrofauna in streams.

3) Geomorphology: We have examined the influence of local geomorphology on structural and functional characteristics of stream ecosystems. We initiated a long-term experimental addition of debris dams to Cunningham Creek and documented changes in macroinvertebrate functional group structure and nutrient and organic matter retention when stream geomorphology is altered by debris dams as described in Section IV.2. Studies have also examined the effect of local geomorphology on retention of nutrients and on abundances and functional group composition of macroinvertebrates at Coweeta. The physical characteristics of habitats such as rock-face, cobble-boulder riffles and pools associated with debris dams influence resource availability and mode of resource use by consumers. For example, production of collector-gatherers is greatest in retentive pool habitats, whereas collector-filterer production is largely restricted to the high velocity moss-covered rock faces where the rate of food delivery to filter-feeders is much higher. Some examples of macroinvertebrate production and standing crops of detritus vs. physical parameters are shown in Figure 6.

Analyses of nutrient retention in Coweeta streams have also examined the role of local geomorphology by assessing the proportion of annual phosphorus, nitrate, calcium and dissolved organic carbon retention occuring in different geomorphic substrates. Substrate types differed significantly in their contribution to annual nutrient retention (Figure 7). This research on nutrient retention in streams forms a critical link between long-term data bases on element export from watersheds and studies of stream processes.

The Future

Studies during the past five years have lead us into research directions that we intend to further develop during the next six years: long-term consequences of the drought, changing patterns of atmospheric deposition and their impact on terrestrial and aquatic ecosystems, and geomorphic regulation of stream processes. We address these phenomena in the present proposal.

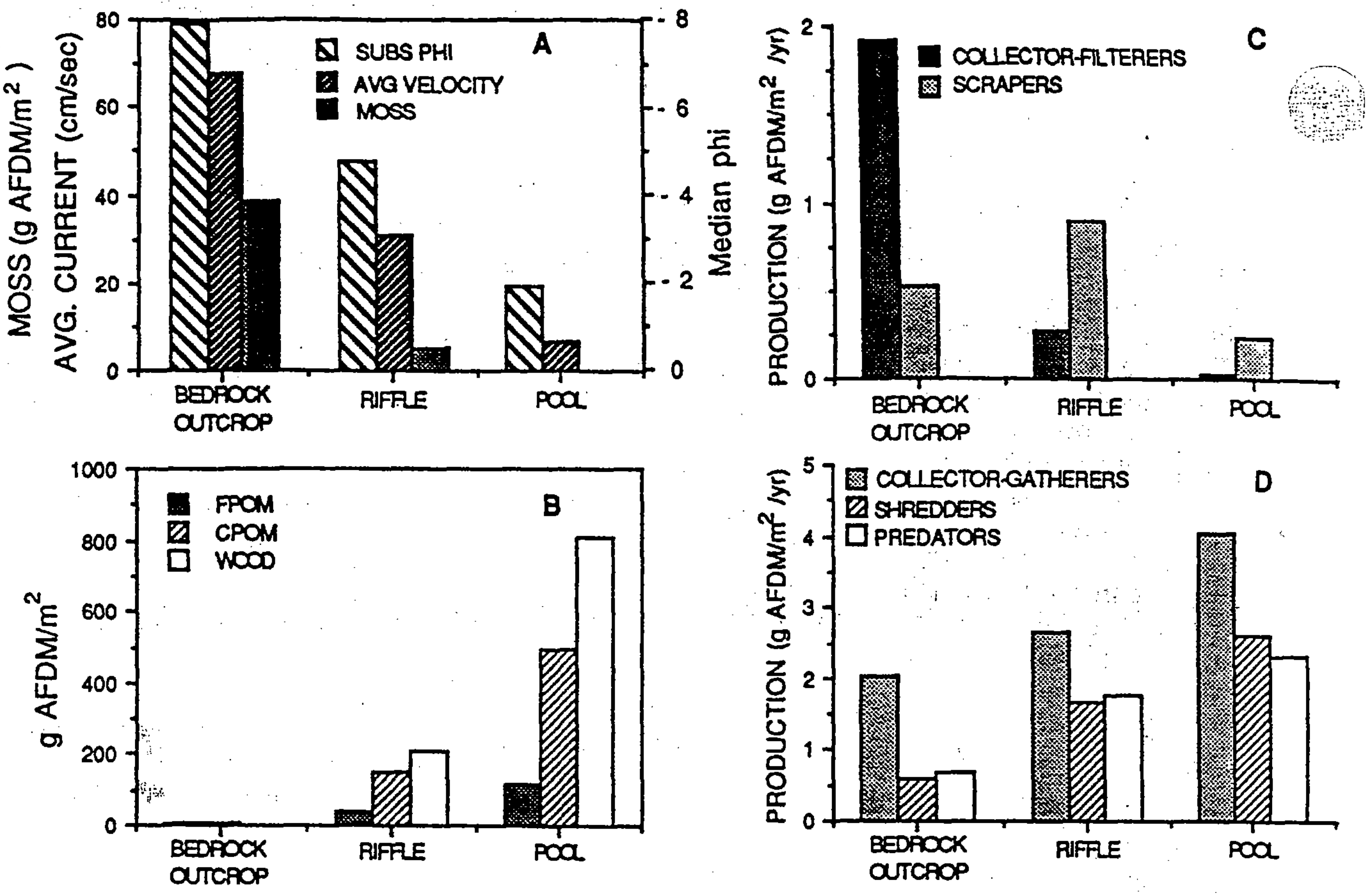


Figure 6: Comparison of some habitat characteristics with production of functional groups of macroinvertebrates in Upper Ball Creek (WS 27). (A) Moss, water velocity, and substrate particle size as measured in bedrock outcrops, riffles and pools. (B) Average standing crops of fine particulate organic matter, coarse particulate organic matter exclusive of wood, and small woody debris. (C) Secondary production for collector-filterer and scraper functional feeding groups. (D) Secondary production for collector-gatherer, shredder and predator functional feeding groups. Data from Huryn and Wallace (1987, 1988).

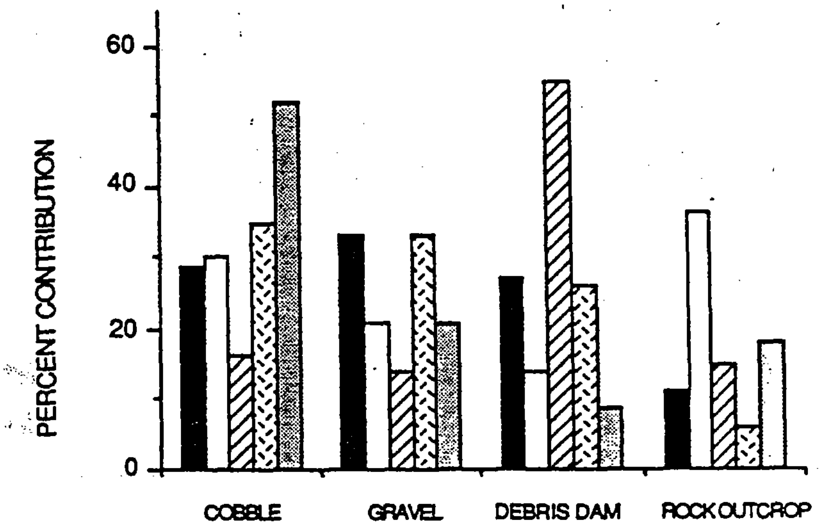


Figure 7: Percent contribution of each substrate to the annual retention of nitrate (open bar), phosphate (slashed bar), calcium (cross-hatch), and dissolved organic carbon (stippled). The percent contribution of substrate types to retention of each solute differs significantly from distributions predicted based on prevalence of substrate-type alone (from Munn 1989).

II. Theme of LTER Program at Coweeta Hydrologic Laboratory

For the past half century, research at Coweeta Hydrologic Laboratory has had four primary goals:

1) To describe and explain hydrologic functions and processes of forested ecosystems.

2) To examine the response and recovery of Southern Appalachian forested ecosystems to disturbance. We have used natural disturbances (e.g. insect outbreak and regional drought), anthropogenic disturbances (e.g. chestnut blight), and experimental disturbance (e.g. clear-cutting) as tools for studying ecosystem response to and recovery from disturbance.

3) To assess the changing nature and effects of atmospheric inputs on the structure and function of Southern Appalachian terrestrial and aquatic ecosystems.

4) To apply this understanding to develop ecologically sound and effective management practices.

These are also the goals of past and currently proposed LTER research. We propose to continue our long-term studies of recovery from disturbance and to concentrate on current disturbances that are of major consequence in the Southern Appalachians and that require long-term research. Previous research at Coweeta has provided us with a rich data base on ecosystem response to disturbance at the watershed level. To advance our understanding of the effects of disturbance on forest ecosystems, it is now necessary to expand our perspective from a watershed to a landscape. Watershed-level experiments have been an invaluable tool for studying disturbance at Coweeta (Swank and Crossley 1988); but understanding and predicting responses to current and emerging environmental problems such as global change, water quality, and cumulative effects requires research on an expanded scale organized along environmental gradients with a continued emphasis on use of experimental manipulation to examine ecosystem response to disturbance. This is what we propose here.

The conceptual model structuring our research is presented in Figure 8. We view the Coweeta landscape as three interconnected ecosystems: forested slopes, riparian zone, and stream. All are influenced by external physical (e.g. temperature, precipitation), chemical (e.g. atmospheric deposition), and biological (e.g. anthropogenic disturbance) driving variables. The nature of the driving variables and the responses of the three component ecosystems will vary across the elevational gradient. We have therefore chosen to focus our proposed research on gradients and exchanges between landscape components. It is this aspect of the landscape that will be most susceptible to alteration induced by disturbance.

The elevational gradient that we propose to study represents a gradient in driving variables such as solar radiation, temperature, precipitation, atmospheric deposition, soil characteristics, and stream size. The combinations of slope, aspect and elevation available in the basin produce a range

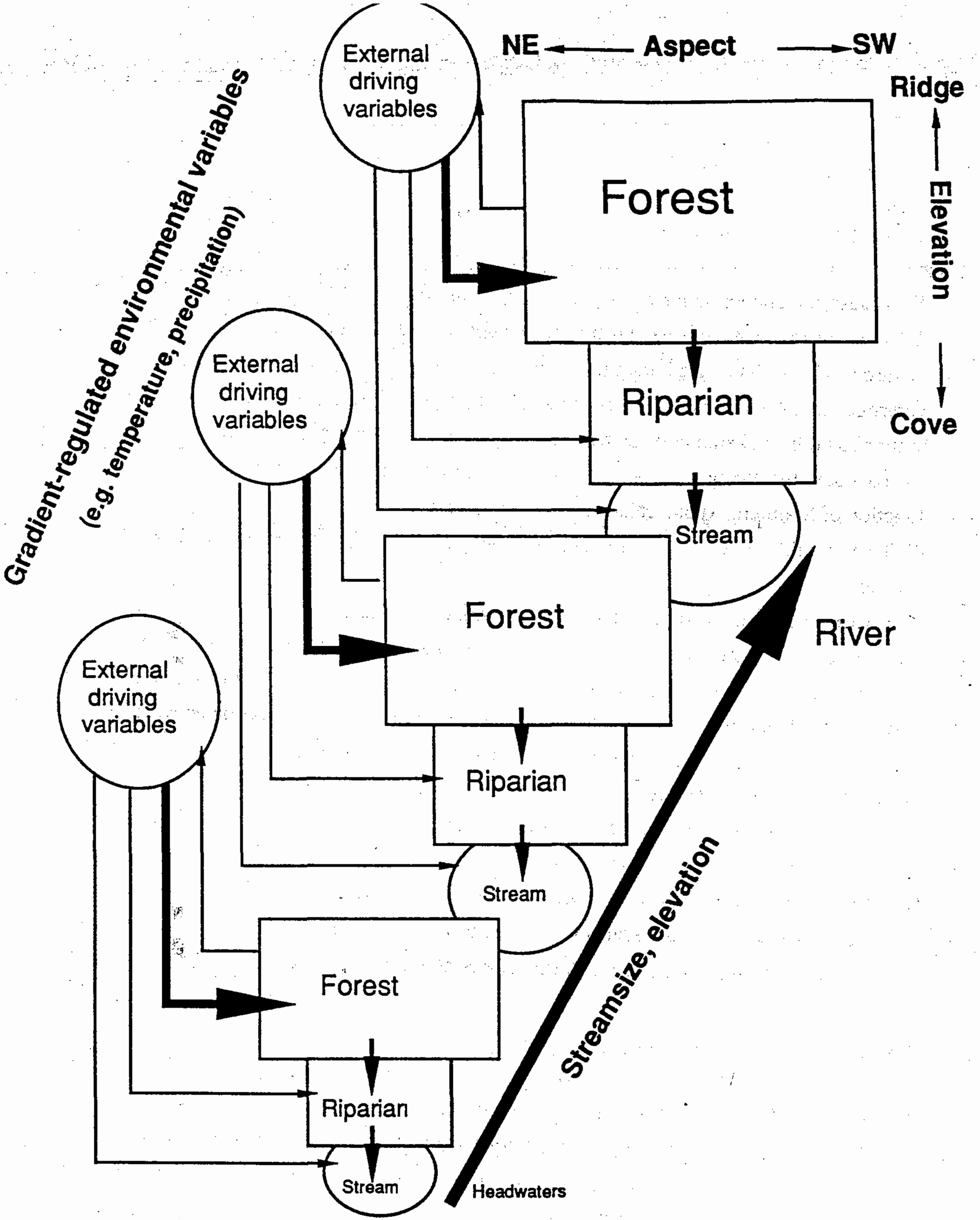


Figure 8: Conceptual model of the Coweeta landscape from the headwaters to a river system. It is pictured as three linked ecosystems (forested slopes, riparian zone and stream) arrayed across a complex environmental gradient. Although this gradient represents a continuum of environmental variables and ecosystems, we have simplified the diagram by showing only three -- like snapshots of a changing landscape. Thickness of the arrows indicates extent of influence, and size of box indicates size of landscape unit. Several gradients are depicted: elevation within a watershed and within the basin, aspect, watershed size, and stream size. The river downstream integrates the cumulative effects of process occurring in the watershed and in upstream reaches.

of solar energy inputs equivalent to a span of 60 degrees of latitude. Annual average precipitation over the gradient ranges from 1780 mm at lower elevations to >2500 mm on upper slopes. Concentrations of atmospheric pollutants also vary across the gradient; for example, much higher doses of ozone are found on ridges compared to lower slopes and valleys. Documented responses to ozone episodes include reduced tree growth attributed to lower rates of photosynthesis and premature foliage senescence (Figure 3).

Response to changes in driving variables (environmental disturbance) also varies along the gradient. An example of these changes can be seen in patterns of streamwater chemistry in response to acid deposition. Although there is no long-term trend of change in precipitation chemistry in the basin, streams appear to be in the initial stages of acidification with increased sulfate concentration and anion deficit and decreased concentrations of bicarbonate and calcium (Swank and Waide 1988). Although all streams show these trends, high elevation streams have lower pH levels (annual average and during storms), reduced bicarbonate concentrations, and elevated sulfate concentrations (Figure 2). Watersheds at higher elevation receive greater precipitation and sulfate deposition, and exhibit higher streamflow. Soils are shallower, quickflow volumes are higher, and the potential for sulfate adsorption is reduced. Lower temperatures at high elevations result in reduced rates of microbial sulfate incorporation into organic matter and reduced C flow through the forests. Thus, high elevation watersheds are characterized by an increased sulfate flux and reduced bicarbonate flux as compared with low-elevation catchments. These differences imply that high elevation forests are more susceptible to acidic precipitation (Swank and Waide 1988).

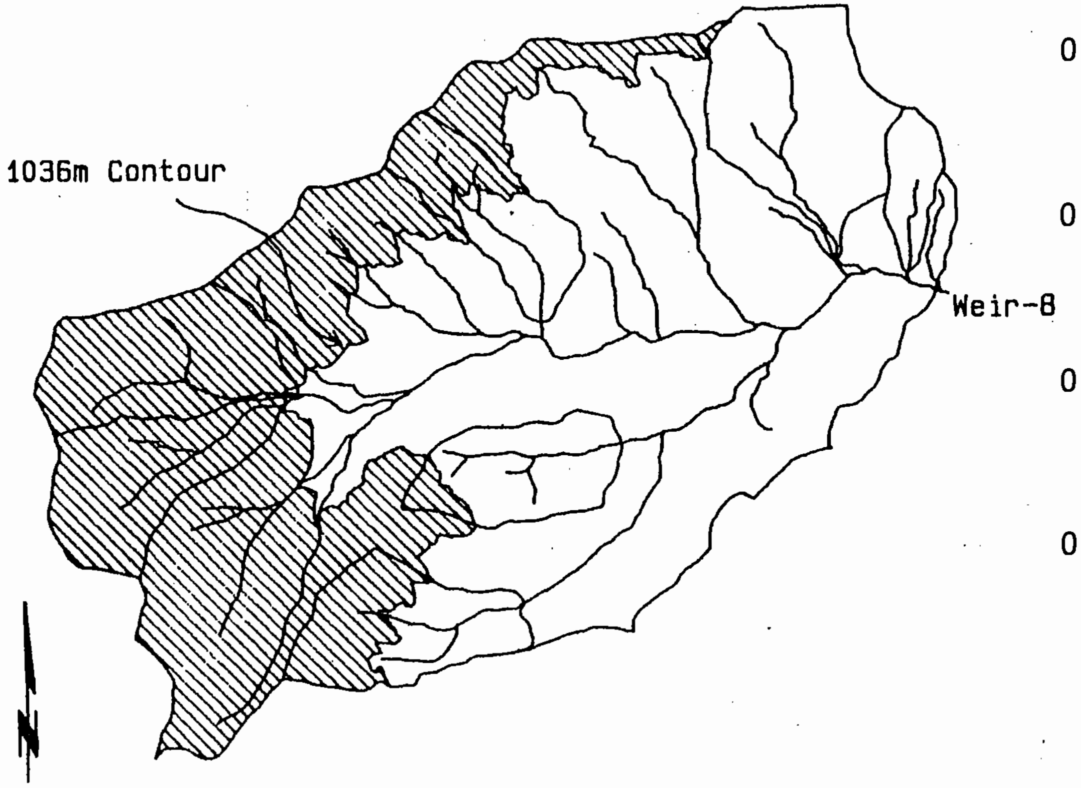
Past research at Coweeta has used both plot- and watershed-level experimentation. In our proposed research, we intend to retain our extensive data base on watershed-level processes while expanding our outlook to a landscape perspective. This expanding perspective is possible with advances in technology such as the development of powerful Geographic Information Systems (GIS). The following is an example of the progress that has already been made in coupling GIS with the extensive data base on water chemistry at Coweeta. Data layers of topographic features, bedrock geology, and soil maps were used to scale up stream chemistry data from past studies on first-order streams to Shope Fork, a fourth-order stream draining a 486 ha portion of the Coweeta Basin. Average annual flow-weighted concentrations measured for individual watersheds were applied to strata lacking stream chemistry data (about 65% of basin). In the case of NO_3 - N and SO_4, elevation was the criterion used for stratification; bedrock and soil types were the criteria used for cations. Area times concentration functions were derived for each strata and summed to obtain an integrated, predicted ion concentration to compare with measured values for Shope Fork. An example of NO_3-N and SO_4 results are shown in Figure 9 for four separate years which encompass both record wet and drought years. Concentrations predicted at Weir 8 on Shope Fork

Figure 9 (on facing page): The 1036 m contour line (distinguished by shading) was used to stratify the 486-ha Shope Fork drainage to weight and predict NO_3-N and SO_4 concentrations at Weir 8 in the drainage. Average annual predicted concentrations were within 10% of measured concentrations.

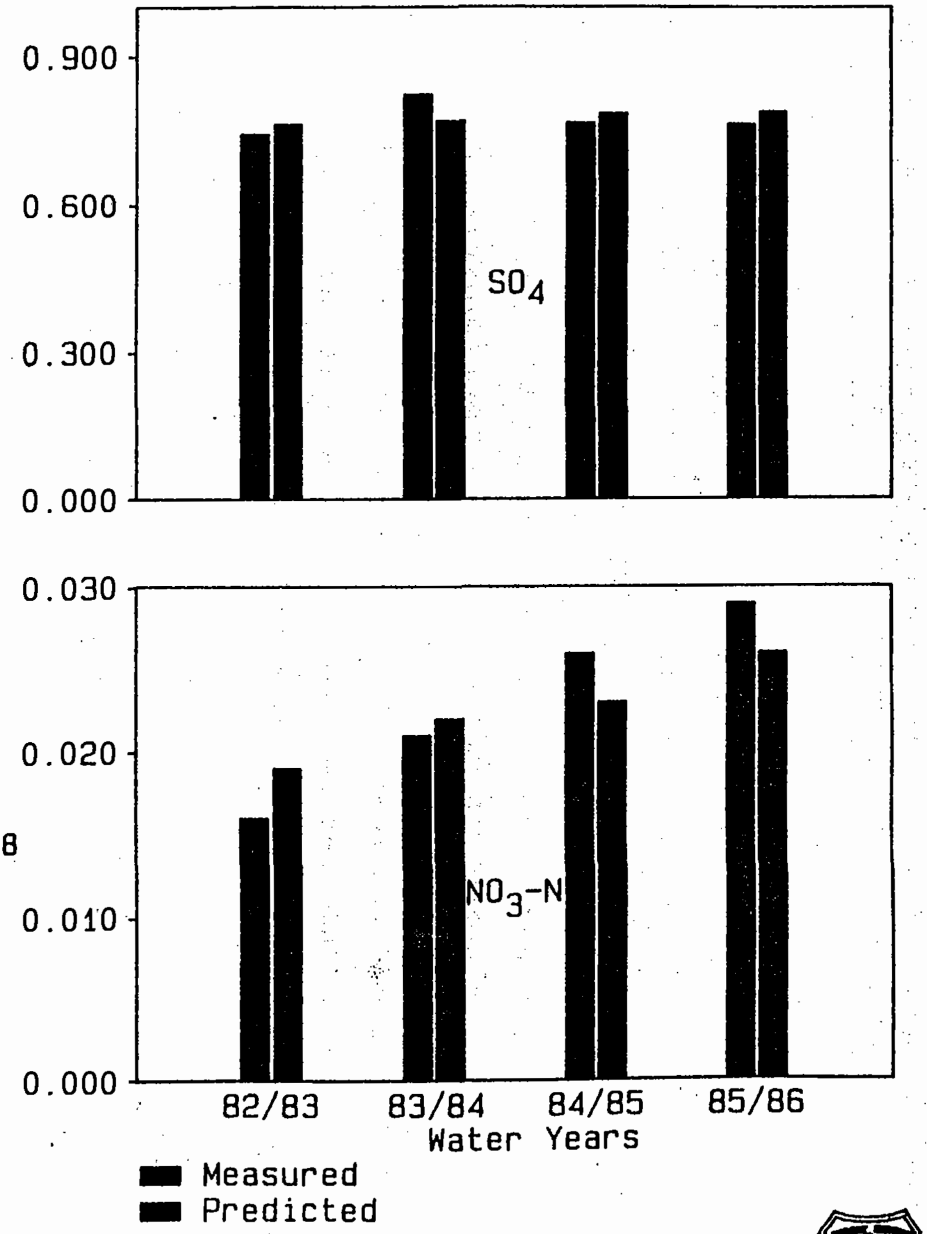
Watershed Stream Chemistry Analysis

Shope Fork, Coweeta Basin

Anion Concentrations Based
on Elevation And Treatment



Average Annual Concentrations
(PPM)



were within 10% of measured values; similar results were obtained for cation predictions. Future efforts will further utilize GIS capabilities to scale-up stream chemistry to the entire Coweeta basin and, in combination with remote sensing,to develop methods appropriate for unified land uses on larger landscape units such as the Little Tennessee River Basin.

With this landscape perspective, the proposed long-term ecological research on ecosystem response to disturbance along environmental gradients at Coweeta consists of projects designed around three hypotheses formulated for the three component ecosystems (Figure 8). Research in the five LTER core areas forms the backbone of the proposed research. The three hypotheses are presented here as statements and developed further in the following section:

1) In the southern Appalachian landscape, the severity of disturbance caused by environmental disturbances such as global change and its impact on forest ecosystem structure and function is strongly influenced by the complex environmental gradient resulting from elevational changes in temperature, precipitation and soil types. Forest structure and processes in the Southern Appalachians are currently changing as a result of both historic chestnut mortality and recent drought-induced oak decline and pitch-pine and dogwood mortality. (Research described in Section III.1.)

2) Differences in structural and functional characteristics of stream ecosystems along elevational and longitudinal gradients are a consequence of changes in the relative abundance of geomorphic patch types along the stream. In order to predict and measure impacts of global change on stream ecosystems, we must understand the effects of longitudinal and elevational gradients on stream processes. (Research described in Section III.2.)

3) The riparian zone is a key regulator of exchanges between terrestrial and aquatic ecosystems in the southern Appalachian landscape. The presence of the dominant riparian species, *Rhododendron maximum*, alters rates of soluble and particulate element export from the forest and reduces primary productivity in streams. An understanding of riparian processes is essential to assessing the impact of environmental change on terrestrial-aquatic interactions. (Research described in Section III.3.)

In the three parts of the following section we discuss research planned to test these ideas. In each part we first present our objectives and then discuss the rationale behind those objectives. We then present our workplan and conclude with our ideas for integration and synthesis. We view simulation modeling as an integral tool in this synthesis effort.

III. Description of Proposed Research

1. Forest disturbance and stress along an environmental gradient

OBJECTIVES

We propose to examine long-term forest ecosystem responses to disturbance and stress along dominant environmental gradients of the Southern Appalachians. Forest structure and processes at Coweeta are extremely dynamic at present as a result of both historic and recent tree mortality. Forest composition and ecosystem processes will continue changing throughout the predictable future (Figure 10). Future disturbances and stresses are likely to be attributable to climate change, atmospheric pollutants, gypsy moths and other pathogens, and ice and wind storms. Our proposed study will permit us to follow currently manifested impacts of past stresses and disturbance, as well as provide us with a framework for quantifying future responses from both predicted and unforeseen perturbations.

Specifically, our objectives are:

1) To quantify environmental regulation of several key ecosystem processes (net primary production, nutrient dynamics, canopy consumption, soil organic matter/carbon dynamics) by intensively measuring these variables across gradients of temperature, moisture, and soil type.

2) To quantify the extent to which gradient regulated environmental differences mitigate or exacerbate the impacts of stress and disturbance on ecosystem processes, and to predict the impacts of potential future perturbations on ecosystem processes.

3) To examine experimentally and by remeasurement of long-term permanent plots the impacts of overstory mortality and subsequent gap formation on ecosystem processes and long-term forest succession.

Our experimental approach will be to address the impacts of stress and disturbance at several levels of resolution: in individual forest communities, along environmental gradients and at the ecosystem (watershed) and landscape (basin-wide) scales. This will be accomplished through an integrated program of field measurement, experimentation, and modeling.

RATIONALE

Forest community structure and disturbance patterns in the Southern Appalachians are strongly influenced by a complex environmental gradient which results from elevational changes in temperature and precipitation (Figure 11), and variable mountain topography and soils (Whittaker 1956, Day et al. 1988). Long-term ecological and hydrologic research at Coweeta suggests that these same environmental gradients regulate many key ecosystem processes, and watershed responses to different types of forest disturbances (Swank and Crossley 1988). Accordingly,

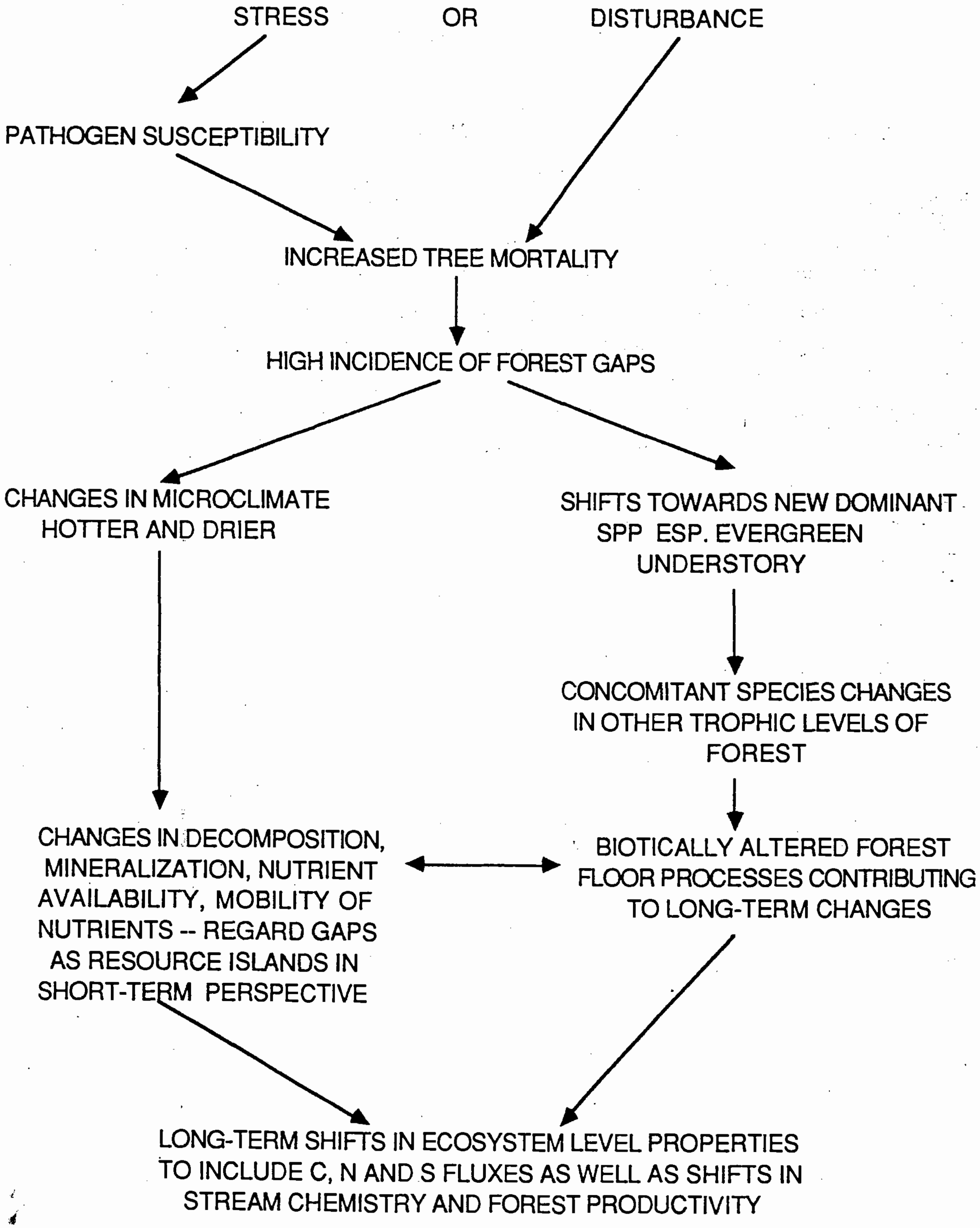
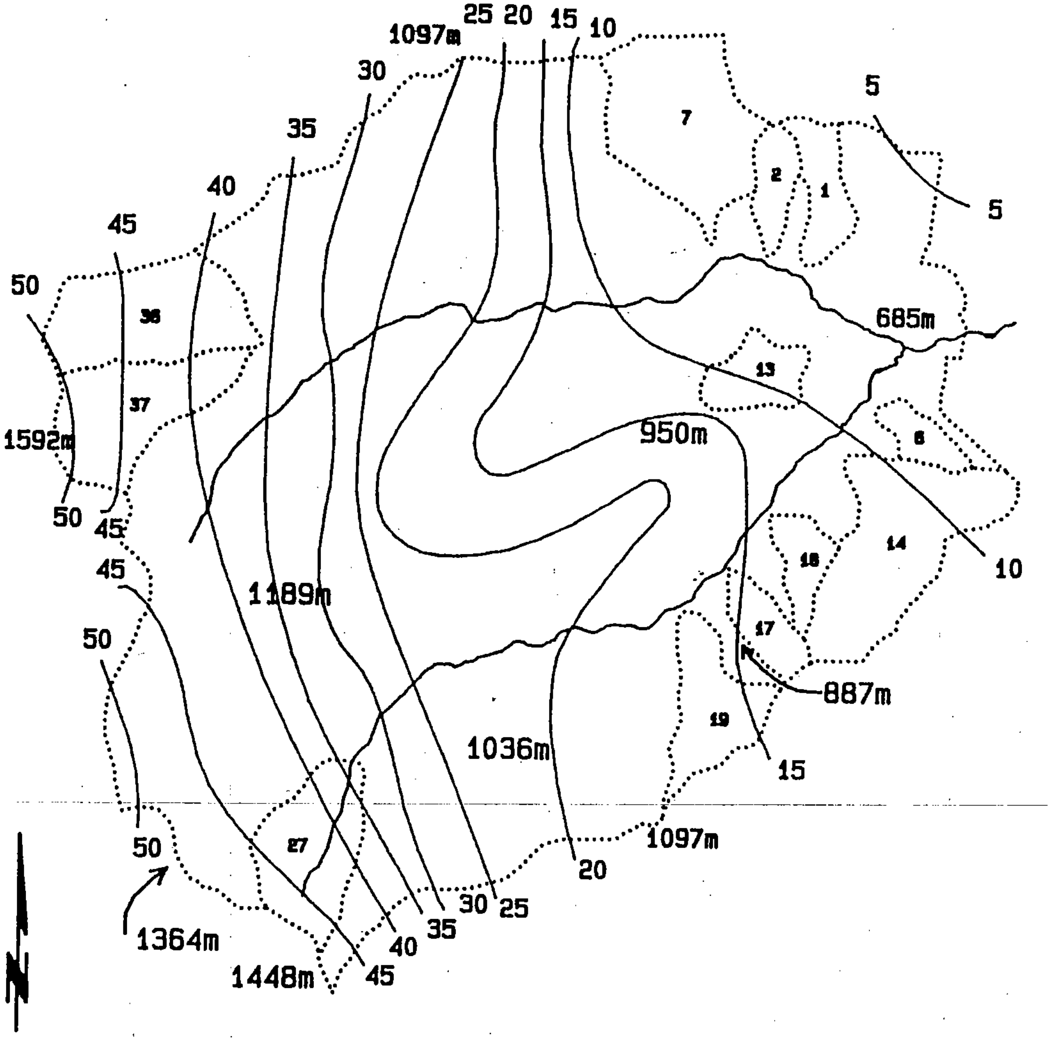


Figure 10: Conceptual model of effect of environmental disturbance on forest composition and ecosystem processes at Coweeta.

adient of Quickflow across Coweeta Basin



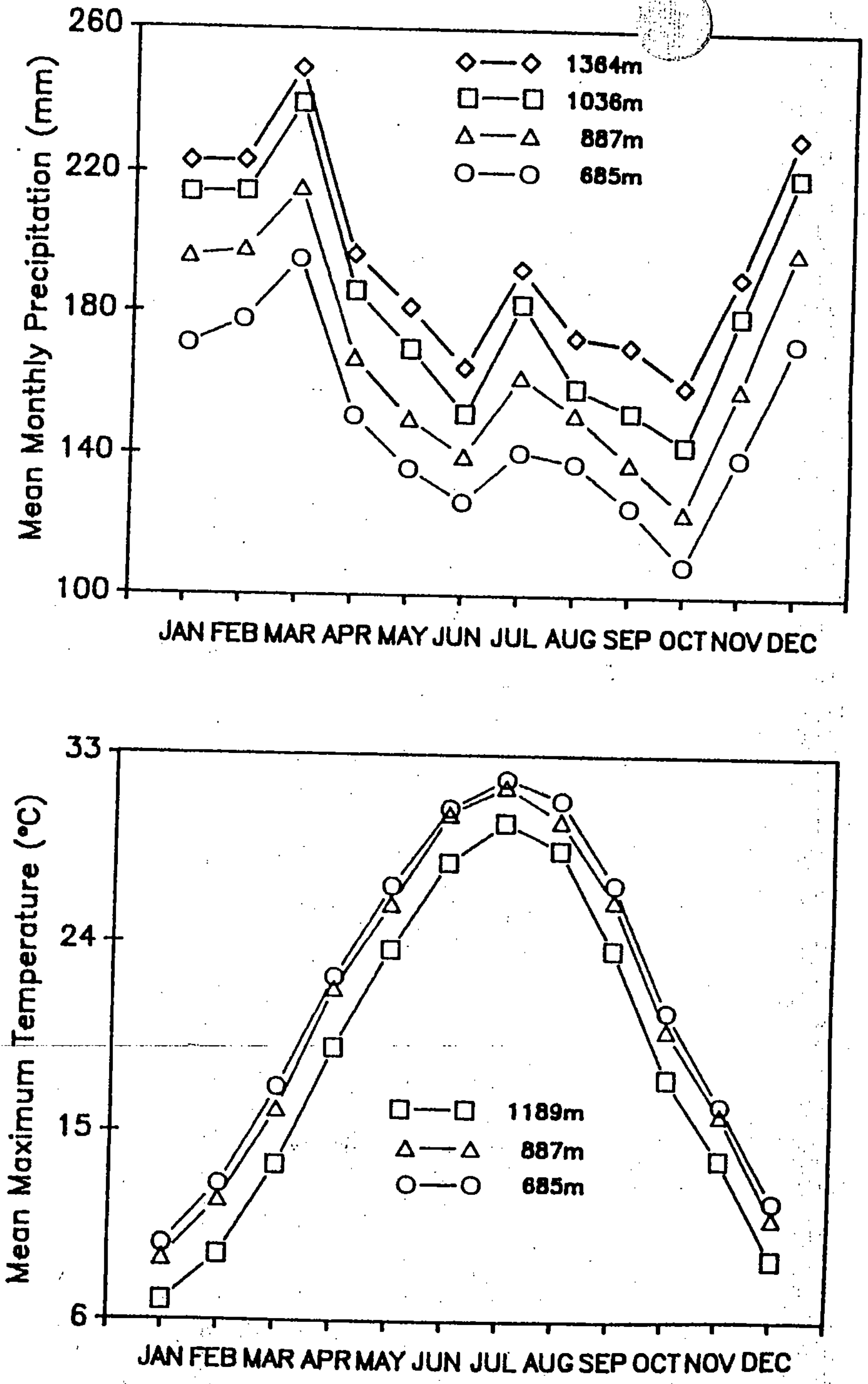


Figure 11.Differences in hydrologic response, precipitation, and temperature across the elevational gradient in the Coweeta basin. Isolines on basin graph are cm of mean annual quickflow(storm runoff).

carefully chosen environmental gradients should be valuable tools to detect and assess general impacts from long-term, low intensity stresses (e.g. climate change or atmospheric pollution) and also from short-term, high-intensity disturbances (e.g. gypsy moth defoliation, ice or wind storms).

Forest composition, successional dynamics, and ecosystem processes differ predictably along the dominant gradients of precipitation and temperature. These differences constrain the response of forests to different types of stresses and disturbances. For example, susceptibility to stress imposed by herbivores such as gypsy moths or fungal pathogens is expected to increase with decreasing water availability (Mattson and Haack 1987), while susceptibility to airborne pollutants such as ozone should decrease with decreasing water availability (McLaughlin and Taylor 1981; Figure 12). Disturbance and subsequent changes in tree species composition are known to produce both short and long-term changes in ecosystem processes such as decomposition, nutrient mineralization, and productivity (Blair and Crossley 1988, White et al. 1988).

Individual-based models of forest ecosystem dynamics (Shugart 1984) can be used to predict the course of succession under different environmental conditions (Huston and Smith 1987; Smith and Huston 1989), and how species composition interacts with nutrient availability and productivity under different climatic conditions of precipitation and temperature (Pastor and Post 1988; Huston et al. 1988). These models can also be used to predict which resources (e.g. light, water, nitrogen) are limiting to different species, under specific environmental conditions (Pastor and Post 1986), and thus the types of stresses to which these species are likely to be susceptible. We will use this conceptual framework to integrate our understanding of current ecosystem patterns, and to predict likely responses to future stresses and disturbances.

Drought is a severe stress in the Southern Appalachians since the region normally receives an abundance of evenly distributed precipitation (>1800mm mean annual precipitation at Coweeta). One impact of severe drought is an increase in tree mortality, documented to be highly significant during drought periods in 1925-1929 and 1985-1988 (Hursh and Haasis 1931, Clinton 1989). During these periods, red oak species have died from drought stress and from associated pathogens such as *Armillaria* spp. which have been implicated in other oak decline studies (Starkey et al. 1989, Wargo 1972, 1977). During the severe drought from 1985-1988, mortality was predominant in *Quercus coccinea, Q. rubra,* and *Q. velutina* species, and most individuals were estimated to exceed 200 years in age (Clinton 1989). Furthermore, remeasurement of permanent vegetation plots revealed a basal area decline in all red oak species since 1970. In addition, most of the pitch pine stands in the Coweeta Basin were weakened by the drought and subsequently decimated by southern pine beetles. A photograph illustrating an example of tree decline and mortality in the Coweeta Basin is presented in Figure 13.

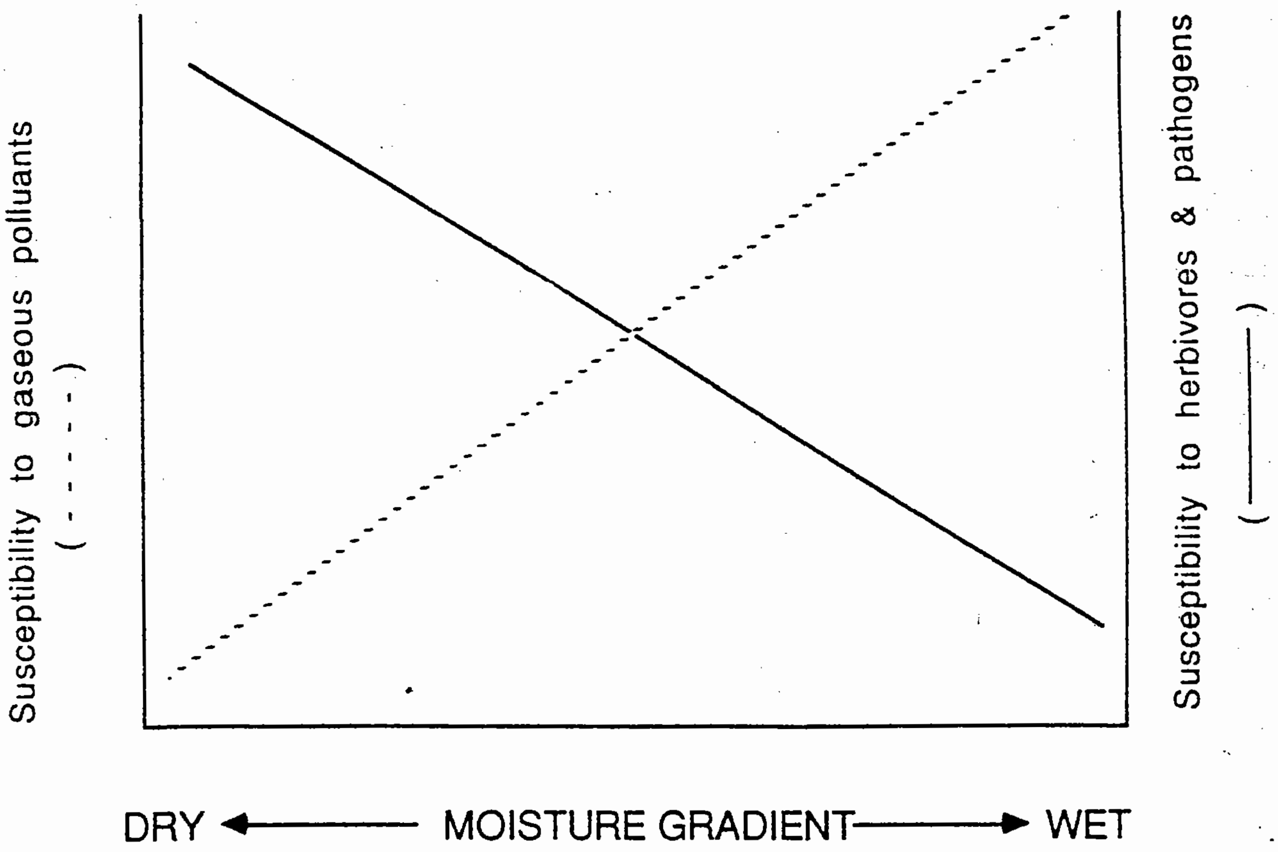


Figure 12: Effect of moisture gradient upon forest susceptibility to stress.

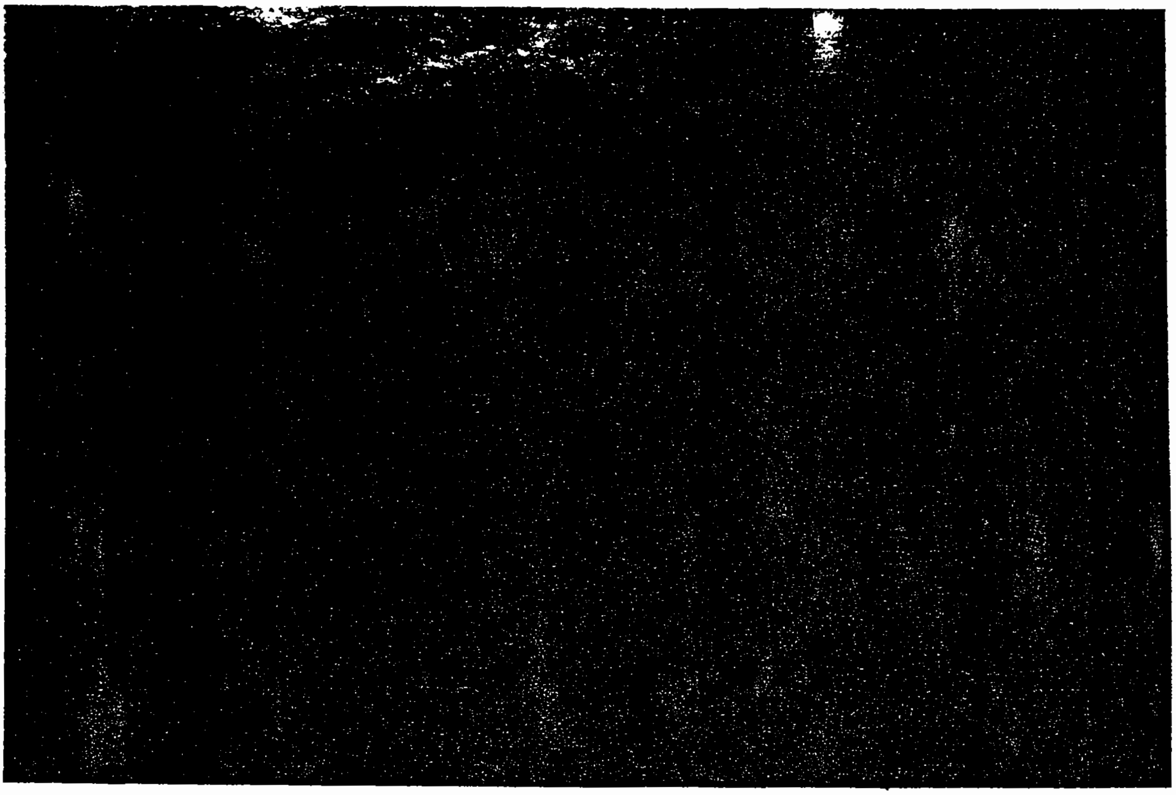


Figure 13: Photograph illustrating tree decline and mortality in the Coweeta Basin. Note the standing dead oaks in the foreground as well as trees with brown foliage scattered throughout the picture.

From these ongoing studies it appears that many of the keystone oak species are losing long-term dominance in these mid-elevational forest communities, and will be displaced by more opportunistic species such as *Acer rubrum* , and other species well-adapted for gap successional conditions. Of perhaps more importance, we hypothesize that *Rhododendron maximum* will continue to dominate mesic sites in the understory and competitively exclude the establishment and growth of overstory species. These shifts in species composition may cause changes in successional dynamics within gaps (through light and soil resource competition), as well as alteration of forest floor nutrient-cycling processes that could have long-term consequences for patterns of NPP, LAI, and stream water chemistry (see Section III.3).

Although we attribute our current oak decline to direct and indirect stresses from a prolonged drought event, it is conceivable that these short-term climatic events may be related to longer-term patterns of global change, which is predicted to change the distribution of rainfall. Another prediction is for increased hurricane intensity and frequency in the southeastern USA (Emanuel 1987). These storms would further increase our incidence of forest gap openings as well as induce debris avalanches which are dominant long-term geomorphic events in the Southern Appalachians (Grant 1988).

Stress and disturbance-induced changes in forest composition and ecosystem processes provide us with an opportunity to address impacts at several levels of resolution. Process and ecosystem level impacts directly attributable to significant short-term climatic events, should provide considerable opportunity to validate hypotheses about response to global change since this hot, dry period is similar to conditions predicted to eventually dominate our region (Davis 1988).

WORKPLAN

We have outlined our three objectives in the previous sections. Objectives 1 and 2 will be addressed with baseline process-level studies along an elevational / environmental gradient of the Coweeta Basin, using both intensive (5) and extensive (24) study plots. Objective 3 will be addressed by coupling baseline measurements with long-term successional changes in structure and processes using experimentally induced forest gaps paired with baseline studies, long-term remeasurement and analysis of permanent vegetation plots, and remeasurement of a selected subset of drought-induced gaps in pine and oak forests. Modeling will be used to synthesize and integrate our long-term measurements and experimental results, and to predict ecosystem responses to future changes.

There will be an initial stratification of the Coweeta Basin into dominant forest and soil types, detailed below. This will be accomplished with our new GIS technology, previously completed soil maps, and summary data from the 1970-75 measurement of 400 permanent vegetation plots. Forest communities identified for stratification and location of intensive and extensive study plots

TABLE 3: SUMMARY OF MEASUREMENTS F[illegible] DISTURBANCE ALONG GRADIENTS

Item	Parameter	Investigators	Frequency	Study Unit	Methods	Reference
NUTRIENT EXPORT		Swank	Weekly	Watershed	Stream water samples: anion and cation analysis	Swank and Waide 1988
FOREST FLOOR PROCESSES:						
Soil mineralization & immobilization	N, P, & S	Fitzgerald, Boring, &Haines	Seasonal Annual	Intensive Extensive	30 day lab incubations; 48 h for S	Kenney 1982; Fitzgerald et al 1988
Decomposition & litter mass		Crossley	3rd years Monthly	Intensive	Litterbags & microplots	Blair and Crossley 1988
Forest floor biota		Crossley & Coleman	Seasonal	Intensive	Microplots & pitfall traps	Blumberg and Crossley 1988
Litterfall	Woody & leaf	Crossley & Vose	Monthly Seasonal	Intensive Extensive	Littertraps & microplots (for woody)	Blair and Crossley 1988
CLIMATOLOGY:	Air, Soil temp.	Swift & Vose	Weekly	Intensive	Loggers & thermometers	Swift and Ragsdale 1985
	Soil moisture		Weekly	Intensive	Time domain reflectometry	Dalston &van Genuchten 1986
	Precipitation		Event	Intensive	Standard and recording gages	Swift & Cunningham 1986
	PAR		Monthly	Intensive	Ceptometer, PAR sensor	Decagon Devices
VEGETATION PROCESSES:						
Net primary production	Aboveground	Vose, Haines & Coleman	Annual	Int. & Ext.	Tree bands, litterfall	Day et al. 1988
	Belowground		Seasonal	Intensive	minirhizotron; obser. windows	Taylor 1987
Leaf area	LAI	Vose & Haines	Seasonal Annual	Extensive Gaps	Ceptometer, wide-angle photography, and calibration	Pierce & Running 1988 Rich 1988
Foliar elements	NPKCaMgFeMnAl ^{15}N; ^{14}N & ^{34}S: ^{32}S	Boring & Haines	Annual	Intensive	Plasma emission element & stable isotope ratios	Schulze 1989 Winner et al. 1989
Gap experiment	Spp Div, Ps, LAI	Boring, Haines, & Vose	Annual	Gaps	Tree mortality experiment	Clinton 1989
Permanent plot & gap resurveys for biodiversity/succession	Dbh & Spp Over & Understory	Boring & Swank	5th year	Extensive & Gaps	Periodic plot remeasurement	Clinton 1989
CANOPY CONSUMPTION:	LAR	Crossley	Seasonal	Intensive	Leaf area removed	Hargrove and Crossley 1988

include: 1) Cove Hardwoods; 2) Mesic Oak-Mixed Hardwoods (*Quercus prinus - Q. rubra*); 3) Xeric Oak-Pine (*Q. coccinea - Pinus rigida - Kalmia latifolia*); and 4) Northern Hardwoods.

Forest communities 1, 2, and 3 are well represented on lower elevation control WS 18, while higher elevation control WS 27 is dominated by communities 2 and 4. Five intensive sample plots will be located in representative stands along an environmental gradient on these two watersheds: one plot in each community type except mesic oak, for which we will have both a high and a low elevation plot. Additional extensive sample plots (6 per forest type) will be used for less intensive sampling of stand level parameters throughout the basin. The intensive sample plots will be large plots (20m x 40m) which will be accessed by boardwalks, towers, scaffolding and ladders to minimize the effects of intensive sampling upon the steep slopes. Extensive sample plots will be chosen from the 400 permanent vegetation plots that have known composition and history since 1934.

We have divided process level measurements into both intensive and extensive level studies. Variables to be measured are based upon our rankings for their relative importances in detecting stand-level ecological changes over the gradient. Many variables are indicators or correlative variables of forest productivity/health or upslope processes potentially influencing water chemistry. A minimal number of response variables are needed to detect long-term changes in forest processes without incurring excess costs. Some variables may be very important, but beyond the funding means of the LTER program. We have identified two levels of variables to measure: less-expensive "extensive" measurements which we could make across the landscape on more sites (30) at a lower sampling frequency (annually); and expensive "intensive" measurements which will be more process-oriented and be sampled more frequently (phenologically, monthly or seasonally) on a limited number of plots (5) along the elevational gradient. These plots will also be used for additional studies funded from other sources.

The following paragraphs describe the measurements we propose to address objectives 1 - 3. In Table 3 we summarize what measurements will be made, methods to be used, and investigators responsible for the work. A timetable for the research is included in Table 4.

Workplan for Objectives 1 and 2

a. Nutrient Dynamics: Previous research at Coweeta has documented differences in nutrient cycling processes across the elevational gradient (Swank and Waide 1988). Several key nutrient cycling processes will be examined on the intensive study plots. Bulk atmospheric inputs to the watersheds will be quantified using the rainfall chemistry network already established for the basin. In addition, watershed scale nutrient outputs will continue to be quantified from streamwater nutrient analyses. Pool sizes, mineralization rates, and immobilization rates of soil nitrogen, sulfur, and phosphorus will be characterized using quarterly lab incubations and isotope studies. Foliar chemistry of the major overstory species will be examined to assess nutritional status (nutrient ratios) and to correlate tissue nutrient status with measures of soil nutrient availability (Schulze 1989). Additionally, stable nitrogen and sulfur isotope ratios will be characterized in the same foliar fractions (Winner et al. 1989). On the extensive plots, nutrient mineralization rates will be characterized for correlation with climatological and productivity data.

b. Soil Organic Matter/Forest Floor Processes: Intensive forest floor studies will provide baseline data on key processes along the gradient, and simultaneously provide comparative measurements for the gap experiment. Litterfall will be sampled monthly using litter collectors in the intensive study plots, and forest floor mass will be sampled bimonthly. Forest floor biota will be sampled seasonally in the intensive plots. Earthworms, enchytraeid worms and nematodes will be sampled once per quarter. Macroarthropod populations will be estimated using pitfall traps (Blumberg and Crossley 1988) plus litter samples during spring and summer seasons. Decomposition rates will be estimated from litterbag measurements taken every third year (Blair and Crossley 1989). Decomposition modelling is described below (Synthesis and Integration section).

c. Net Primary Production: Differences in resource availability and microclimate result in different patterns of net primary production. Stresses and disturbance will also have differential effects on NPP depending upon the location along the environmental gradient (see Rationale section). We will quantify annual above- and below-ground net primary production on the intensive plots and relate NPP to corresponding measures of resource availability (water and nutrients). All trees will be mapped and tree diameters will be measured at the end of each growing season. Species specific allometric equations will estimate biomass from diameters, and annual remeasurement of mapped trees will provide population dynamics. Stand level measurements of NPP and leaf area index will be coupled with our replicated (6 plots per community type) "extensive" study plots. Litter inputs will be quantified using litter traps, which will be sampled monthly during the summer and fall. Leaf area removed by folivore insects (LAR) will be estimated seasonally, using photocopied images of foliage samples taken adjacent to the intensive-study plots (Hargrove and Crossley 1988). Belowground productivity will be quantified using root phenology observation windows and root biomass coring.

d. Climatology: Studies at intensive study plots will be supported by both site-specific and basin-wide climatic measurements. Climatic data will characterize physical variables along the elevational gradient, and especially support forest floor and modeling studies. In each intensive study plot along the environmental gradient, soil temperature and moisture at 5 and 20 cm depth, and air temperature under the canopy at 1.3 m will be sampled weekly. Soil and air temperatures will be sensed by max/min thermometers, supplemented by continuously recorded temperatures at a high and a low elevation plot. Soil moisture will be measured using time-domain reflectometry. High resolution estimates of temperature and moisture for the other plots will be estimated using

Table 4: Timetable for studies of disturbance along gradients

Item	Year 1	2	3	4	5	6
Plot selection	X					
Installation of scaffolding & plot access system	X	X				
Soil mineralization	X	X	X	X	X	X
Decomposition & litter mass	X	X	X	X	X	X
Forest floor biota	X	X	X	X	X	X
Litterfall	X	X	X	X	X	X
Climatological measurements	X	X	X	X	X	X
Net primary production	X	X	X	X	X	X
Leaf area	X	X	X	X	X	X
Foliar elements	X	X	X	X	X	X
Gap experiment	X	X	X			X
Permanent plot & gap resurveys for biodiversity/succession		X	X			
Canopy consumption	X	X	X	X	X	X

existing models developed at Coweeta. Monthly cumulative photosynthetically active radiation (PAR) will be measured using a portable PAR sensor. Precipitation data at four recording raingage stations spanning the study area will be available as storm period amounts or as hourly, daily and monthly totals. Two more gages can be reactivated to increase definition of precipitation patterns over the elevational range. Air and soil temperature, relative humidity, wind speed and direction, and solar radiation will continue to be measured at three climatic stations which bracket the study plots.

Workplan for Objective 3

a. Experimental Gaps Study: We hypothesize that elevated oak mortality and increased understory dominance of *Rhododendron maximum* will result in substantial shifts in overstory composition and be accompanied by changes in forest floor processes. By creating artificial gaps along our environmental gradient we may examine these changes under controlled conditions, and couple these measurements with intensively sampled control plots and with long-term vegetation plot data. Experimental gaps will be created in the cove, mesic oak, xeric oak-pine, and northern hardwood community types. There will be 6 gaps in each forest type; 3 with *Rhododendron* and 3 without, except that no *Rhododendron* is present in the xeric oak-pine community. Multiple tree gaps will be created by killing two to three less vigorously growing canopy dominant individuals of *Q. rubra, Q. prinus, Q. coccinea,* and *Pinus rigida*.. We will girdle the trees and follow with basal injections of herbicide to create gaps roughly 200-300 m^2 in size, which approximates the average size of drought/*Armillaria* induced gaps in the Coweeta Basin (Clinton 1989). Three pairs of gaps (with and without *Rhododendron* in a given community type) will be compared with three measurement areas inside control plots along the environmental gradient.

Year 1 will require pretreatment measurements, year 2 will be the year of tree death, and year 3 will be the first response year after treatment. Thereafter, measurement will be at 3 year intervals for 24 years. Measurement variables will include understory plant population measurements (species and size), photosynthetically active radiation, soil and air temperatures, soil moisture, forest floor biota, decomposition, soil carbon, nutrient mineralization potentials, and leaf area index. We will experimentally compare pre- and post-treatment measurements using our control plots for annual climatic controls. Besides direct comparisons, these response variables will also permit us to model structural and process-level changes resulting from elevated tree mortality and from potential *Rhododendron* competitive exclusion of overstory species. Process-level studies of *Rhododendron* in the riparian zone (Section III.3) will be coupled with observations in this section to evaluate its full impact on both structural and functional parameters.

b. Long-term Vegetation Plot and Gap Studies: We also propose to remeasure periodically a large number (100-200) of the Forest Service's permanent vegetation plots (800 m^2) which were established in 1934 and remeasured in the 1970's. During 1992 and 1993 we will remeasure 100-

200 plots; the next remeasurement would be planned for 1997. In addition to the historical overstory data which are extensive, we will also include more detailed understory measurements to better understand stand recruitment and evergreen understory competition.

Coupled with this work is the need to assess stand dynamics following our 1986-1988 drought. It is proposed to permanently mark and periodically remeasure (every 5 years for 20 years) successional composition of a subset of our past study gaps in oak and pitch pine forests. This will consist of population-based measurements which will be used to validate our experimental gap data, and both will be used for stand models.

SYNTHESIS AND INTEGRATION

A key to understanding and predicting responses to stress and disturbance, as well as the variation of ecosystem structure and processes along environmental gradients, is the feedback linkage between environmental conditions, tree species composition, and hydrologic and nutrient cycles. These linkages can be incorporated into individual-based models of tree competition (Botkin et al. 1972; Shugart and West 1976; Shugart 1984). We plan to use a model of this type to integrate our monitoring and experimental results, and to predict ecosystem responses to future changes. The model will include both the effect of soil moisture availability and drought on tree growth, and the effect of species-specific leaf chemistry on nitrogen and carbon cycling (Pastor and Post 1986, 1988). We will use data from our intensive and extensive plots along this environmental gradient, as well as population and process-level data from experimental gaps and long-term vegetation plots.

Model parameters for tree growth will be obtained from historical Forest Service data from forest inventory plots, while data on leaf chemistry and decomposition will come from this study and previous work at Coweeta (Cromack 1972, Day and Monk 1978, Blair and Crossley 1988, White et al. 1988). With climatological input from this study, model predictions will be tested against data from our plot studies for leaf area index, species composition, litterfall, decomposition rates, soil organic matter, total nitrogen, and nitrogen mineralization rates; and against extensive data from the long-term inventory plots for successional dynamics and structural change along gradients.

Gaining a better understanding of the effect of interacting resources, such as nutrients, light and water, on tree growth and mortality is essential to understanding complex patterns of spatial and temporal change in plant community structure (Huston and Smith 1987; Smith and Huston 1989). Changes in the relative importance of nutrient inputs, internal recycling, and total pool sizes that we will be able to predict with our models and to measure at our field sites are critical for predicting long-term changes in ecosystem stability (DeAngelis et al. 1989).

III. 2. Stream ecosystems along an environmental gradient

OBJECTIVES

An assessment of long-term trends in stream ecosystem structure and function in response to a disturbance such as global change requires that information be collected across a gradient of stream sizes since response to disturbance will vary with stream size. Hence our overall objective in this research is to determined the longitudinal pattern of key ecosystem processes in Coweeta streams as they are controlled by longitudinal changes in geomorphology and patch frequency. Our general hypothesis is that longitudinal changes in the relative abundance of geomorphic patch types will produce differences in structural and functional characteristics of stream reaches. Specific hypotheses guiding this research are as follows:

1) Nutrient uptake length within a geomorphic patch type will increase downstream, and nutrient uptake length in a reach can be predicted from a knowledge of the relative abundance of geomorphic patch types in the reach.

2) Periphyton primary production will a) vary among patch types within reaches based on substratum stability/stream flow relationships; and b) vary among patch types over longitudinal/altitudinal gradients as a function of temperature, light gaps in the canopy, and aspect during foliated periods with reduced variation during defoliated periods.

3) Standing crop of benthic detritus will decrease along the gradient as will benthic respiration on an aerial basis; respiration per unit ash-free dry mass (AFDM) will not change along the gradient.

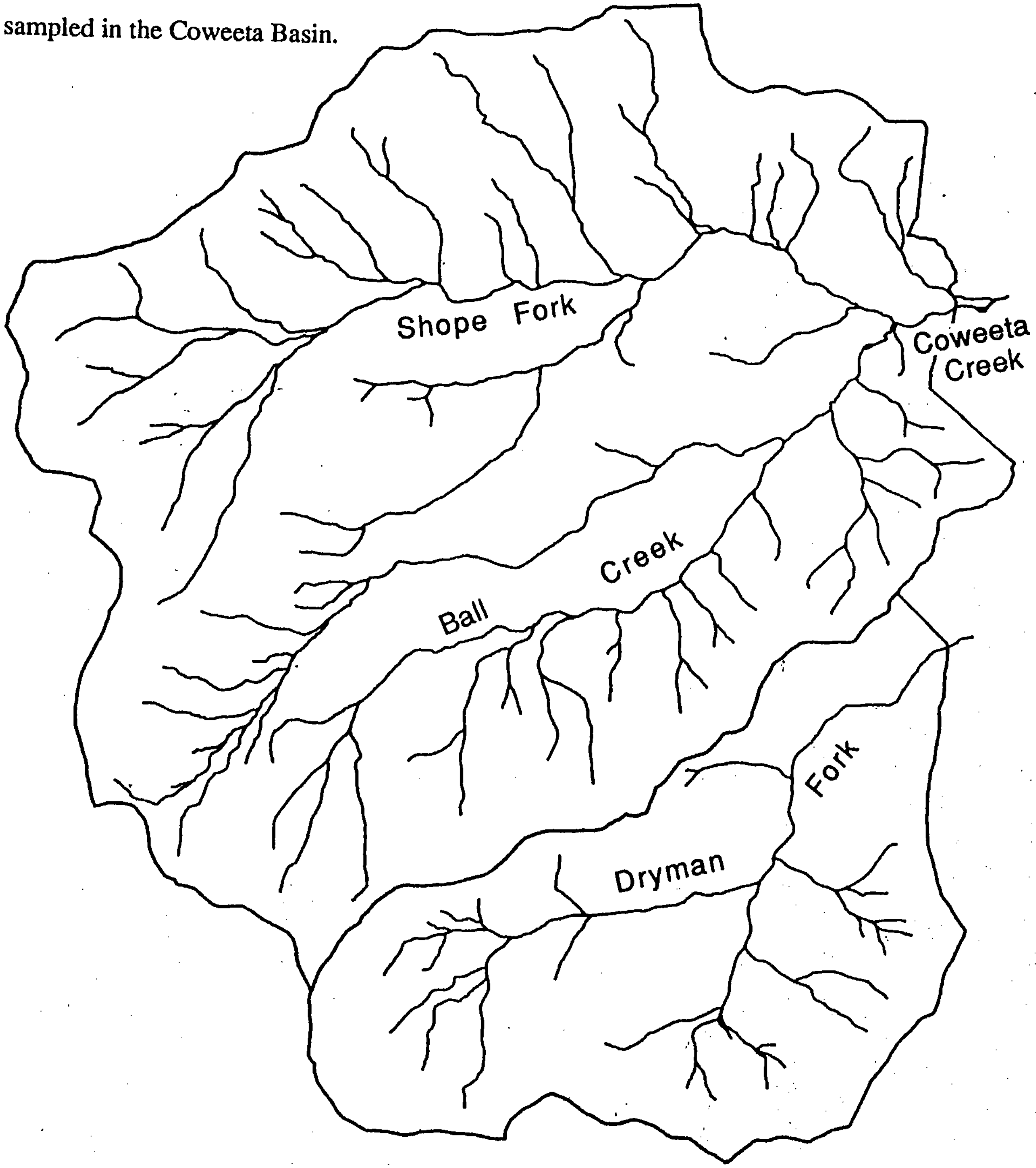
4) Thermal effects will lead to increased litter breakdown rates along the gradient, whereas the impact of shredders will lead to highest litter breakdown rates in the headwaters.

5) Ecosystem function (e.g. macroinvertebrate functional groups) will be similar within a geomorphic patch type along the gradient (patch fidelity of ecosystem function); however taxonomic structure of individual functional groups within patches will differ along the gradient. Total abundance of functional groups within a reach will change along the gradient because of changing patch frequencies.

6) Fish assemblage structure and production of species will differ along the gradient in concordance with the changing abundance of patch types.

An additional objective of LTER stream research is to continue to assess recovery from ecosystem disturbance in several on-going long-term experiments. Much of the stream research at Coweeta during the past decade has been oriented toward assessing the influence of disturbance on individual watersheds. These initiatives need to be maintained as they represent long-term commitments to studies of the influence of disturbance on stream ecosystem processes. These include: (1) studies in streams draining WS 7 (clearcut 1977) and WS 14 (reference for WS 7)

Figure 14: Streams to be sampled in the Coweeta Basin.



examining patterns of recovery in dissolved organic carbon (DOC) concentration, seston, litter decomposition, geomorphology, amount of woody debris, and stream invertebrate communities; and (2) long-term studies of the influence of debris dam additions to Cunningham Creek (invertebrates, geomorphology, and nutrient retention). These are discussed more fully in Section IV.2.

RATIONALE

Most of our past work has focused on Coweeta streams that drain small individual or paired (i.e., manipulated and unmanipulated) watersheds. These studies have greatly improved our understanding of the structure and function of stream ecosystems at Coweeta. They have also allowed us to address the influence of various disturbances such as clear-cutting, pesticides, and debris additions on stream biota and ecosystem processes. These studies have demonstrated the importance of substrate and geomorphic factors as influencing processes ranging from nutrient uptake length (Munn 1989) to secondary production by stream animals (Huryn and Wallace 1987). It is now time to apply knowledge gained in our past efforts to increase the spatial scale of our studies in order to encompass a broader perspective. The stream research proposed for the next six years at Coweeta centers on longitudinal linkages and elevational gradients. Our basis for this work is the need to expand the perspective of our Coweeta stream studies into the broader context of the southern Appalachian landscape in order to assess the impact of environmental disturbances such as global and regional climatic change on aquatic ecosystems.

Long-term change of ecosystem function in response to environmental disturbances such as global change (e.g. acidification, climate change) requires that measurements be made over stream gradients. Both immediate and long-term functional responses may vary with stream size. For example, there is already evidence of pH depression during storms at Coweeta in high elevation streams, and less pH depression at lower elevations (Swank and Waide 1988). Furthermore, global warming may alter thermal regimes along the gradient, which could alter the pattern of biotic community structure and rates of carbon flow and nutrient cycling along the stream gradient.

The proposed research will also address changes in stream ecosystem function influenced by longitudinal changes in geomorphology and patch frequency. Although great debate exists over the term "patch" (Pringle et al. 1988), we will define it functionally. Patches are small, relatively homogeneous areas with quantifiable physical characteristics. It is likely that stream geomorphology and velocity are the main factors affecting patch formation. The interaction of these forces creates patches with differing velocities, depths, and substrate particle size distributions. These in turn, influence both organism abundance and process level phenomena (e.g. organic matter retention) within patches. Examples of readily identifiable patches within the

Table 5: Changes in stream channel parameters as measured at 10 m intervals from 1st-order Upper Ball Creek (elevation = 1221 m asl) to 5th-order Coweeta Creek (elevation = 675 m asl) during the summer of 1989 based on simple linear correlations along the 5.25 km stream length. All % covers are based on arcsine transformed percentages. Temperature data are from recording thermographs at upper and lower reaches. Unless stated otherwise all correlations significant at $p<0.01$.

Parameter	Significant upstream to downstream change?	Direction of upstream to downstream change
Forest canopy		
% overstory cover	no ($p<0.1>0.05$)	decreases
% understory cover	yes	decreases
Stream		
Mean depth	yes	increases
Bankful width	yes	increases
Wetted width	yes	increases
Substrate % cover		
Rock outcrop	yes	decreases
Boulder	yes	decreases
Cobble	yes	increases
Sand and silt	no	not sign.
Organic debris (including wood)	yes	decreases
Number of debris dams per 10 m reach		
Spanning < 50% of wetted width	yes	decreases
Spanning > 50% of wetted width	yes	decreases

Stream Temperatures	Upper[1] reach	Lower[2] reach
Annual degree days	3400 to 3641	4161
Minimum (C)	0.5 to 1.2	2.5
Maximum (C)	16.9 to 17.1	19.0

[1] = based on 3 years of continuous data

[2] = based on 1 year of data

Coweeta drainage are: cobble riffles, rock outcrops, depositional low velocity pools, and debris dams.

To document longitudinal changes in patch frequency, we measured a variety of parameters (Table 5) at 10-m intervals, from the headwaters of Ball Creek to below its confluence with Shope Fork (= Coweeta Creek) (Figure 14). These data (Figure 15) coarsely depict how patch composition and frequency changes along this elevational and geomorphic gradient. As the stream descends it becomes deeper, wider, and slightly more open. The percentage of cobble increases, whereas bedrock, boulder, organic debris, and debris dams decrease (Figure 15). Although such changes are common in streams, we predict that changes in ecosystem and community structure and function along this continuum (sensu Vannote et al. 1980) will be strongly affected by the more subtle differences in patch frequency. In particular, we hypothesize longitudinal changes in the relative abundance of patch types will produce differences in the structural and functional characteristics of stream reaches. We will test these hypotheses by quantifying changes in ecosystem processes (e.g., nutrient uptake length, primary production, leaf litter processing, heterotrophic respiration, and detrital standing crops), animal communities (meiofauna and macroinvertebrates [biomass and community structure], and fishes [biomass, community structure, production, recruitment, and mortality]) along the elevational and stream size gradient. This integrated study, conducted along a 5.25 km longitudinal and 546 m elevational gradient with geomorphic changes, represents a major step toward increasing our understanding of southern Appalachian streams within the landscape context. Furthermore, data from permanent and well-mapped study reaches represent valuable baseline data against which any future changes can be compared.

This research will focus on Ball Creek and Coweeta Creek just below the confluence of Shope Fork and Ball Creek (Figure 14). Because a long-term goal of our project is scaling up to the level of the southern Appalachian landscape, we must consider the problem of replicate streams. For example, can we extrapolate results from Ball Creek to other southern Appalachian streams? To address this question, during two years we will measure key parameters in two additional major Coweeta drainages, Shope Fork and Dryman Fork. Each of these streams possesses attributes (i.e. different aspects and somewhat different geology) that will contribute to our understanding of the effects of elevational and longitudinal gradients on stream dynamics and therefore increase our ability to scale up our results to the southern Appalachian landscape.

WORKPLAN

Study reaches and habitats

Four 100-m reaches ranging from a high elevation first order stream (WS 27), to a lower elevation 5th order stream (Coweeta Creek) will be established along the gradient from upper Ball

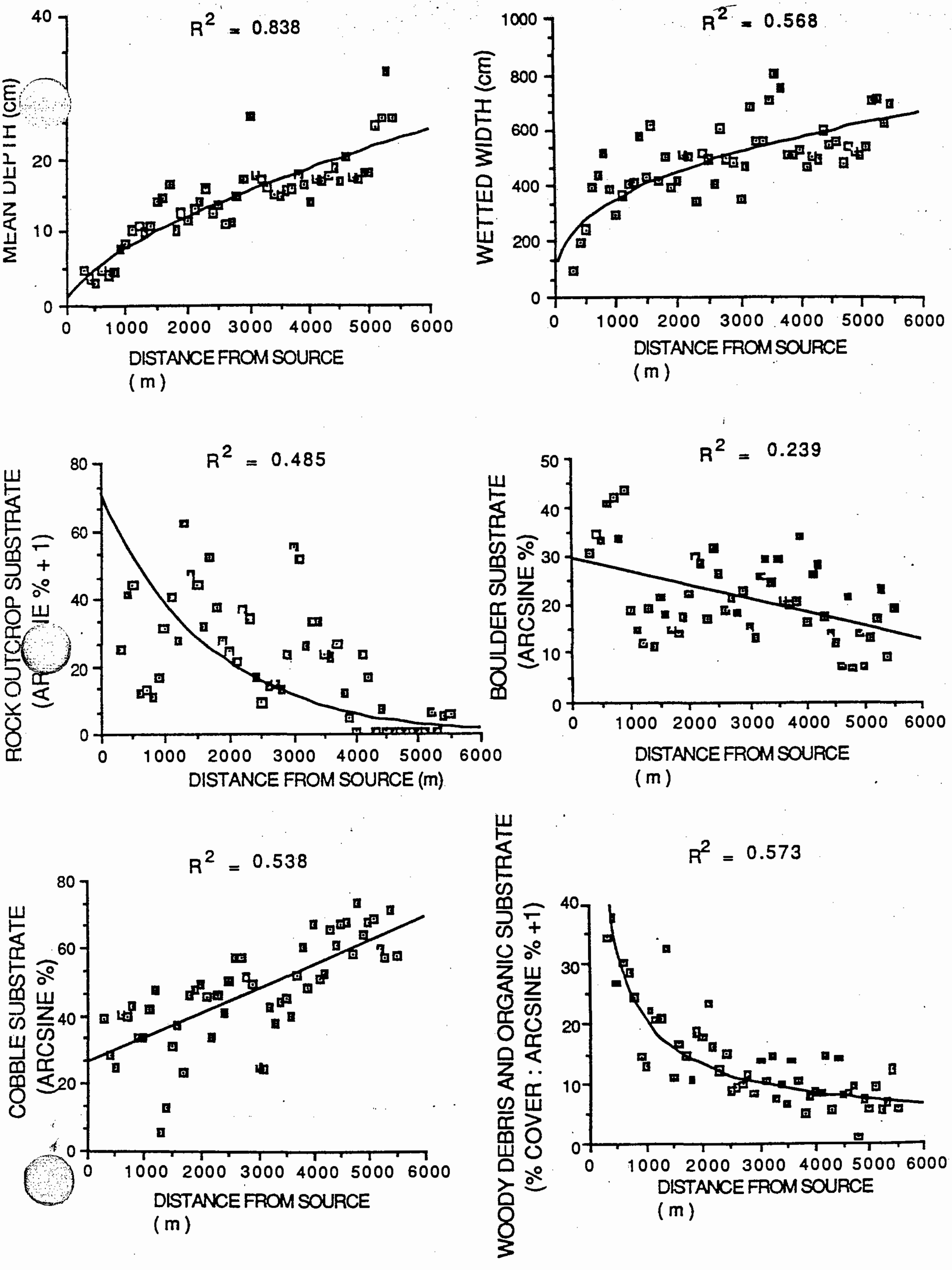


Figure 15: Changes in physical features and habitats along an elevational gradient in Ball Creek.

Creek to Coweeta Creek already surveyed (Figures 14 and 15). Photographs in Figure 16 illustrate the range of stream sizes encompassed by this gradient. We will choose reaches with characteristics that are not significantly different from the means of the elevational zone within which they are located (Figure 15). Each reach will be permanently marked with metal posts at 10-m intervals. Habitats (patch abundance) will be mapped within each each reach annually. Measurements will be taken along transect lines perpendicular to the flow at 1-m intervals and will include depth (cm), average velocity, and ocular estimates of percentage of the substrate composed of bedrock, boulder, cobble, gravel, sand, silt, and organic debris. We will estimate substrate composition in a 20 X 20 cm quadrat directly beneath the meter mark. Substrate will be categorized by particle diameters (e.g. Minshall 1984) as used previously for microhabitats at Coweeta (Grossman and Freeman 1987).

<u>Patch types</u>

Our primary criteria for patch identification rests on three intercorrelated habitat characteristics: substrate composition, mean velocity, and depth. Our first step in patch identification will consist of subjecting transect data from a study reach to a principal component analysis (PCA). This technique can be used for the identification of groups when apriori knowledge of group membership is not possible (Pimentel 1979). These data will then be used to calculate the relative proportion of each study reach composed of each patch type. In the event that PCA does not yield easily interpretable results, we will employ other multivariate techniques such as multidimensional scaling, or canonical analysis of discriminants.

We will also use GIS systems to produce habitat maps of each reach (i.e. substrate types such as silt-sand, mixed, cobble-boulder, rock outcrop, etc.). Our main hypothesis is that as one progresses downstream the relative frequencies of patch types change. This change promotes differences in both population and processing-level phenomena observed along the longitudinal gradients in streams.

One difficulty with application of the patch concept to an ecosystem is that organisms utilize patches differently (Levins 1968). Patch use will depend upon movement patterns of a particular species. For a bacterium, a habitat patch may be a sand grain, whereas for a fish, a 30-m reach of stream may constitute a habitat patch. Most of the processes (e.g. primary production, nutrient dynamics, organic matter retention) and organismal properties (abundance and production of benthos) in Coweeta streams can be quantified within a patch characterized by substrate, velocity, and depth. Fishes, however, move across such small patches (e.g. debris dams, rock outcrops) at will (Hill and Grossman 1987). Rather than disregard the contribution of fishes to this system, we will quantify fish characteristics (for specific details see below) in each study reach and assume that among reach differences in patch frequency will be sufficient to have an effect on these

Figure 16 A: Upper Ball Creek (1st order) showing woody debris, rock outcrop substrate, and riparian rhododendron cover.

Figure 16 B: Coweeta Creek (4th order) showing wider channel, predominantly cobble substrate, and

characteristics. Among-reach differences in patch frequencies will then be examined using PCA and GIS.

In the following paragraphs, we describe studies to test hypotheses 1 through 6 (above) along the elevational and stream size gradient. Variables to be measured, number of replicates, responsible investigator(s) and methods are listed in Table 6. The timetable for this work is presented in Table 7.

1) Nutrient uptake: A major focus of LTER research at Coweeta has been the long-term record of stream chemistry. Element concentrations are a consequence of inputs from the terrestrial system as well as uptake and regeneration in streams. Research at Coweeta over the past several years has demonstrated that element uptake rates (N, P, Ca, DOC) in first and second order streams vary with channel geomorphology and season (Munn 1989, Webster et al. in press), yet we do not know how uptake varies with stream size. Element uptake has been measured as uptake length, as recommended by the Solute Dynamics Working Group (ms. submitted). Our prediction is that uptake length within a geomorphic patch type will increase downstream and that uptake length in a reach can be predicted from a knowledge of relative abundance of patch types.

To test these predictions we will measure uptake lengths for N (as NH_4) and P (as PO_4) annually during the summer (more frequently would be logistically too costly) over the four stream reaches selected for intensive study. During the first summer we will also measure patch-specific uptake rates at each site. Uptake lengths will be measured with methods used by Munn (1989) and Webster et al (in press).

2) Primary production: We predict that periphyton primary production will: a) vary among patch types within reaches based on substratum stability/stream flow relationships; and, b) vary among patch types over longitudinal/ altitudinal gradients as a function of temperature, light gaps in the canopy, and aspect during foliated periods. During defoliated periods, variation may be reduced or disappear entirely.

Except for streams draining recently logged watersheds, autotrophic production is extremely low in Coweeta streams (Hains 1981, Webster et al. 1983). Experimental studies suggest that because of the heavy forest canopy, periphyton production is limited by light (Lowe et al. 1988; C. Tate, Kansas State University, unpubl. data). However, we have not attempted to measure primary production in streams larger than second order. As streams widen, we would expect some periphyton production in more open canopy patches of stable substrate (Hawkins et al. 1982). Because of patchiness, any random or stratified random sampling scheme would require an extremely large number of samples. Therefore, we propose to measure production and chlorophyll a on artificial substrate, and develop a relationship between the two. The relationship between chl-a and production will be used to estimate primary production from chl-a measurements on natural substrates at the site.

Table 6: Items to be measured, parameters, frequency of measurements, study units, and number of replicates, for proposed stream studies.

Item	Parameter	Investigator	Frequency	Study Unit	# Replicates	Methods	Reference
Nutrients	NH_4 PO_4	Meyer	Annual	Patch	1	Uptake lengths	Munn 1989 & Webster et al. in press
Periphyton	Primary Production	Benfield Webster	Seasonal	Patch (Tile)	5	light/dark on tiles	APHA (1984)
	Chlor-a	Benfield Webster	Seasonal	Patch (Tile)	10	acetone extraction on tiles with phaeophytin correction	Stockner & Armstrong (1981) APHA (1984)
	"	Benfield Webster	Seasonal	Natural substrates	10		
Benthic Organic Matter	CPOM & FPOM	Wallace Webster	Seasonal	Patch	5	Core, separate, dry, AFDM	Golloday et al. 1989 Wallace et al. 1989
Benthic Respiration	CPOM & FPOM	Webster Benfield	Seasonal	Reach	5 of each CPOM & FPOM	Respiration Chambers	Bott et al. 1985 Cuffney et al. 1990
Leaf litter	Processing Rate	Webster Benfield	Yr-round	Patch (2)	4 of each species on each coll. date	Litter Bags AFDM remaining, invertebrates, penetrance	Webster & Benfield 1986 Wallace et al. 1986 Suberkropp & Klug (1981)
Macroinverts	Abundance & AFDM	Wallace	Seasonal	Patch	3	Surber, Corer & Hess	Huryn & Wallace (1987) Wallace et al. (1989)
	Functional groups	Wallace	Seasonal	Patch	3	"	" & Merritt & Cummins (1985)
Meiofauna	Abundance	Meyer	Seasonal	as above	as above	as above from < 250 um fraction	O'Doherty (1988)
Fish	Abundance	Grossman	Seasonal	Reach	1	Electrofishing, Program Capture	Freeman et al. 1988 White et al. 1982
	Assemblage stability	Grossman	Annual	Reach	1	Coefficient variation	Freeman et al. 1988 Grossman et al. 1990
	Production	Grossman	Annual	Reach	1	Size - frequency	Krueger & Martin 1980 Garman & Waters 1980 Freeman et al. 1988

A relationship between chl-a and primary production was proposed by Ryther and Yentsch (1957), and there have been many attempts to use and improve the method (reviewed by Hall and Moll 1975). Because photosynthetic activity of chlorophyll varies with age, temperature, season, and other factors, the technique is not very useful as a general method. However, we propose to use a chlorophyll-production relationship measured at a particular site at a particular time and applied only at that site at that time.

3) Standing stock and respiration of benthic organic matter: We predict that standing crop of benthic detritus (both CPOM and FPOM) will decrease from 1st-order, high elevation study reaches to 5th-order, low elevation reaches. These results are predicted on the basis of the frequency and abundance of partial and complete debris dams along the elevational and stream size gradient (Figure 15). This will be tested with methods outlined in Table 6.

Studies of benthic respiration at Coweeta (Cuffney, et al. 1990) and other sites have typically shown that respiration measurements made on an areal basis are extremely variable whereas respiration rates expressed per unit AFDM of substrate are reasonably consistent. Therefore, we will measure respiration on qualitative collections of benthic coarse and fine particulate organic matter (CPOM and FPOM) and use our quantitative benthic detritus measurements to determine areal respiration rates.

4) Leaf Breakdown: Predictions on longitudinal patterns of leaf litter breakdown rates vary within our group. Based only on thermal considerations, one would predict that leaf litter breakdown rates would be highest in downstream reaches (higher annual degree days than headwater reaches). However, another school of thought predicts that leaf litter breakdown rates will be higher in the headwaters where shredders should be more numerous. CPOM retention and storage are generally higher in the headwater reaches and hence there is more food available for shredders. There appears to be less CPOM storage and fewer shredders in downstream reaches; however, the addition of retained litter in large meshed (>5mm) bags may represent an island of resources for invertebrate shredders in these higher order, lower elevation streams (Webster and Waide 1982).

Leaf breakdown will be measured at each of the 4 study reaches on Ball Creek during the first year using large-mesh litterbags. While several studies have shown that enclosure in fine mesh bags slows leaf breakdown (e.g., Cummins et al. 1980), large-mesh bags do not affect breakdown rates (reviewed by Webster and Benfield 1986) and are much easier to work with than leaf packs. The following variables will be measured on each pack: shredder abundance, ash free dry weight remaining; and leaf penetrance. Penetrance will be used as an index of microbial colonization and conditioning (Suberkropp and Klug 1981). Ash free dry weights remaining will be used to calculate breakdown rates on both a per day and per degree-day basis. Macroinvertebrates will be sorted and identified to the level necessary to recognize shredders.

Table 7: Timetable for stream studies.

	1991	1992	1993	1994	1995	1996
	s su f w	s su f w	s su f w	s su f w	s su f w	s su f w
Ball Ck [1]	* * * *	Analyses	* * * *	Analyses	* * * *	Analyses
Shope Fk [2]					* * * *	and
Dryman Fk [3]					* * * *	Synthesis
WS 7 & WS 14 [4]				* * * *->	Analyses	
Cunningham Ck [5]	*	*	*	*	* ->	Analyses

[1] Seasonal samples for all parameters except nutrient uptake which is summer season only. Includes the following: primary production, benthic detritus, benthic respiration, leaf breakdown, invertebrates, and fish.

[2&3] Shope Fork and Dryman Fork studies will involve only two stations each at high and low elevations. Data collection will follow that outlined for Ball Ck under (1) above.

[4] WS 7 (clearcut 1977) and WS 14 (reference) stream studies includes litter inputs, litter breakdown, stream seston, and invertebrate sampling. In addtion long-term studies of dissolved organic carbon are being measured at weekly intervals in each of these two streams.

[5] Cunningham Ck (debris dam addition study - debris dams were added to three cobble riffles in July 1988 and three additional cobble riffles serve as reference sites. This study involves seasonal sampling of invertebrates, changes in stream geomorphology, long-term decomposition of logs, and nutrient retention studies (annual). In 1990, we will shift all seasonal sampling to an annual sampling regime.

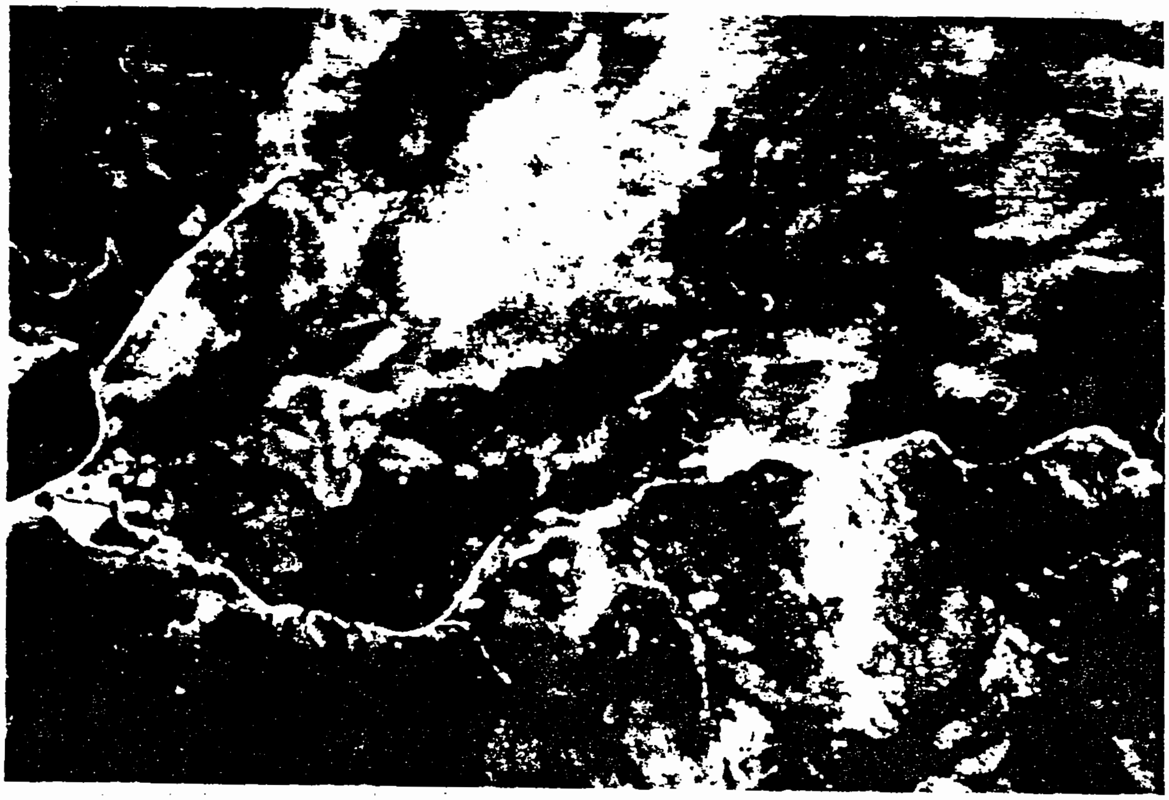


Figure 17: Aerial photograph (1976) of part of Coweeta Basin during the dormant season showing the extent of rhododendron cover in the basin. The darkest green patches are pine plantations (WS 1 is in the lower left), whereas the intermediate green patches are rhododendron. The very light green patches are mountain laurel.

information on thermal regimes of key macroinvertebrate species into the model, we will be able to make prediction about the likelihood of species replacements with altered temperature regimes.

Streams are integrators of land management in the landscape, and the proposed studies will provide a valuable comparison of gradients in both terrestrial and aquatic processes. The following section describes proposed research on the riparian zone, which is the vital link between terrestrial and aquatic ecosystems in the Southern Appalachians (Figure 8).

III. 3. Riparian zone as the regulator of terrestrial - aquatic linkages

OBJECTIVES

Riparian zones represent key linkages between terrestrial and aquatic ecosystems in the landscape (Figure 8). The riparian zone in the Southern Appalachians is commonly dominated by rosebay rhododendron (*Rhododendron maximum*). The extent of riparian rhododendron cover at Coweeta can be seen in Figure 17, and the completeness of rhododendron canopy closure over streams is apparent in Figure 16. Our working hypothesis is that rhododendron is a keystone species in the Southern Appalachian landscape, because riparian rhododendron thickets act as terrestrial debris dams with an impact on organic matter processing in the riparian zone, on element transport into streams, and on stream ecosystem structure and function. We propose to test this hypothesis with a long-term experimental manipulation in which we selectively remove rhododendron from the riparian zone. We predict the following specific effects when rhododendron is removed from the riparian zone, and have designed our measurements to test these predictions:

1) Amount of leaf litter entering the stream will increase because of increased movement of coarse particulate material from upslope through the physically-destroyed riparian "debris dam." Quality of leaf litter will also increase because of the absence of inputs of highly refractory rhododendron litter.

2) Transport of cations, nitrate, sulfate, and dissolved organics through the riparian zone to the stream will increase, but transport of phosphate will remain unchanged.

3) Rate of breakdown of organic matter in the riparian zone will increase as the amount of rhododendron-derived lipids, waxes and cuticular compounds decreases.

4) Soil fauna in the riparian zone will shift to more typical terrestrial species such as microarthropods, and away from aquatic / interstitial species such as enchytraeids and nematodes, which are more numerous under rhododendron.

5) Periphyton biomass in the stream will increase because of increased light reaching the channel. One consequence of increased periphyton biomass will be greater retention (shorter uptake lengths) of phosphate. However, significant increases in periphyton biomass may be obliterated by enhanced populations of grazing organisms (see #7, below).

6) Standing stock of benthic organic matter in the stream will not change.

7) Abundance of scrapers will increase in benthic macroinvertebrate communities.

8) If the study site is within the elevational range of the herbivorous fish *Campostoma* , its abundance will increase.

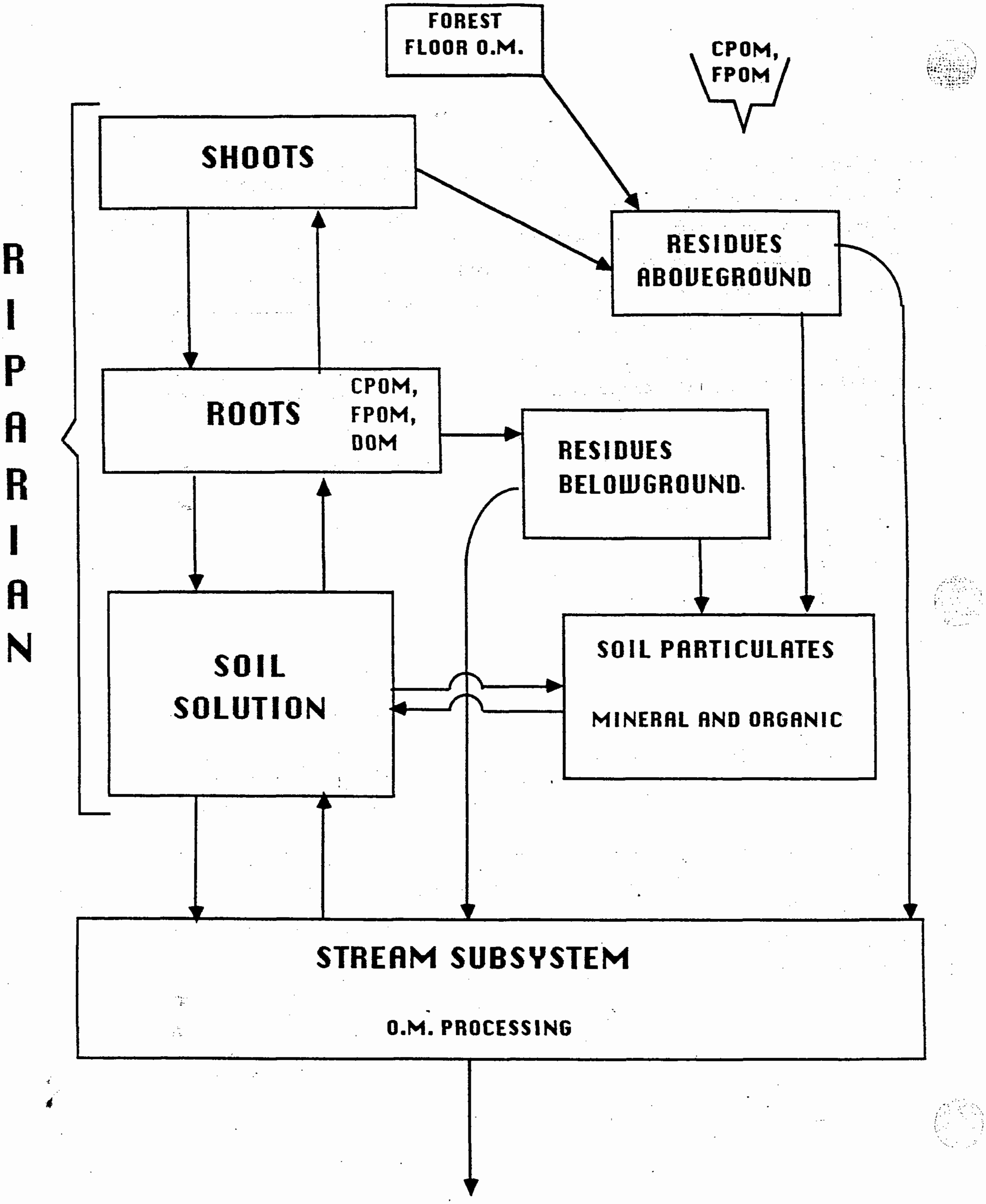


Figure 18: Conceptual model of the riparian zone as a terrestrial "debris dam" positioned in the landscape between the forests and the stream.

RATIONALE

In the Southern Appalachians, processes occurring in rhododendron-dominated riparian zones control the linkage between terrestrial ecosystems upslope and stream ecosystems (Figure 8). Leaf litter entering streams is either generated in or passes through the riparian zone. Variable source areas in the riparian zone are extremely important in stream flow generation. Water and nutrients exported from the upland areas of a small catchment pass through the riparian zone; hence stream chemistry is influenced by the chemical and biological processes that occur there. With the exception of some classic hydrologic research (Hibbert and Troendle 1988), previous work at Coweeta has not addressed the role of the riparian subsystem in the landscape. We view this as a critical gap in our understanding of forest ecosystem function at Coweeta.

Rhododendron is a major component of the understory in Southern Appalachian forests and often forms extensive monospecific riparian thickets (Monk et al. 1985, Phillips and Murdy 1985, Plocher and Carvell 1987, Figure 17). Since the 1940's rhododendron has assumed increasing importance throughout the Southern Appalachians with its competitive exclusion of regenerating overstory species (see Section III.1). Nowhere is this dominance more apparent than along stream margins and in other mesic habitats at Coweeta (Monk et al. 1985, Phillips and Murdy 1985). Such thickets frequently are of sufficient size to cover even fourth order streams (e.g. Figure 16). An important feature of these thickets is the accumulation of substantial amounts of leaf litter and woody debris on the forest floor.

The riparian zone, dominated by rhododendron, functions as a terrestrial debris dam that operates as diagrammed in Figure 18. One can view riparian rhododendron thickets as organic filters that have a major impact on the structure and function of Southern Appalachian stream ecosystems by: a) reducing light transmission to the streams; b) preventing terrestrial debris and soluble nutrients from reaching the stream; and c) altering carbon and nutrient cycling processes in the forest floor. Therefore we expect major changes in forest floor and stream processes with rhododendron removal.

We expect processes in the A horizon and OA and OE layers to be qualitatively and quantitatively different in the presence of rhododendron. Its roots proliferate in the upper 10 cm of the soil more than other riparian species. Soil pH is slightly lower in the presence of rhododendron, and ericaceous mycorrhizae abound on its roots. These observations suggest that there is a tighter recycling loop of nitrogen and phosphorus under rhododendron (Read 1983). Decomposition of leaves, roots and other organic matter is probably also slower under this species because of the refractory nature of its litter and the relatively wet soil conditions, both of which contribute to an apparent build up of humic materials in soils under rhododendron. Because of reduced root uptake and accelerated decomposition, removal of rhododendron should result in

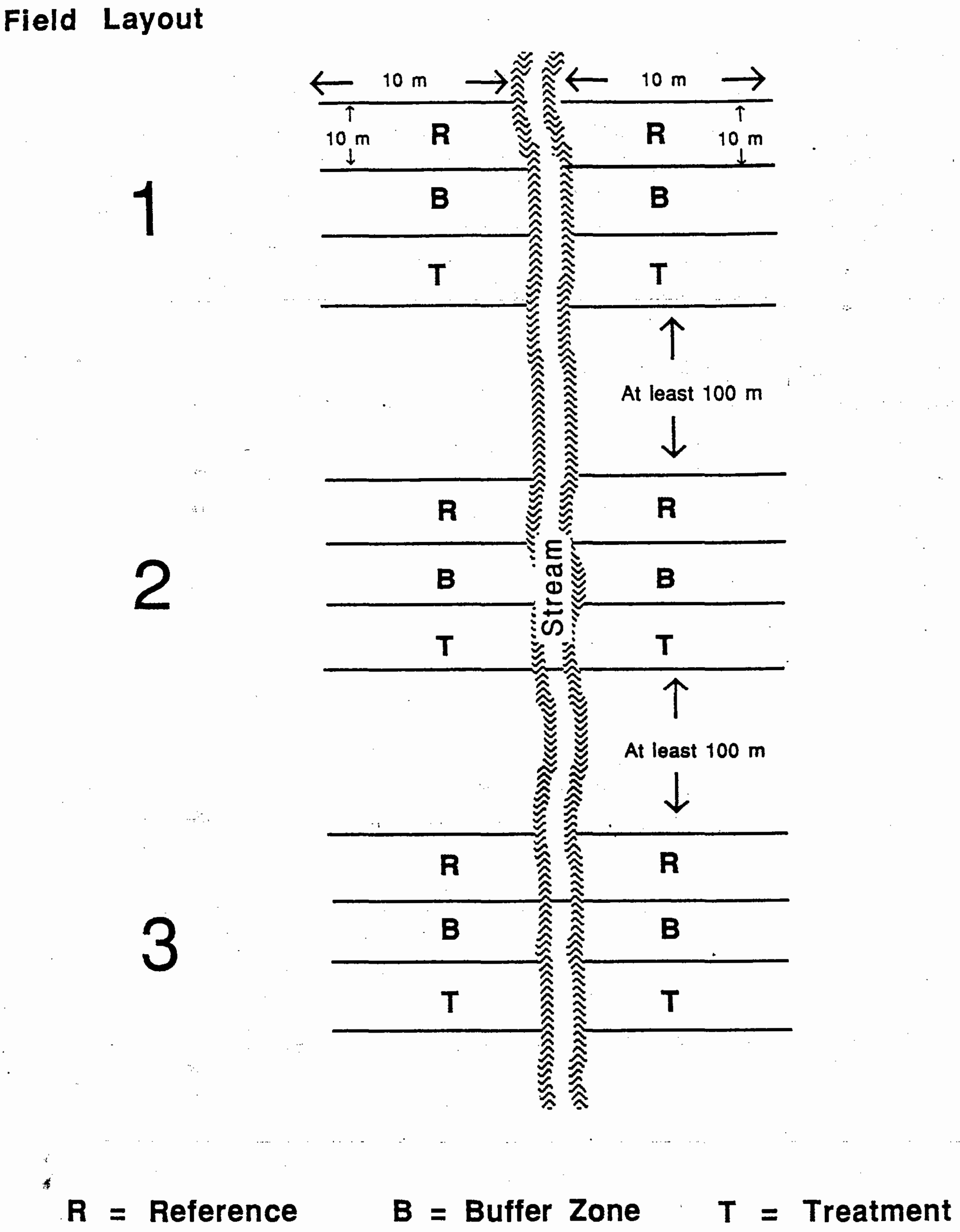


Figure 19: Diagram of the proposed riparian manipulation experiment.

increases in amounts of cations, dissolved organics, nitrate, and sulfate in soil solution and therefore increased transport of these elements to the stream. It is likely that phosphate will continue to be tightly adsorbed in the soil and hence we anticipate no increase in transport of this element to the stream.

There is strong evidence for light limitation in Coweeta streams (Lowe et al. 1988), and hence the increase in light reaching the stream when rhododendron is removed is expected to result in increased periphyton growth. If there is an increase in abundance of grazers (see below), increased periphyton growth may not be translated into increased biomass. When light is adequate in Coweeta streams, periphyton growth is phosphorus-limited during spring (C. Tate, Kansas State University, unpubl. data); hence, we predict increased uptake of phosphate after rhododendron removal. Increases in periphyton production in other Coweeta streams have lead to shifts in aquatic macroinvertebrate communities with an increase in scrapers such as *Baetis* (Gurtz and Wallace 1984), and we therefore predict a similar effect with rhododendron removal. We also postulate a change in amount and quality of litter reaching the stream. The quality will increase because of the elimination of highly refractory rhodoendron litter. Although rhododendron removal will decrease the amount of litter falling directly in from the riparian zone, we predict an increase in the amount of litter entering via lateral movement. Despite this increase in litter input, we are unlikely to see changes in standing stock of benthic detritus in the stream because we are manipulating a relatively short section, and downstream transport will probably move much of this litter out of the reach.

Because the riparian subsystem is uniquely situated between forest floor processes upslope and the stream (Figure 8), we consider it to be a potentially key regulator of exchanges between terrestrial and aquatic ecosystems. We propose a long-term experimental manipulation to test the predictions just discussed and assess the role of this subsystem in the landscape.

WORKPLAN

Experimental Design

We will survey the Coweeta Basin in Year 1 and locate three study sites (probably in Watershed 19, or along Cunningham Creek) with bankside rhododendron thickets about 10 m wide. We will find sites just below a gaged watershed so that stream discharge and chemistry data will be available but our experiments will not affect the suitability of that watershed for other research. Each of the three sites will contain two 10-m sections, a reference section and a downstream rhododendron removal (= treatment) section, separated by a 10 m buffer zone (Figure 19). We will collect pretreatment data in these sections during years 2 and 3. We will install root observation boxes in year 2. All rhododendron stems in treatment and reference sections will be counted. Boardwalks will be installed in both treatment and reference sections to minimize

Table 8: Summary of measurements in riparian.

Item	Parameter	Investigators	Frequency	Methods	Reference
FOREST FLOOR PROCESSES					
Decomposition, mass-loss		Coleman	Seasonal	Litter bags Litter baskets	Crossley et al. 1988
Labile microbial nutrients		Coleman	Seasonal	CFIM	Vance et al. 1987
Forest floor biota		Coleman & Crossley	Seasonal		Crossley et al. 1988
Litterfall	Woody & leaf	Coleman & Haines	Seasonal		
Litter movement		Coleman & Haines	Seasonal	Litter traps	Webster et al. 1983
Soil solution movement		Dowd & Haines	Monthly	Lysimeters	Haines et al. 1982
CLIMATOLOGY	Litter, air temp. Soil moisture, PAR	Swift & Vose Haines & Coleman	Continuous	Data loggers & sensors	
VEGETATION PROCESSES					
NPP	Aboveground Belowground	Haines & Coleman	Annual Seasonal	Harvest, Allometry Soil cores, rhizotrons	Boring, Swank, & Monk 1988 Taylor 1987
AQUATIC PROCESSES					
Periphyton	Chlorophyll-a	Meyer	Seasonal	Colonization of tiles; acetone extraction	APHA (1984)
Invertebrates	Abundance	Wallace	Summer	Surber in cobble/riffles	Huryn &Wallace 1987
Fish	Abundance	Grossman	Summer	Electroshocking	Freeman et al. 1988

disturbance to the forest floor. In year 4 we will cut and haul off all rhododendron within 10 m of the stream channel. Stumps will be treated with the herbicide Roundup during years 4 - 6 to prevent resprouting and seedling establishment. Understory species other than rhododendron will not be cut in the treatment plots. Rhododendron control will be terminated at the end of year 6, and we anticipate examining recovery from this disturbance in future research.

Our experimental design enables us to test for the effects of rhododendron on ecosystem structure and function through comparison of treatment and reference sections. Using annual or more frequent sampling regimes, we have a blocked 3 x 2 x 5 design representing sites x treatments or reference sections x years. Depending on the year of study, either two- or three-way ANOVA will be used to test for significance of main effects and interaction terms. If the distributional properties of the data render it inappropriate for ANOVA, a cross-classified contingency table analysis will be employed (Fienberg 1977).

Ecosystem Properties to be Examined

The variables to be measured in both terrestrial and aquatic habitats and investigators responsible for them are summarized in Table 8, and explained in greater detail in the following paragraphs. The timetable for this research is in Table 9.

a. Litterfall and litter movement (Hypothesis 1): Litterfall will be measured in the riparian zone and immediately adjacent to the stream using litterfall traps in both treatment and reference sections. Litter movement will be measured using lateral movement traps as used previously in stream research at Coweeta(e.g. Webster et al. 1983).

b. Element transport (Hypothesis 2): Both water flux and soil solution chemistry must be determined to calculate nutrient transport through the riparian zone. Water flux will be determined in two locations in each treatment or reference section on an annual basis. Throughfall will be measured using a data-logged tipping bucket from gutters 1 m long. We will measure matric potential and piezometric head in 24 tensiometers located on each side of the stream. The tensiometers will be installed at 15, 30, 45, and 70 cm depths. Pressure transducers connected to a data logger will be monitored every 15 minutes. Volumetric moisture content will be determined in the riparian zone by time domain reflectometry (Ledieu et al. 1986) on a weekly basis. Spatial and temporal variability in moisture content will be examined. Water flux will be determined using the soil suction and moisture content data to calibrate an unsaturated/saturated flow model based upon the Richard's Equation. We anticipate using HYSPAC, which is a three-dimensional model developed to simulate hydrologic processes in landscapes with spatially correlated soil characteristics (Sharma et al. 1987).

Element flux will be determined on an annual basis by coupling information on soil solution chemistry with the water flux model just described. Monthly soil solution concentrations will be determined with porous cup lysimeters (16 per plot) placed at up- and downslope locations in the

Table 9: Timetable for riparian rhododendron manipulation.

	Years					
	1	2	3	4	5	6
Select sites	X					
Construct boardwalk	X					
Pre-treatment measurements		X	X			
Cut and prevent regrowth of *Rhododendron*				X	X	X
Measurements				X	X	X
Data analysis		X	X	X	X	X
Synthesis						X

treatment and reference pairs. Pairs of lysimeters will be placed at 4 depths (15, 30, 45 and 70 cm) in each location. Lysimeters will be sampled weekly, and monthly composites used for analysis of pH, calcium, magnesium, potassium, sodium, aluminum, ammonium, nitrate, sulfate, bicarbonate, dissolved organic carbon (DOC) and total Kjehldal nitrogen (TKN) concentration. Monthly and annual chemical mass fluxes will be determined using the water flux determined by the model.

Soils characterization is required to determine the water flux and to develop predictive models for element flux. Physical properties of the soil will be determined for each transect and used to parameterize the hydraulic model. Measurements will include saturated hydraulic conductivity by Guelph permeameter (Soilmoisture Equipment Inc., Santa Barbara CA), moisture release curves, and soil texture. Chemical characterization will include carbon, nitrogen, and extractable and exchangeable cations. This information will be used to parameterize a chemical equilibrium model from which we will derive predictions of element flux.

c) Forest floor processes (Hypotheses 3 and 4): We will measure the soil microbial biomass and key microbivorous fauna (e.g., enchytraeids, nematodes) seasonally. To obtain a measure of changes in turnover of litter and root-derived particulate organic matter with rhododendron removal, we will set up litter and root decomposition packets in both treatment and reference plots and follow losses of organic matter over six years. Measures of $\Delta\ ^{13}C$, ^{15}N and organic matter (OM) quality will be taken on these samples using Isotope-ratio Mass Spectrometry GC/MS and will enable us to follow changes in OM quality with decomposition. This work will be performed in collaboration with Dr. David Wenner, Geology Department, and Dr. Karl Espelie, Entomology Department, UGA and is explained in greater detail in section IV.10.

d) Stream processes (Hypotheses 5 - 8): Periphyton biomass will be sampled monthly for six months each year (3 in summer and 3 in winter) by measuring the amount of chlorophyll accumulating over a one-month period on five unglazed tiles in each of the stream sections using techniques described in Section III.2. of this proposal. Uptake lengths for phosphate will be determined during the summer in each reach using methods outlined in Section III.2. Standing stock of fine and coarse benthic organic matter will be measured at the same time as periphyton biomass using techniques described in Section III.2. Five samples for benthic organic matter will be taken from each stream section. Community composition and biomass of benthic invertebrates will be analyzed in triplicate samples taken every summer from cobble/riffles in each stream section. Community composition and biomass of fishes in each stream section will be determined every summer using electroshocking techniques detailed in Section III.2.

SYNTHESIS AND INTEGRATION

Rhododendron appears to be a keystone species in the Southern Appalachian landscape. Its dominance in the riparian zone, apparent increase in the basin during the past decades, and potential for future increase in drought-induced gaps (Section III.1) make it particularly important to understand the consequences of rhododendron dominance for terrestrial and aquatic ecosystem function. The research described in this section will help us understand the impact of rhododendron on functional attributes of both forest floor and streams. We anticipate it will allow us to uncover mechanisms for the gradual spread of rhododendron across the landscape and therefore increase our ability to predict whether the spread of rhododendron will accelerate with the production of more drought-induced gaps (Section III.1). We plan to coordinate sampling associated with forest floor processes as outlined in Sections III.1. and III.3. to clarify the impact of rhododendron on major functional attributes of the forest floor such as organic matter decomposition and element dynamics and to enable us to compare soil processes upslope and in the riparian zone. The proposed studies of element movement through the riparian will offer valuable insight for interpretation of our long-term data base on streamwater chemistry.

Rhododendron dominance in the riparian is an obvious feature of Coweeta streams, yet we can only speculate on the consequences of this for stream ecosystem function. The proposed research will help remedy that situation. It is conceivable that the impact of cable-logging on trophic resources of stream ecosystems (summarized in Webster et al. 1983) was in part a consequence of riparian rhododendron removal. The riparian manipulation will complement the proposed research on ecosystem processes along stream gradients (Section III.2). The removal of dense understory shading may shift the functional structure of the stream downstream, making headwater reaches more like downstream reaches with more light, more periphyton production, and more grazers. Rhododendron removal may also result in lower inputs of woody debris and hence a less retentive channel. We will be able to test these ideas by comparing the nature of the shifts observed with rhododendron removal with the changes observed along the natural stream gradient.

It is likely that the nature of the riparian linkage will vary along the elevational gradient. That variation is in fact a part of our conceptual model (Figure 8). Because of limited resources, we are unable to test the validity of this aspect of the model since it would require that the study just described be repeated in at least three more elevational zones. This may prove to be a fruitful area for future research outside of LTER if the results of the proposed manipulation appear promising.

The overall theme of proposed LTER research at Coweeta is the expansion of our focus from watershed- to landscape-level in order to better understand and predict ecosystem response to disturbance. We have postulated that the riparian zone is critically positioned in the landscape, regulating the movement of water and elements between terrestrial and aquatic ecosystems (Figure 8). Disturbances such as climate change or increased acid deposition are likely to result in [illegible]ration of water and element movement across the landscape, and therefore the experimental manipulation proposed in this section is an integral part of our effort to predict ecosystem response to disturbance .

IV. Description of Specific Items

In this section we discuss how prior and proposed research at Coweeta meets the unique requirements of a LTER site. These requirements include: research in five core areas; research utilizing long-term experiments and associated data sets, archives, and their management; evidence of and plans for project synthesis; utilization of the LTER network for comparative analyses of ecosystems; diversity of funding sources for research projects at the site which expand the core support; overall project management; application of new technologies to answer important ecological questions; and dissemination of information to the public. In this section we also address the contribution of this project to education and human resources.

1. Five core areas

a. Pattern and control of primary productivity

Net primary production (NPP) by mature vegetation in the Coweeta basin varies along gradients of incident solar radiation, soil chemical properties, soil physical properties, herbivores and plant pathogens. General patterns of mature vegetation at Coweeta were described by Day et al. (1988) and production estimates were reviewed by Monk and Day (1988). One focus of research on patterns of primary production at Coweeta has been the recovery of vegetation from disturbance. NPP of successional vegetation from three forest types on the south-facing WS7 during the first 8 years after clear cutting was reported by Boring and Swank (1986) and Boring et al. (1988). Re-measurement was performed again in year 11 and will be repeated in year 15 (1992). Root production in the mid-successional, black-locust dominated WS6 was estimated by Harker-Grimm (1988). The proposed new research (III.1.) will enhance our understanding of the controls of primary productivity along environmental gradients and permit us to better understand the effects of stress and disturbance on primary production.

Rates of primary productivity in Coweeta streams are extremely low (Hains 1981, Webster et al. 1983) and appear to be limited by light rather than nutrients (Lowe et al. 1988; C. Tate, personal communication). Controls on aquatic primary productivity will be examined in the proposed research on the stream gradient and in the riparian manipulation described in sections III.2 and 3.

An outline of past, current, and proposed research in this core area can be found in Table 10 (on p.41).

b. Spatial and temporal distribution of populations selected to represent trophic structure

LTER research on consumer populations has included work on both terrestrial and aquatic species. Research on terrestrial consumer populations has included canopy arthropods as well as forest floor invertebrates. Forest canopies at Coweeta contain a varied and abundant fauna of insects, spiders, mites and other invertebrates. We have an 18-year record of canopy arthropod biomass arrayed into a functional guild model, encompassing 6 tree species across 6 watersheds with varying treatment histories (Schowalter and Crossley 1988, Crossley et al. 1988). Research questions have concentrated on the significance of arthropods in forest processes, using such data sets as nutrient element dynamics in functional guilds, and elemental dynamics in canopy throughfall. Shifts in functional guilds were found to accompany succession or disturbance (Schowalter 1981). The impact of the folivore arthropod community on its resource base is evaluated by measuring damage to foliage (LAR, leaf area removed) as a function of season, tree species and watershed parameters (Crossley et al. 1988). Response to drought and subsequent recovery, for example, were interpreted through shifts in canopy arthropod biomass and leaf area consumption as well. Current research is extending arthropod and LAR measurements to higher elevation watersheds, where early responses to climatic changes might be expected to occur.

Forest floor invertebrate populations at Coweeta are dominated by a diverse arthropod fauna (Abbott et al. 1980, Gist and Crossley 1975). Activities of forest floor arthropods were shown to have major impacts on nutrient dynamics during decomposition at Coweeta (Cornaby 1973, Cromack 1973, Crossley 1977). Research has concentrated on the effects of microarthropods and millepedes on leaf litter decomposition, using litterbag techniques and unconfined litter. In LTER research at Coweeta, the importance of biotic influences on decomposition within the context of resource and microclimate quality has received emphasis. Nitrogen dynamics in decomposing leaf litter have been related to leaf type, lignin content, watershed treatment history and arthropod population abundance (Blair and Crossley 1988). Recent research involves use of N-15 in experimental studies of nitrogen dynamics where arthropod populations are manipulated. Comparisons of aquatic and terrestrial decomposition processes have suggested many points of similarity in biotic control.

Ongoing and prior research on aquatic consumer populations includes projects involving meiofauna, macroinvertebrates, fishes, and salamanders. Efforts with meiofauna focus on assessment of the effects of macroinvertebrate removal (by insecticide) on meiofaunal populations. Macroinvertebrate studies concentrate on: 1) seasonal changes in macroinvertebrate abundance and drift, 2) macroinvertebrate production, including the effects of channel geomorphology on the abundance, biomass, and production of functional groups, 3) the influence of macroinvertebrate reduction on ecosystem processes (e.g. leaf breakdown, FPOM export, and nutrient export), 4) macroinvertebrate recolonization of previously denuded (by insecticide) streams, 5) the effect of debris dam addition on macroinvertebrate community structure, 6) the influence of insecticide treatment on abundance, biomass, and secondary production of macroinvertebrates, 7) long-term changes in macroinvertebrate assemblages in response to clear-cutting, 8) the effects of temperature on growth rates of macroinvertebrates in streams of different elevation and aspect, and 9) the influence of macroinvertebrates on FPOM turnover in headwater streams.

Ongoing and recently completed projects on vertebrate populations include: 1) long-term studies of the effects of environmental variability on fish assemblage structure and function, 2) experimental assessment of competition for space and food between the two most abundant benthic fishes, 3) an experimental study of competition for space between the two most abundant water-column fishes, and 4) development of energetic-based optimality models of microhabitat selection for the two numerically dominant water-column species.

Outlines of past, present and proposed research in this core area is included as Table 11 (p. 42) for terrestrial populations and Table 12 (p.43) for aquatic populations.

c. Pattern and control of organic matter accumulation in surface layers and sediments

Research in this core area at Coweeta has encompassed both terrestrial and aquatic studies. Dynamics of terrestrial organic matter at Coweeta have been studied for leaf and woody litter, and have included both decomposition and mineralization processes (Abbott and Crossley 1982, Cromack and Monk 1975, Mattson 1986, Seastedt and Crossley 1980, White et al. 1988). Leaf litter decomposition rates and woody decomposition were measured as a function of resource quality and biota within constraints of microclimates (see Section IV. 1.b., above). The effects of clearcutting, replanting with pine trees, and defoliation on decomposition and mineralization rates have been studied across watersheds with different treatment histories. Recent LTER research is extending these studies by concentrating on the control of nitrogen dynamics during decomposition (White et al. 1988), and microclimatic constraints within elevations at Coweeta.

Studying organic matter dynamics in streams involves following distribution, interrelationships, and fate of three size classes of organic material: dissolved organic matter (DOM), fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM). Interrelations and fate of the material are functions of biotic and abiotic agents in streams. We have studied the dynamics of organic matter processing in streams at Coweeta for about 15 years.

The benthic microbial community has been demonstrated to be important in dissolved organic carbon (DOC) uptake from reference and disturbed streams (Meyer et al. 1987, 1988) . DOC concentrations increase in a downstream direction as a consequence of instream sources of DOC (Meyer and Tate 1983, Meyer 1990), one of which is interstitial DOC leached from stored FPOM in the sediments (Crocker and Meyer 1987). The impact of disturbance on DOC dynamics has also been investigated in Coweeta streams (Meyer and Tate 1983, Tate and Meyer 1983).

We have an extensive data base on leaf decomposition in streams at Coweeta. J. B. Wallace and colleagues have completed 13 annual measurements of litter decomposition in 3 reference streams and 4 years of measurement in disturbed streams examining the importance of invertebrates on leaf-litter breakdown. These studies also included FPOM and CPOM export and measurements of respiration on decaying leaves, benthic FPOM, and wood. In addition, information has been collected in 5 continuous years on export of DOM, FPOM, and CPOM from 3 streams. The five-year period included a record dry year and a near record wet year.

The CoPIs at Virginia Tech have contrasted litter-fall and leaf breakdown rates in treatment and reference streams in 4 different years. They have contrasted benthic organic matter standing crops in treatment and reference streams and seasonal seston export in over 20 treatment and reference streams. In addition, they contrasted export of seston by treatment versus reference streams during storm flows. They examined the chemical quality of CPOM and FPOM at various stages of decay and shredder production in treatment versus reference streams.

Past, current, and proposed research in this core area is listed in Table 13 (p.44) for terrestrial systems and Table 14 (p.46) for aquatic systems.

d. Inorganic inputs and movement of nutrients

Hydrologic and nutrient cycling studies continue to provide the framework for linking terrestrial and aquatic processes and response to disturbance at Coweeta. The long-term hydrologic, precipitation and stream chemistry, and nutrient cycling patterns and processes for baseline and disturbed forested watersheds were synthesized in the recent book (Swank and Crossley 1988). Past and current studies can be examined in the context of (1) long-term responses of ecosystems to disturbance/stress; (2) shorter-term terrestrial and aquatic process level findings.

Analyses continue to support the observation that Coweeta watersheds are exhibiting delayed response to atmospheric deposition as defined by increases in stream SO_4 concentrations and anion deficits, concomitant with decreases in HCO_3 concentrations. Hydrologic characteristics of watersheds have been used to interpret the gradient of acidification responses with elevation. Substantial progress has been made toward characterizing the recent drought at Coweeta and assessing its impact on various ecosystem processes. The analysis has focused on statistical definition of drought severity and frequency; effects on chemistry of precipitation and streams as related to biogeochemical cycles; mortality and growth of forest species; shifts in aquatic and terrestrial invertebrates; and impacts on fish dynamics. Another major effort in progress deals with analyses of the long-term Coweeta data bases on climate and hydrology which suggest trends of increasing streamflow and decreasing evapotranspiration that may be related to trends in growing season temperatures. The data set extends over 55 years and covers 7 reference watersheds; building on this extensive base of knowledge, research will continue to address influences of climate variability on potential changes in the hydrologic cycle. Hydrologic and stream chemistry recovery on WS7, the clearcut and cable-logged watershed, continues to be examined. By the seventh year after cutting, annual streamflow returned to baseline levels. The rapid hydrologic recovery is attributed to rapid regrowth and the re-establishment of LAI close to values for the original hardwood forest. Concentrations of most dissolved inorganic nutrients have also returned to baseline levels except for NO_3-N which is still clearly above pretreatment levels. Additional synthesis of system levels responses as related to documented alteration of nutrient cycling processes is planned over the next several years.

Shorter-term process research has encompassed both aquatic and terrestrial ecosystems. Studies on nutrient dynamics in Coweeta streams have (1) quantified the fate of elements entering streams by measuring uptake rates and uptake lengths; (2) examined substrate-specific exchanges between surface and interstitial waters that influence nutrient removal; (3) elaboration of DOC dynamics in streams; (4) expanded work on the microbial food web in streams to include bacteria, fungi, and meiofauna; (5) effects of forest disturbance on nitrate and phosphate uptake in streams and leaf type and CPOM:FPOM ratios as determinants of phosphorus uptake in streams; and (6) qualitative differences in seston. Hydrologic process studies are examining flow paths of water on hillslopes at Coweeta using several different methods. In one approach, intensive sampling with tensiometers at different depths are used to quantify vertical and lateral water fluxes. In another approach, stable oxygen is being used as a tracer to assess its utility as an index of flow paths. In other studies, improved estimates of interception loss in hardwood and pine covered watersheds at Coweeta have been incorporated into a hydrologic model. Subsequently, the model has been successfully applied and tested for a variety of forest types investigated in the IFS project. Detailed research has quantified atmospheric deposition to forest canopies, effects on canopy leaching, and ion exchange processes in soils. Another study identified and quantified the sources and movement of dissolved organic nitrogen, phosphorus, and carbon in a hardwood forested watershed.

Past, present and proposed research in this core area is outlined in Table 15 (p.47).

e. Pattern and frequency of disturbance to research site

In the southern Appalachians current communities and geomorphic structures of ecosystems are the result of past disturbances. White and Pickett (1985) provided a useful definition of disturbance as including environmental fluctuations and destructive events, whether or not these are normal for a particular system. Using this definition, we can classify disturbances into three types: (1) Natural, major environmental changes that have occurred without human influence; (2) Anthropogenic, those resulting directly or indirectly from human activities; and (3) Perturbations, that is disturbances under direct experimental control.

Hurricanes have caused major forest damage throughout the Southeast. In 1835, a hurricane blew down much of the timber in a few sections of the Coweeta Basin (Douglass and Hoover 1988). However, regrowth was apparently rapid -- in 1920 Coweeta forests were described as containing the heaviest stand of hardwood timber in the southern Appalachians and a stand of young and middle-aged timber because of cyclonic storms blowing down old timber.

While major floods have occurred in the Coweeta area in recent history, they seem to have had little impact on the 1st-5th order streams within the Coweeta Basin. In this area of frequent heavy rainfall, these highly resilient systems (Webster et al. 1988) recover rapidly following periods of high discharge and apparently go through long periods of organic accumulation followed by brief periods of degradation (Tate and Meyer 1983, Webster et al. submitted). On a longer time scale, debris avalanches and landslides are probably the major land forming processes in the area (Grant 1988, Velbel 1988).

The occurrence of a major drought from 1985 through 1988 greatly increased our awareness of the impact of drought on Coweeta ecosystems. The 1985-86 water year was the driest on record (since 1934), and analysis of longer-term precipitation records for the region showed that the event ranked high in the extended history of drought severity (Swift et al. 1989). Ongoing and proposed research on oak and pine decline will fully reveal the long-term impacts of this record drought on forest structure and function (Section III.1).

Natural outbreaks of defoliating insects such as the fall cankerworm significantly altered vegetation growth and nutrient processes at Coweeta (Swank et al. 1981). Insects also affect successional processes by attacking early successional plant species and accelerating growth of climax species (Schowalter 1981).

Anthropogenic disturbance to Coweeta ecosystems began long before European settlement. Cherokee Indians practiced spring and fall burning to control understory growth, a practice that was continued by white settlers (Douglass and Hoover 1988). Between 1842 and 1902, several homesites were established in the Coweeta Basin. While only a small area was cleared for cultivation, the forests were extensively used for grazing. Between 1909 and 1922 the entire Coweeta Basin, with the possible exception of some steep, high-elevation areas, was commercially logged. The area purchased by the Forest Service in 1922 was described as an uninhabited tract of land that had recently been selectively logged (Douglass and Hoover 1988). However, from a long-term perspective, a perhaps greater indirect anthropogenic disturbance was the death of chestnuts between 1933 and 1940. Chestnut was a dominant tree in the basin, representing up to 46% of the basal area (Day et al. 1988). Coweeta forests are still undergoing change following burning, logging, and elimination of chestnut.

More recently, threats from atmospheric pollution, including acid precipitation, oxidants such as ozone, heavy metals, and nutrients, are being intensively studied at Coweeta. Atmospheric pollution will likely increase in the future. Other anthropogenic disturbances are also anticipated. Significant loss of dogwood, a major understory species, will probably result from dogwood anthracnose caused by a species of *Discula*. Gypsy moths continue to move south, and local infestations have occurred within 40 miles of Coweeta (Blanton 1989). Major infestation at Coweeta is likely to occur within 10-20 years, and areas dominated by oaks will be severely damaged. The past and ongoing research design at Coweeta provides the opportunity to measure and evaluate the response of forest and stream ecosystems to these and other unanticipated disturbances.

Since its beginning as a Forest Service research facility, Coweeta has been a site to study disturbance at an ecosystem level (Swank and Crossley 1988). The emphasis of research has been on forest management with whole-watershed perturbation experiments ranging from careful logging using good management practices to unrestricted logging. Watersheds have also been used to study forest grazing and mountain farming. Other perturbations have been designed to investigate effects of complete and partial vegetation removal. The earliest studies were primarily to look at hydrologic responses, but later emphasis changed to include water quality (Douglass and Hoover 1988). Since the beginning of NSF support in 1968 and continuing through the current LTER, these watershed perturbations have formed the basis for comprehensive ecosystem studies. Some examples of LTER research being done on these watersheds are included in the next section (IV.2).

Our past, current, and proposed research in this core area is outlined in Table 16 (p. 49).

Table 10: Research at Coweeta Hydrologic Laboratory in Core Area 1: Pattern and control of primary productivity. Numbers refer to papers in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Category	Past	Present/Future
Baseline Hardwood Forest NPP		
Aboveground	NPP and phenology (36, A93, A27) NPP and nutrients (37, A93, A91)	Permanent Reference Stands (e)
Belowground	NPP and nutrients (104, A27,4 35)	Fine root production, mortality, nutrients (r)
Baseline Pine Plantation NPP		
Aboveground	Biomass, leaf surface area, and NPP (320, 331)	Biomass, leaf surface area, and NPP (f)
Belowground	NPP and nutrients (435)	
Regenerating Forest NPP		
Aboveground	Clearcut regeneration (10, A9) Importance of black locust (a, A8) Oldfield regeneration (b)	Modeling NPP and nutrients (g) Clearcut regeneration (h) Oldfield regeneration (i) Whole tree harvest regeneration (j)
Belowground	Comparison with mature hardwood (c) Calcium uptake kinetics (d)	Oldfield root dynamics (k)
Stream NPP	Algal NPP (419, A87)	Algal biomass and NPP (l) Nutrients controlling NPP (m)
Controls of NPP	Canopy arthropod effects (296, 420, 286) Acid rain solution effects (100) Trace metal effects (A3)	Atmospheric oxidant effects (n) Gypsy moth outbreak (o) Canopy arthropod effects (p) Environmental controls (r)
Related Vegetation Studies	Long-term permanent plot data (A108, 258) Environmental gradients (A82, 38, A93, A27) Species responses (438, A82, A83, 268, 38, A108)	Long-term permanent plot data (q) Root decomposition (t) Nitrogen cycling (s)

FOOTNOTES FOR TABLE 10

a. Boring, L. R. and W. T. Swank. 1984. The role of black locust (Robinia pseudoacacia) in forest succession. Journal of Ecology 72(3):749-766.

b. Boring, L. R., W. T. Swank and B. L. Haines. Unpublished data for aboveground biomass on Coweeta WS6 for years 1-15 of old-field succession.

c. Swank, W. T. Unpublished data for comparison of root standing crop biomass between a mature forest and a regenerating clearcut.

d. Haines, B. L. 1985. Calcium uptake kinetics of plants from a southern Appalachian forest succession. Botanical Gazette: unpublished.

e. Yeakley, A., W. T. Swank, and H. H. Shugart. Stand level models of water use and productivity of mesic hardwood reference stands.

f. Swank, W. T. Ongoing measurement of 25 year-old white pine stand for biomass, leaf surface area and net primary production.

g. Swank, W. T., J. B. Waide and D. West. Future application of an adapted FORET-type model to examine production and nutrient dynamics of forest succession.

h. Boring, L. R., W. T. Swank and B. L. Haines. Ongoing and future measurements of biomass, NPP, and nutrient accumulation on a clearcut hardwood watershed.

i. Boring, L. R., W. T. Swank and B. L. Haines. Ongoing permanent plot study of old-field succession on Coweeta WS6.

j. Swank, W. T. Regeneration of hardwood stand following whole-tree harvesting treatment.

k. Harker, A. 1987. Early-successional root production, decomposition and nutrient dynamics. M.S. Thesis, Emory University.

l. C. Tate, Kansas State University, in preparation; periphyton biomass and production in Section III.2 and III.3 this proposal.

m. C. Tate, Kansas State University, in preparation: periphyton biomass accumulation under different nutrient regimes.

n. Teskey, R. O. and C. Maier. Ongoing study of the effects of atmospheric oxidant damage upon white pine productivity.

o. Crossley, D. A. Future contingency plans stratified into LTER study to detect potential future effects of gypsy moth infestation upon hardwood forests.

p. Crossley, D. A., W. Hargrove and L. Risley. Ongoing studies examining the effects of low-level canopy arthropod consumption upon forest leaf production.

q. Swank, W. T., L. R. Boring, and B. Clinton. Ongoing study of long-term forest dynamics in permanent study plots.

r. Smith, R., L. R. Boring, and W. T. Swank. Use of archived air photos and permanent plots to study pine distributions.

s. Rauch, S., L. R. Boring, and J. Donaldson. Fire influences upon nitrogen cycling investigated by use of 15-N tracers.

t. Coleman, D. C. Proposed research on root dynamics along the elevational gradient (Section III.1).

Table 11: Research at Coweeta Hydrologic Laboratory in Core Area 2: Spatial and temporal distribution of populations selected to represent trophic structure in TERRESTRIAL ecosystems. Numbers refer to papers in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Category	Past	Present/Future
Soil-litter Microarthropods	Oribatid mite distribution (2) WS 17 - WS 18 comparisons (18) WS18 populations/biomasses (86) Collembolans on WS 2 - WS 7 (e) Response to clear-cutting (293-294) Effects on litter decomposition (294) Two-year decomposition study (296) Review of all data sets (A127) Eight-year study of litter arthropods (A209,A8)	Litterbag studies (Section III.2 & 3) N dynamics in decomposition (a) Arthropod effect on N dynamics (a)
Soil-litter Macroinvertebrates	Densities/biomass in WS18 (87) Densities/biomass in WS 7 - WS 27 (f) Densities/biomass in WS 7 - WS 2 (g) Review of data sets (A127)	Snail studies (b)
Canopy Arthropods	Species diversity (21) Community structure (A123, h) Herbivory on ROBINIA (A57, A126) Community structure on WS 6, 18 (452) Effects of clear-cutting (A123,286) Feeding guilds (A21) Models of herbivory 420,A222 Arthropod biomass (h)	Effects of herbivory on greenfall (A120) Response of herbivory to drought (c) Densities, biomass (d)

FOOTNOTES

a. Crossley and Blair, NSF project

b. Caldwell, current work on snails

c. Blanton, Crossley, Hargrove, in preparation

d. Section III.1 in this proposal

e. Reynolds 1976 (M.S. Thesis)

f. Crossley, unpublished data sets

g. Reynolds, unpublished data sets

h. Blanton 1989

Table 12: Research at Coweeta Hydrologic Laboratory in Core Area 2: Spatial and temporal distribution of populations selected to represent trophic structure in AQUATIC ecosystems. Numbers refer to papers in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Category	Past (Bibliography Numbers)	Present/Future
Stream Invertebrates		
General (Functional Feeding Groups)	95,384,392,417,418,467,470 A190,A75,A76,A77,A188,A224,a	Section III.2
Meiofauna	A231,A229,b	Section III.2,j
Invertebrates Associated with Litterbags	240,374,A192,A231,c	Section III.2,k
Influence of Invertebrate Feeding on Litter Decomposition and DOC	90,240,241,367,374,470,385,A94 A231,d	k
Feeding Mechanisms and Food Selection	5,85,90,233,239,366,367, 368,370,371,372,375,A190,A131, A229,A231,e	l
Bioenergetics	5,90,380,383,A33,A34	
Secondary Production	5,94,280,281,380,382,444,A108, A109,A190,A229,A45,A73,A224, A74,A75,A76,A77,f	m
Influence of Local Geomorphology on Invertebrate Abundance and Production	A51,A131,A75,A216,A224,g	Section III.2
Trophic Basis of Production	5,94,280,281,382,384,A51,A189,A231	
Invertebrate Predators	A189,A229,h	
Salamanders	470,A75	n
Fish	A1,A50,A68,A69,i	Section III.2,o

FOOTNOTES FOR TABLE 12

a. Wallace et al. 1988. Verh. Internat. Verein. Limnol 23:1224-1231; Wallace et al. 1989. Hydrobiologia 179:135-147; Wallace et al. In press. Freshwater Biology.

b. Perlmutter, ms. under review by JNABS; Perlmutter and Meyer, ms. under review by Ecology; O'Doherty ms. under review by Freshwater Biology; O'Doherty and Meyer, ms. under review by Ecology.

c. Cuffney et al. 1990. JNABS.

d. Wallace et al. 1986 JNABS; Cuffney et al. 1990. JNABS; Perlmutter and Meyer, ms. under review by Ecology.

e. Wallace et al. 1987. Can. J. Zool.; Schurr 1989, M.S. Thesis.

f. Huryn and Wallace 1988. Freshwater Biol. 20:141-155; Huryn, in press, Limnol. Oceanogr.; Lugthart et al., in press, Freshwater Biology.

g. Wallace et al. 1988. Verh. Internat. Verein. Limnol. 23:1224-1331; Huryn and Wallace 1988. Freshwater Biol. 20:141-155.

h. Lugthart et al., in press, Freshwater Biology.

i. Grossman and Freeman 1987. J. of Zool. 212:151-176; Barrett 1988. Ph.D. Dissertation; Hill 1988. Ph.D. Dissertation.

j. Vila, dissertation research on meiofauna in streams treated with insecticide.

k. Chung et al., in progress: litterbag invertebrates in streams treated with insecticide and those recovering from treatment.

l. Schurr and Wallace, in preparation: chironomid feeding.

m. Stout, Webster, Benfield, in progress: secondary production of stoneflies.

n. Lugthart, dissertation research on prey selection in manipulated and unmanipulated streams.

o. Stouder, dissertation research on fish feeding; Freeman, dissertation research on fish schooling behavior; Grossman, influence of environmental variability on fish assemblages.

Table 13: Research at Coweeta Hydrologic Laboratory in Core Area 3: Pattern and control of organic matter accumulation in TERRESTRIAL surface layers and sediments. Numbers refer to papers in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Category	Past	Present/Future
Organic matter and nutrient inputs to surface layers and soils		
Leaf liter	Undisturbed hardwood forest; WS 2, 7, 18, 36 (26, 403, a) White pine forests; WS 1, 17 (26, 403, a) Successional changes following clearcutting; WS 13, 37 (a) N, S, P dynamics in decomposing litter (A209) Influence of black locust and locust stem borer; WS 6 (A239)	Impacts of and recovery from cankerworm defoliation; WS 27 Successional changes following clearcutting with and without residue removal; WS 7, 48 (a) Ozone impacts on white pine forests; WS 1, 17 (b) N dynamics in decomposing leaf litter (c) Litterfall along an elevational gradient (f)
Woody litter	Undisturbed hardwood forests; WS 18 (26, 403) White pine forests; WS 17 (26, 403) Logging residue remaining following clearcutting; WS 7 (A226,a)	
Roots	Undisturbed hardwood forests; WS 18 (104, 435) White pine forests; WS 17 (104, 435)	Influence of black locust and locust stem borer; WS 6 (d) Root dynamics along an elevational gradient (f) Root dynamics with and without rhododendron (g)
Organic matter and nutrient standing crops in surface layers and soils		
Leaf litter	Undisturbed hardwood forests; WS 2, 7, 18 (26, 394, 403, a)	Successional changes following clearcutting with and without

Table 13: (Con't.)

Category	Past	Present/Future
Leaf litter (con't.)	White pine forests; WS 17 (26, 394, 403, a) Successional changes following clearcutting; WS 6, 13 (a) Impacts of cankerworm defoliation; WS 27 (322, a) Influence of black locust and locust stem borer; WS 6 (A239)	residue removal; WS 7, 48 (a, b, e) Impacts of atmospheric deposition; WS 1, 2 (b)
Woody litter	Undisturbed hardwood forests; WS 18, 48 (26, 403, a) Successional changes following clearcutting; WS 7 (A226, a)	
Soils	Undisturbed hardwood forests; WS 2, 7, 18 (393, A180, A187, a) White pine forests; WS 17 (393, a) Successional changes following clearcutting; WS 6, 7, 13 (a, A226, A187) Impacts of cankerworm defoliation; WS 27 (322, a) Influence of black locust and locust stem borer; WS 6 (A239)	Successional changes following clearcutting with and without residue removal; WS 7, 48 (a, e) Impacts of atmospheric deposition; (a, f) Soil organic matter along an elevational gradient (f) Influence of riparian rhododendron on soil organic matter (g)
Rates and controls of organic matter decomposition		
Leaf litter	Undisturbed hardwood forests; WS 2, 7, 18 (26, 403, A127, a) White pine forests; WS 17 (26, 403) Successional changes following clearcutting; WS 7 (A127, A209, a) Impact of cankerworm defoliation; WS 27 (322, a) Climatic and microarthropod regulation (29, 291, 294, 297, 390, a)	Successional changes in decay rates and microarthropod abundance; WS 7 (e) Role of microarthropods (c) Decomposition along an elevational gradient (III.1) Decomposition in the riparian (III.3)

Table 13: (Con't.)

Category	Past	Present/Future
Leaf litter (con't.)	Influence of black locust and locust stem borer; WS 6 (A239, a)	
Woody litter	Successional changes following clearcutting; WS 7 (1, A226) Decay of logging residue; WS 7 (A226)	
Other	Decay of arthropod remains (299)	
Microbial processes in surface organic layers and soils		
C mineralization and CO_2 efflux	Undisturbed hardwood forests; WS 2, 18 (A226, a)) White pine forest; WS 17 (29) Successional changes following clearcutting; WS 6, 7, 13 (a, A226) Impacts of cankerworm defoliation; WS 27 (322, a) Techniques for assessing available soil C (A24)	
Nitrogen fixation	Undisturbed hardwood forests; WS 2, 7, 18, (19, 349, 353, 439, A187) White pine forests; WS 17 (353, a) Successional changes following clearcutting; WS 6, 7, 13, 48 (a, A187, A9, A11) Impacts of cankerworm defoliation; WS 27 (322, a)	
Denitrification	Comparison of methods (350) Undisturbed hardwood forests; WS 2, 18 (326, A187, a) Study of factors regulating denitrification rates; WS 6, 18 (A25, A26, A27, A28, A214)	
Nitrification and N mineralization	MPN microtechnique (282) Relation to stream nitrate losses (271, 351, 361) Factors regulating nitrification and nitrogen leaching from successional forests (A227, A99, h) MPN assays of nitrifier populations on diverse watersheds (A187, a) Gaseous N losses via nitrification (A25, A26, A27, A28, A214)	

Table 13: (Con't.)

Category	Past	Present/Future
Sulfur transformations	Incorporation of SO_4 into organic S in surface organic layers and soils (78, 80, 328, 79, A41, A236, A138, A155) Mineralization of organic S in surface organic layers and soils (79, A41, A236, A138, A155, 311, A35, 78, A141, A40) Forms of adsorbed and soluble S in surface organic layers and soils (A41, A236, A40)	Sections III.1 and IV.6
Microbial enumeration, biomass, and element content	SEM studies of microbes (13, 345, 348) Element accumulation by litter-soil microbes (24, 25, 27, 28, 346, 352) Enumeration of microbial populations on diverse watersheds (a)	

FOOTNOTES

a. Unpublished data in the Coweeta data bank at the University of Georgia or files of the Coweeta Hydrologic Laboratory.

b. W. T. Swank, J. Vose: Research in progress.

c. D. A. Crossley, J. Blair: NSF-funded project on N dynamics during decomposition.

d. C. Berish and H. L. Ragsdale: manuscripts being prepared.

e. Section IV.2.

f. Section III.1.

g. Section III.3.

h. Montagnini et al. 1986, 1989a, 1989b.

Table 14: Research at Coweeta Hydrologic Laboratory in Coweeta 3: Pattern and control of organic matter accumulation in AQUATIC surface layers and sediment. Numbers refer to papers in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Category	Past	Present/Future
Organic matter decomposition		
Leaf litter	Effect of disturbance (381, 385, A46, A198, a) Nutrient effects (240, b) Invertebrate effects (374, 382, A76, A23, A192, c) Meiofauna effects (A231)	Litterbag studies along gradient (h) Nutrient effects (d)
Wood	Standing stock (A219, A47) Decay (A46, A219)	Wood movement and decay (e)
Dissolved organic matter		
Water column	Effect of disturbance (242, 343, 373, A94, A95) Role of invertebrates (241)	Disturbance effects (f)
Interstitial	Relation to bacteria and organic matter (A20, A213, A228, g)	
Particulate organic matter		
Benthic storage	Variation between watersheds (A219, A46, A47)	Variation along elevational gradient (h) Effect of rhododendron removal (i)
Bacterial biomass	Relation to POM (b, A33, g) Availability to invertebrates (A33, A34)	
Role of woody debris	Impact on transport (A47, A219)	Debris addition experiment (j)
Water column POM	Seston studies (93, 373, 379, A22, A47, A199)	Seston studies (j, l)
Benthic respiration		Variation along elevational gradient (h) Impact of macroinvertebrates (l)
Fungal biomass	Effects of nutrient enrichment (b)	Effects of nutrient enrichment (d)
Organic matter sources		
Autochthonous	Algal NPP (419, A87)	Algal biomass and NPP (l) Nutrients controlling NPP (m)
Allochthonous	Litter inputs (379, 384, 385, 242, m) Bacterial biomass and production (A113, A213, A20, A94)	

FOOTNOTES

a. Benfield et al. In press. Effects of forest disturbance on leaf breakdown in four southern Appalachian stream. Verh. Internat. Verein. Limnol.

b. Smith, Solon. 1989. M.S. Thesis, University of Georgia.

c. Cuffney and Wallace, 1989; Cuffney et al. 1985; Wallace et al. 1986; Wallace et al. 1989; Cuffney et al. 1990; Wallace et al. 1990.

d. J. Meyer and C. Thomas, effect of N and P enrichment on leaf decomposition and microbial communities, manuscripts in preparation.

e. J. Webster and A. Covich, research underway and continuing.

f. J. Meyer, continue weekly sampling of DOC in WS 7, 14 and 27.

g. J. Meyer, unpublished data.

h. Section III.2.

i. Section III.3.

j. Section IV.2.

k. Cuffney and Wallace 1989. Peters, Benfield and Webster, 1989.

k. J. B. Wallace et al., continuing research on impacts of invertebrate removal on ecosystem processes.

m. Coweeta LTER datafile.

Table 15: Research at Coweeta Hydrologic Laboratory in Core Area 4: Inorganic inputs and movement of nutrients.

Solution Compartment	Past	Present	Future
Precipitation	Eight-gage bulk precipitation network (1, 2, 3) Detailed studies of the magnitude & form of dry deposition to hardwood & white pine canopies (4) Determination of the fate of dry deposited nitric acid vapor (5) Temporal & spatial variability of precipitation chemistry over Coweeta basin (6)	Intersite comparison of precipitation chemistry during an extreme drought event (7) Temporal & spatial variability of precipitation chemistry over the Coweeta Basin (8) EPA & NADP sponsored measurement of dry atmospheric chemical inputs Comparison of bulk & event only atmospheric chemical inputs (9) LTER intersite analysis of chemistry (8) USFS sponsored CO_2 concentration measurements	Continuation of bulk precipitation network for trend analyses (10) Continuation of EPA & NADP sponsored measurement of atmospheric chemical inputs Continuation of USFS sponsored measurement of CO_2 concentration
Throughfall	Characterization of throughfall chemistry in hardwood & conifer ecosystems for selected solutes (11, 12) Temporal & spatial dynamics of throughfall chemistry in regenerating hardwood ecosystems (13)	Refinements in interception in hardwood & pine canopies & linkage between throughfall quantity & chemistry (14) Influence of dry deposition on canopy processes & throughfall chemistry (14)	
Soil Solution	Examination of temporal trends in chemistry of baseline forest ecosystems (8) Effects of whole-tree vs. conventional harvesting on soil solution chemistry (15) Changes in solution chemistry during storm events & relationship to flow paths (16) Aluminum speciation for baseline ecosystems (17)	Long-term baseline chemistry (8) Linkages between atmospheric deposition, throughfall chemistry, & ion exchange processes in soils (14) Development of an integrated forest hydrology, productivity, & biogeochemical cycling model (18)	Influence of upland processes & Rhodendron maximum on riparian zone soil solution chemistry (10)

Table 15: (Con't.)

Solution Compartment	Past	Present	Future
Soil Solution		Characterization of water & nutrient fluxes through hardwoods & white pine watersheds (19)	
Streamflow	Establishment of baseline chemistry for selected ecosystems (6) Trace metal outputs Changes in solute concentration & export associated with man-induced disturbances (21, 22, 23)	Continuation of solute analyses (8) Changes in solute concentration & export associated with man--induced disturbance (8) Effects of ozone damage on stream chemistry (20)	Continuation of long-term stream chemistry trends (10) Influence of riparian processes on stream chemistry (10) Stream chemistry responses associated with natural & man caused disturbances including recovery (10) Changes in solute concentration & export associated with an extreme drought event (10)
Element Uptake in Streams	Uptake length as a function of season and geomorphic substrate (Munn 1989, Munn and Meyer 1989) and disturbance (Webster et al. in press)	Continuation of uptake length measures as a function of organic matter quality and quantity (Webster, D'Angelo) and of debris damage (Meyer)	Uptake length measures along the stream gradient (Section III.2)

FOOTNOTES FOR TABLE 15

1. Swank, W. T.; Douglass, J. E. 1977. Nutrient budgets for undisturbed and manipulated hardwood forest ecosystems in the mountains of North Carolina. In: Correll, David L., ed. Watershed research in eastern North America: a workshop to compare results; 1977 February 28 - March 3; Edgewater, MD. Edgewater, MD: Smithsonian Institution; pp. 363-364.

2. Swank, W. T.; Douglass, J. E. 1975. Nutrient flux in undisturbed and manipulated forest ecosystems in the southern Appalachian Mountains. In: Proceedings of the Tokyo symposium on the hydrological characteristics of river basins and the effects on these characteristics of better water management; 1975 December; Tokyo, Japan. Washington, DC: International Association of Hydrological Science; pp. 445-456.

3. Swank, Wayne T.; Henderson, Gray S. 1976. Atmospheric input of some cations and anions to forest ecosystems in North Carolina and Tennessee. Water Resources Research 12: 541-546.

4. Swank, Wayne T.; Reynolds, L. J. 1987. Analysis of dry and wet deposition, throughfall, and stemflow event chemistry in a Pinus strobus L. plantation. In: Acidification and water pathways; 1987 May 4-5; Bolkesjo, Norway. Oslo, Norway: Norwegian National Committee for Hydrology; pp. 127-136.

5. Vose, James M.; Swank, Wayne T.; Taylor, Randolph W.; Dashek, William V.; Williams, Arthur L. 1989. Foliar absorption of ^{15}N labeled nitric acid vapor (HNO_3) in mature eastern white pine (Pinus strobus L.). In: Delleur, Jacques W., ed. Atmospheric Deposition; Symposium of the 3rd Scientific Assembly of the IAHS; 1989 May 10-12; Baltimore, MD. IAHS Pub. No. 179, Oxfordshire, UK; pp. 211-219.

6. Swank, W. T.; Waide, J. B. 1988. Characterization of baseline precipitation and stream chemistry and nutrient budgets for control watersheds. In: Swank, W. T.; Crossley, D. A., Jr., eds. Forest hydrology and ecology at Coweeta. Ecological Studies, vol. 66. New York: Springer Verlag; pp. 57-79.

7. Swank, W. T.; Blood, Liz. LTER Intersite Workshop; North Inlet and Coweeta.

8. University of Georgia Research Foundation, Inc. Long-term Ecological Research in Forested Watersheds at Coweeta. 1986 proposal to National Science Foundation.

9. Swank, W. T.; Reynolds, B.; Padgham, J. 1989. Comparison of chemistry for NADP, bulk precipitation, and wet plus dry collectors in the Southern Appalachians. NADP (IR-7) Technical Committee Program Annual Meeting (Poster). Provincetown, MA.

10. University of Georgia Research Foundation, Inc. Long-term Ecological Research in Forested Watersheds at Coweeta. Unpublished proposal to the National Science Foundation. 1990

Table 16: (Con't.)

Disturbance	Past	Future
	363, 364, 379, 381, 385, 399, 400, 410, 417, 419, 457, A12,A51,A90,A175,A176, A190,A201,A203,A226, Lowe et al. 1986, Mattson et al. 197, Johnson et al. 1988, Golladay et al. 1988, 1989, Swank & Vose 1988, Wallace et al. 1988. Boring et al. 1988, Schowalter & Crossley 1988, Waide et al. 1988, Swank 1988, Swank et al. 1988, Blanton 1989, Rickerk et al. 1989, Benfield et al. submitted, Webster et al. submitted	Hydrologic and nutrient export monitoring -- continuing
Road Building	(WS 7) 48, 57, 158, 169, 170, 178, 179, 180, 199, 269, 305, A160,A165,A166,A167,A168, Swift et al. 1988.	
Introduced Insects and Disease		
Chestnut Blight	19, 258, A33, A34, A35, Day et al. 1988	
Gypsy moth	Blanton 1989	
Atmospheric Deposition		DOE studies -- continuing
Ozone	Taylor et al. 1989	Ozone monitoring -- continuing
Trace metals	227, 228, Berish and Ragsdale 1987, Ragsdale and Berish 1988	
Nutrients	126, 330, A152, Boring et al. in press	Uptake of $H^{15}NO_3$ -- continuing
Acidity	98, 99, 100, 101, 126, 227, A55, A79 Swank & Reynolds 1987, Haines & Carson 1988, Haines & Swank 1988, Vose et al. 1989	EPRI studies -- continuing EPA studies -- continuing

Table 16: Research at Coweeta Hydrologic Laboratory in Co[illegible]a 5: Pattern and frequency of disturbance. Numbers refer to paper[illegible] in the Coweeta Bibliography (Gaskin et al. 1984); numbers preceeded by A refer to papers in the October 1989 update to the bibliography; letters refer to footnotes.

Disturbance	Past	Future
I. General Studies of Disturbance	386, Douglass & Hoover 1988, Waide 1988, Swift et al. 1989	
II. Natural Disturbances		
Hurricanes, Tornadoes, high winds	Douglass & Hoover 1988	Forest gap studies -- proposed
Floods, periods of high flow	343, Cuffney & Wallace 1989, Webster et al. submitted	Golladay et al. in prep.
Debris avalanches, landslides	175, A105, Grant 1988, Velbel 1988	
Drought	198, Swift & Blood 1987, Wallace et al. 89	Canopy gap studies -- continuing
Insect Epidemics	39, 81, 287, 296, 322, 407, 446, 456, Blanton 1989	
Fire	257, Douglass & Hoover 1988	
III. Anthropogenic Disturbance		
Burning	(WS 1,WS 6) 71, 72, 221, 431	Prescribed burning studies -- continuing
Forest grazing	(WS 7) 7, 206, 275, 468	
Mountain farming	(WS 3) 41, 91, 167, 303, 408	
Commercial logging	(WS 7, WS 48) 1, 2, 10, 23, 46, 48, 56, 57, 59, 60, 67, 68, 69, 70, 76, 80, 93, 151, 158, 223, 224, 242, 265, 277, 286, 293, 309, 315, 316, 317, 321, 326, 333, 338, 340, 341, 344	DOC concentration in streams -- continuing Stream insect response to logging -- continuing Stream OM dynamics -- continuing

11. Swank, W. T.; Swank, W. T. S. 1983. Dynamics of water chemistry in hardwood and pine ecosystems. In: Proceedings of catchment experiments in fluvial geomorphology; Exeter, England; pp. 335-346.

12. Swank, W. T. 1985. Biological control of solute losses from forest ecosystems. Chapter for a book, Solute Processes. John Wiley & Sons.

13. Potter, Christopher S. 1987. Acid deposition interactions with a regenerating Southern Appalachian forest canopy at the Coweeta Hydrologic Laboratory. Atlanta, GA: Emory University. Ph.D. dissertation; 227 p.

14. Integrated Forest Effects Study - Synthesis in Progress.

15. Mann, L. K., et al. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science 34(2): 412-428.

16. Gaskin, J. W., et al. 1989. Vertical and lateral components of soil nutrient flux in a hillslope. Journal of Environmental Quality 18(4): 403-410.

17. Gibb, Dorothy Margaret. 1988. Aluminum distribution in a Southern Appalachian forested watershed. Athens, GA: University of Georgia; Ph.D. dissertation; 180 p.

18. Cooperative agreement between USFS and University of Virginia (H. Shugart).

19. Vose, J. M.; Swank, W. T. 1990. Water balances for IFS study sites. Book chapter for IFS synthesis volume.

20. Swank, W. T.; Vose, J. M. 1990. Watershed scale responses to ozone events in a Pinus strobus L. plantation. Submitted to Water, Air, and Soil Pollution.

21. Swank, W. T. 1988. Stream chemistry responses to disturbance. In: Swank, W. T.; Crossley, D. A., Jr., eds. Forest hydrology and ecology at Coweeta. Ecological Studies, vol. 66. New York: Springer-Verlag; pp. 339-357.

22. Swank, W. T.; Caskey, W. H. 1982. Nitrate depletion in a second-order mountain stream. Journal of Environmental Quality 11: 581-584.

23. Swank, W. T.; Waide, J. B.; Crossley, D. A.; Todd, R. L. 1981. Insect defoliation enhances nitrate export from forest ecosystems. Oecologia 51: 297-299.

Table 16: (Con't.)

Disturbance	Past	Future
Pesticides		
Insecticides	Neary 1988, Wallace 1989, Wallace et al. 1989	
Herbicides	46, 92, 225, 253, 254, 255, 156, A101, A102, A106, A107, Neary 1988	
IV. Perturbations		
Deforestation	(WS 5, 6, 13, 17) 21, 65, 66, 70, 94, 95, 114, 144, 145, 153, 154, 159, 209, 211, 212, 229, 236, 240, 244, 268, 289, 315, 326, 318, 336, 343, 351, 361, 384, 391, 392, 393, 395, 400, 411, 412, 418, 432 936, 442, 452, 461, 467, 469, 470, A9, A11, A59, A71, A84, A85, A98, A99, A201,A225, A227, 239, Davidson & Swank 1987, White et al. 1988, Webster et al. 1988, Montagnini et al. 1989	Stream seston quality studies -- continuing Wood breakdown in stream -- continuing Hydrologic and nutrient export monitoring -- continuing
Manipulation of Wood in Streams	(WS 28) 69,105	Cunningham Creek studies -- continuing
Stream Poisoning	374, A23, Cuffney & Wallace 1988, 1989, Cuffney et al. 1990, Wallace et al. 1987, 1989a, 1989b	Stream studies -- continuing
Forest Type Conversion	(later WS 17, WS 1 studies) 6,18,21,26,27,54,70,116,119,135 212,319,320,327,329,358,359,394, 403,435,439,A158,A227,240,Swank 1988, Swank et al. 1988, Gholz and Boring in press	Hydrologic and nutrient export monitoring -- continuing

2. Long-term experiments

With 16 experimentally manipulated watersheds (Table 17), there are numerous long-term experiments on-going at Coweeta. In these watersheds Coweeta researchers are studying effects of vegetation changes on water yield, storm hydrograph, flow frequency and element export. These watersheds are also being used for long-term studies of forest succession in mixed hardwood forests of the Southern Appalachians. The anticipated duration of each experiment is approximately 80 years, the length of a rotation cycle. In this section we highlight seven of the long-term experiments on Coweeta watersheds in which LTER researchers have been actively involved.

Recovery of terrestrial and aquatic ecosystems from disturbance: In 1977 WS7 was clear-felled by cable-logging and LTER scientists have examined the recovery process over the past 12 years. We have examined recovery of both terrestrial and aquatic components of the ecosystems. The terrestrial components examined include: meteorology; vegetation (species succession, NPP, nutrient uptake, physiological changes); decomposition of wood, roots and leaf litter; biogeochemistry (streamwater fluxes and internal solute flux); forest floor biota; canopy insects and herbivory. Recovery of the stream has also been studied including: hydrology; seston transport; organic matter dynamics (DOC and litter quality, standing stock and decomposition); consumer communities. Papers summarizing results from this work are listed in Section V.1. During the next 6 years, we will continue to follow recovery from disturbance. Streamwater chemistry is sampled weekly, and vegetation will be remeasured once during this period. Recovery of stream processes (Table 7), rates of insect herbivory, and litter decomposition will also be assessed during one year . In addition to this ongoing assessment of recovery, we plan a volume synthesizing these results, which is described under IV.5. We anticipate continuing this experiment until about 2060.

Long-term studies of ecosystem dynamics during old-field succession: WS 6 was clearcut in 1958, then planted to grass, limed, and fertilized. Grass was herbicided in 1966 - 67 and has been undergoing secondary succession since that time. A natural disturbance occurred in 1979 - 80 with an outbreak of locust stem borers, which lead to the death of many black locust , *Robinia pseudoacacia*, the dominant species on the watershed. Recent studies on this watershed have examined the impact of this natural disturbance on biogeochemical cycling in the watershed, concentrating on the nitrogen cycle as well as studies of seston transport in streams and its response to disturbance. We anticipate continuing this experiment until about 2050.

Addition of debris dams to a Southern Appalachian stream: A study on the effects of debris dam addition on channel geomorphology, invertebrate community structure, and stream nutrient dynamics was initiated on Cunningham Creek in 1987. At each of 3 sites cross sectional profiles have been measured with respect to permanent bank markers for 30-m long cobble riffle sections.

le 17: Summary descriptions of Coweeta watershed treatments (from Swank and Crossley 1988).

Watershed No.	Treatment Description
1	Entire watershed prescribed burned in April, 1942. All trees and shrubs within the cove-hardwood type (areas adjacent to stream) deadened with chemicals in 1954. This treatment represented 25% of both land area and total watershed basal area. Retreated as necessary for three consecutive growing seasons. All trees and shrubs cut and burned in 1956-57, no products removed; white pine planted in 1957. In subsequent years, pine released from hardwood competition by cutting and chemicals as necessary.
3	All vegetation cut and burned or removed from the watershed in 1940. Unregulated agriculture (farming and grazing) on 6 ha for a 12-year period, followed by planting yellow poplar and white pine.
6	All woody vegetation cut and scattered in the zone 5 m vertically above the stream; reduced total watershed basal area 12%. Clearcut in 1958, products removed and remaining residue piled and burned. Surface soil scarified, watershed planted to grass, limed and fertilized in 1959; fertilized again in 1965. Grass herbicided in 1966 and 1967; watershed subsequently reverted to successional vegetation.
7	Lower portion of watershed grazed by an average of six cattle during a 5-month period each year from 1941 to 1952. Commercially clearcut and cable logged in 1977.
8, 9, 16	Combination watersheds containing both control and treated watersheds.
10	Exploitive selective logging during the period 1942-1956 with a 30% reduction in total watershed basal area.
13	All woody vegetation cut in 1939 and allowed to regrow until 1962 when the watershed was again clearcut; no products removed in either treatment.
17	All woody vegetation cut in 1940 and regrowth cut annually thereafter in most years until 1955; no products removed. White pine planted in 1956 and released from hardwood competition as required with cutting or chemicals.
19	Laurel and rhododendron understory cut in 1948-1949; comprised 22% of total watershed basal area.
22	All woody vegetation within alternate 10 m strips deadened by chemicals in 1955; reduced total watershed basal area 50%. Treatment repeated from 1956 to 1960 as required to maintain conditions.
28	Multiple use demonstration comprised of commercial harvest with clearcutting on 77 ha, thinning on 39 ha of the cove forest and no cutting on 28 ha; products removed.
37	All woody vegetation cut in 1963; no products removed.
40	Commercial selection cut with 22% of basal area removed in 1955.
41	Commercial selection cut with 35% of basal area removed in 1955.
2, 14, 18, 21, 32, 34	Controls with mixed hardwoods stands remaining undisturbed since 1927.
27	Control, but partially defoliated by fall cankerworm infestation from 1972 to 1979.
36	Control, but partially defoliated by fall cankerworm infestation from 1975 to 1979.

Six benthic samples (3 from upstream and 3 downstream reaches of each site) were collected from each of the three riffles each season for measurements of substrata, invertebrate standing stocks and detritus standing crop. In July, 1988, logs were added to the downstream portion of each riffle. Uptake lengths for SRP, NH_4, Ca and DOC have been determined prior to log addition and annually thereafter. Following log additions, wetted cross sectional areas are wider, deeper, and have a lower current velocity at the debris addition sites compared with the unmanipulated upper reaches of each riffle. Furthermore, within six months massive sediment accumulations obliterated the underlying cobble substratum at the debris addition sites. This has been accompanied by large scale changes in the invertebrate fauna as some taxa disappeared from the former cobble riffles and have been replaced by other taxa. We will continue this seasonal sampling regime through 1990 and switch to annual sampling in 1991 in order to follow long-term patterns in debris accumulations and changes in benthic community structure. Annual measures of nutrient uptake lengths will also be continued. We anticipate continuing this experiment for 25 years, although the intensity of our sampling effort will decrease over time.

Impact of macroinvertebrates on stream ecosystems: In 1980 Wallace and colleagues greatly reduced the macroinvertebrate populations of a headwater stream using the pesticide methoxychlor and examined the effect of this on ecosystem processes. This type of experimental manipulation has continued over the past ten years funded by separate NSF grants and has included detailed studies not only of the impact of the disturbance but also of population and ecosystem recovery from disturbance. These experimentally manipulated streams offer a valuable resource to LTER researchers. Examination of recovery from disturbance will continue for ten years, although the intensity of effort will depend on continued availability of resources.

Changes in aluminum cycling as a consequence of acid deposition: Although this is not an experimental manipulation, we are taking advantage of an on-going natural experiment, namely increasing acid deposition, to examine the long-term impact of acid deposition on aluminum cycling in forested ecosystems. Increased concentrations of aluminum in soil, stream water, and lakes have been reported for regions of northeastern U.S. and northern Europe that are impacted by acid precipitation. Aluminum solubility increases with increasing H^+ concentration, and its speciation (and therefore toxicity) changes. In an earlier study of aluminum at Coweeta, aluminum species were quantified in rainwater, throughfall, soil solution and stream water on higher elevation WS 27, and for stream water on lower elevation reference watersheds 2 and 18 and on lower elevation white pine dominated watersheds 1 and 17 (Gibb 1988). Quarterly sampling of stream solution aluminum (all species) will continue. The goal is to determine whether there are long term changes in aluminum cycling taking place in high elevation southeastern forests resulting from acid rain inputs.

Table 18: Long Term Data Sets
At Coweeta Hydrologic Laboratory

Hydrologic data:

Continuous flow and daily mean flow for 14 streams for 42 to 54 years each.

Shorter records on 8 other streams.

Sediment and associated chemistry for 15 years on two watersheds and for intermittent years on four additional watersheds.

Climatic data:

Storm intensities, daily and monthly total precipitation for 9 rain gage sites for 50+ years each.

Monthly precipitation totals for 50+ other sites for 20+ years.

Air temperature, relative humidity, wind travel, evaporation at main station for 50+ years and at 3 additional stations over basin for 5 years.

Barometric pressure recording at main station for 40+ years.

Solar insolation at main station for 23 years.

Air temperature, relative humidity, wind speed & direction, soil temperature at three forest stations for 14+ years.

Water and air chemistry data:

Bulk precipitation at 8 sites for 20 years for 12 ions.

Dry deposition at 2 sites for 17 years.

Wetfall chemistry at base station for 13+ years.

Streamflow at 9 streams for 18 years.

Ozone concentrations for 3 years; SO_2, HNO_2 for 5 years; particulate nutrients for intermittent years.

Trace metal concentrations in streams and precipitation for intermittent years.

Aquatic data:

Invertebrate inventories on various streams for 20 years.

Stream temperature data on 6 streams for 5 to 15 years each.

Terrestrial data:

Permanent vegetation plots, 408 1/5 ac strip plots in the 4,015 ac basin, first measured in 1934 and resurveyed 2 or 3 times since.

Permanent vegetation plots on 8 natural and disturbed watersheds.

Primary productivity estimates for selected forest stands for 20+ years.

Intensive soils mapping to latest standards and complete geologic map of basin.

First-order topographic map of basin.

Invertebrate inventories in various forests for 20 years.

Plant species inventory and herbarium.

Two 1 ha mapped vegetation plots on undisturbed watersheds; established in 1984.

Impact of canopy gaps on ecosystem processes: A long-term consequence of the 1986 drought has been increased tree mortality resulting in the formation of canopy gaps. As described in part III.1 of this proposal, we have proposed long-term experiments to examine the impact of these gaps on ecosystem processes using both naturally-occurring gaps and experimentally created gaps. Process-level measurments in these experiments are proposed to continue for 10 years; vegetation response will be followed for about 80 years.

Riparian manipulation: As described in part III.3 of this proposal, we are initiating a new long-term experiment designed to assess the importance of the riparian zone in controlling exchanges between terrestrial and aquatic components of the landscape. This experiment is anticipated to continue for about 50 years, although the intensity of effort over that time will vary.

3. Long-term data sets

Data sets stored in the USFS Databank at Coweeta are summarized in Table 18 and include data from 1934 to the present. A list of data sets currently in the LTER-Coweeta Data Catalog and stored at the University of Georgia (UGA) is included as Table 19 to summarize the wealth of information available about this site. These data sets include information collected under NSF funding prior to LTER. They cover the period 1968 to the present. The project did not have funds to hire a fulltime data manager from 1986-88, and hence we have a backlog of data sets needing to be entered. Coweeta-LTER now has a data manager (2/3 time), who is devoting his efforts to bringing the data catalog up to date. We have budgeted to retain this position in the next six-year period.

4. Data management

Documentation: Standardized documentation forms follow the guidelines proposed by LTER data managers and describe the pertinent information about data collection and dataset identification. Watershed maps for the location of permanent plots are available.

Secure storage and transferability: All data files and their respective documentation are saved on 3 different media: magnetic tapes, floppy discs and hard-copies. Each consists of a working copy and a backup. USFS Coweeta files are stored in a fire-proof vault, and UGA is purchasing a fire-resistant safe. Since all documentation and data files are stored as flat ASCII files, any data or documentation can be easily transported to a different medium. This also facilitates the transfer of files via electronic mail.

Quality assurance: Coweeta LTER participates in the EPA standards program to assure analytical quality of precipitation and streamwater chemistry data. QA checks and reviews have been adopted by the Coweeta Databank. Data submitted to be archived are first visually checked by both the investigator and the data manager during completion of the documentation forms. Data are then checked by a scanning program to detect data entry errors. Statistical reports are generated

Table 19: Coweeta data bank catalog of data stored at UGA: Table of contents including list of data set titles organized by LTER core research area.

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and reviewed to verify and validate the data. Only after data meet these QA procedures are they archived in the databank.

Access to data by scientists: All LTER dataset requests should be addressed to Gildo Calabria, Coweeta-LTER Data Manager, Institute of Ecology, UGA. Some of the data have limited access and require the permission of the original investigator prior to release. To facilitate data access, a Coweeta-LTER Databank catalog is currently being prepared. An on-line version of the catalog is also being implemented and should be available during 1990. Data from Coweeta have been extensively used by the scientific community outside LTER. Examples include: use of long-term vegetation data by ORNL investigators to test the FORET model; compiling stream chemistry data to interpret IFS results; the use of climatic and streamflow data to interpret crayfish (Virginia Tech) and salamander (U. of North Carolina - Chapel Hill) population dynamics; use of precipitation, soil and stream chemistry data in modeling direct/delayed response to acidification (multi-institutional EPA study).

Relationship of data manager to group: The data manager is viewed as a scientific collaborator. He confers with PI's and graduate students to arrange data formats which meet the objectives of their project and are consistent with the format required for the databank. He helps investigators run descriptive statistical analysis. He also serves as a link between outside scientists, the databank and the investigators who collected the data. The data manager is an integral part of the Coweeta-LTER.

Maintenance and availability of data in the future: Considering the lifespan of magnetic media, the entire databank is rewritten every four years to prevent data dissipation. To further diminish the possibility of such a problem, all files are checked annually for integrity. These procedures have proved adequate to guarantee that data sets have remain available over the past 20 years. We believe that an optical back up system would be the best solution for the future and have plans to switch to this new technology when the market becomes stable and standards are established.

Databank facilities: Hardware facilities at UGA include: IBM 3090 Model 400E, CDC Cyber 845 and CDC Cyber 850, and CDC Cyber 205 and DEC VAX 11/70 super computers. We have also purchased equipment to install a Local Area Network (LAN) and a GIS system described in section III.10. The LAN will connect 4 PI's to the facilities via Ethernet, and the number of links will increase as required. Data management facilities include a SPARCstation1, Laser printer, TOPS-SUN(networking software), SAS, Ingres (relational DBase), Professional Publisher, and bibliographic software.

5. Synthesis and modeling

A volume synthesizing results of fifty years of research at Coweeta was recently published (Swank and Crossley 1988) and has received several favorable reviews. The table of contents of this volume is listed in Section V.1 of this proposal. A second volume synthesizing studies of

Table 19 (cont.): Coweeta data bank catalog of data stored at UGA: Table of contents including list of data set titles organized by LTER core research area.

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recovery of biogeochemical processes with succession on WS 7 (experimental clear-cut) is planned during this six-year period. The volume will be edited by Swank and Meyer, and a preliminary outline is included as Table 20. In addition to these book-length syntheses, Coweeta-LTER investigators have published numerous synthetic papers during the previous five years. Several of these are listed in Table 21.

Coweeta PI's have also been involved in planning workshops aimed at synthesis of results in several areas. For example, Meyer and Webster were involved in the planning of a workshop for synthesis of studies of solute dynamics in streams and wrote major sections of the resulting manuscript. Several PI's attended a workshop to compare the response of southeastern ecosystems to the recent drought, and Swank is preparing a paper for BioScience describing the outcome of that comparison.

We are proposing to use modeling as an essential tool in our studies of forest disturbance and stress along environmental gradients as described in section III.1. In addition, several of our current and proposed LTER network activities (see next section) focus on modeling. Coweeta is cooperating with several modeling efforts that are using selected sites in the LTER network; these include developing intersite models linking soil and vegetation (with Shugart, Parton, and Lauenroth), developing models of biogeochemical cycles (with S. Bledsoe), and modeling forest-stream interactions (with McKellar). In addition to these modeling efforts, several non-LTER funded modeling activities are currently underway at Coweeta. These models range from detailed models of soil temperature variation to landscape assessments of forest succession following the chestnut blight.

Coweeta has a long record of modeling activities dating back to the late sixties. The spectrum of modeling activities has included theoretical models of ecosystem organization, detailed site-specific process models and regional-scale and site-specific management models. Table 22 documents both past and present modeling research at Coweeta.

6. Intersite and network activities

Coweeta scientists have been active in the LTER network during the past five years; these efforts are summarized in Table 23. Because of space limitations in the proposal, it is not possible to describe each of the thirty activities listed. We include further information about seven of these projects to provide the reviewer with the flavor of our intersite research. The intersite research conducted to date has resulted in several publications listed in Table 24 as well as several manuscripts in progress.

Comparative climatology (3 in Table 23) has involved a summary of the climates of 11 LTER sites, which was published by the Climate Committee in 1987. The Committee intends an update to include the present 17 sites as soon as all the new sites can assemble representative long-term climatic records. In the study of trace elements in tree rings (5 in Table 23), we have cored trees at

Table 20: Outline of proposed volume synthesizing research on recovery from disturbance, using primarily information from WS7 at Coweeta.

Deciduous Forest Ecosystem Recovery from Cutting Disturbance in the Southern Appalachians

1. General introduction: hypotheses and objectives, site description, experimental approach, treatment
2. Response and Recovery of Evapotransporation: water yield and timing, sediment, and other abiotic parameters
3. Vegetation Recovery: species succession, NPP, nutrient recycling, physiological changes
4. Biogeochemical Recovery
    a. Atmospheric deposition, throughfall, and streamwater fluxes
    b. Soil and soil water fluxes
5. Decomposition: wood, roots and leaf litter
6. Forest Floor Biota
7. Canopy Insects and Herbivory
8. Recovery of the Stream Ecosystem
    a. Seston transport
    b. Organic matter dynamics: standing stock, litter quality, decomposition, DOC
    c. Macroinvertebrate communities
9. Synthesis
    a. Changes in nutrient cycles: N, C, S, P, cation models
    b. Identify principles of recovery for this type of disturbance and contrast to other types of disturbance through concepts of resistance and resilience
    c. Comparison of process of recovery from cutting in the Southern Appalachians with that seen in other biomes (e.g. H. J. Andrews and Hubbard Brook)
    d. Management implications: economics of treatment, site productivity, water quality, stream productivity, overall economic consequences

most LTER sites to determine if trace element concentrations for a species show an increase over time prior to 1930 and if there is an increase over time since 1930. Hillslopes at Hubbard Brook (HBR) and Coweeta have been similarly instrumented in the project on hillslope hydrology (6 in Table 23) so that model and field results will be comparable from these two sites. This type of comparison has not been feasible in the past because different sites have been instrumented and modelled in different and incompatable ways.

We have done considerable intersite research on S dynamics. The intersite research on S gas emissions (7 in Table 23) examined S gas emissions from soil, litter, and living plants at three sites to determine if discrepancies in the mass balance of S could be a consequence of failure to measure gaseous S emissions. Results to date indicate that the answer is no. This research is also of interest with respect to the global S cycle and acid precipitation: namely, how does the magnitude of natural sources of gaseous S compare with anthropogenic emissions? Comparative studies of S processing in soils and litter (8 in Table 23) have examined the dynamics of S in soils at several sites. We have examined formation of organic S from precipitation sulfate as well as mineralization of organic S in litter and upper soil layers. Differences in S dynamics between sites were related to both geologic (iron and aluminum oxide content of the soils; e.g., sulfate adsorption) and biotic processes (activity of the microbial community; e.g., organic S formation).

Questions in stream ecology have also been the focus of several intersite research projects. In the work on substrate-specific solute retention in streams (9 in Table 23) we compared solute retention using low-level releases of nutrients into the same substrate types in similar-sized streams at Andrews (AND) and Coweeta. The AND catchment is of volcanic origin whereas Coweeta streams flow over granitic bedrock. At Coweeta strong biotic control of P uptake coupled with high P demand results in relatively short P uptake lengths and a strong impact of P spiraling on ecosystem dynamics. At AND strong biotic control of N uptake combined with strong N demand results in short N uptake lengths. These differences are predictable based on the N:P ratio in stream water, which is a reflection of the geology of the region. Debris dams are important sites of DOC retention in both systems. In a recently initiated project, we are comparing wood breakdown and movement in streams (11 in Table 23). Downstream movement of marked wood is being followed in headwater streams at Coweeta and Luquillo (LUQ). The streams are similar in geomorphology but differ in the amount of rainfall received. Incorporation of marked wood into debris dams will allow us to determine the dynamics of debris dam formation and the residence time of wood as it slowly moves downstream or decays. Additional "cohorts" of marked dowels will be added and monthly maps of dowel positions will be incorporated into a GIS analysis to document seasonal dynamics in patterns of movement and debris dam formation.

The first fifteen of the current intersite research projects will be continued during the next granting period. In addition, several new intersite initiatives are proposed for the next period.

Table 21: Synthetic papers (1985 - 1990) in addition to the volume entitled Forest Hydrology and Ecology at Coweeta (Swank and Crossley, editors).

Boring, L.R., W.T. Swank, J.B. Waide, and G.S. Henderson. 1988. Sources, fates, and impacts of nitrogen inputs to terrestrial ecosystems: review and synthesis. Biogeochemistry 6: 119-159.

Cuffney, T., J.B. Wallace and G.J. Lughardt. 1990. Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics of headwater streams. Freshwater Biology 23 (in press).

Huff, D.D. and W.T. Swank. 1985. Modelling changes in forest evapotranspiration. pp. 125-151 in: M.G. Anderson and T.P Burt (eds.) Hydrological Forecasting. John Wiley and Sons.

Johnson, D.W., J.M. Kelly, W.T. Swank, D.W. Cole, H. Van Miegroet, J.W. Hornbeck, R.S. Pierce and D. Van Lear. 1988. The effects of leaching and whole-tree harvesting on cation budgets of several forests. Journal of Environmental Quality 17: 418-424.

Meyer, J.L. et al. 1988. Elemental dynamics in streams. Journal of the North American Benthological Society 7: 410-433.

Meyer, J.L. 1990. Production and utilization of dissolved organic carbon in riverine ecosystems. In: E.M. Perdue and E.T. Gjessing (eds.) Organic Acids in Aquatic Ecosystems. John Wiley and Sons.

Pringle, C.M. et al. (including Webster). 1988. Patch dynamics in lotic systems: the stream as a mosaic. Journal of the North American Benthological Society 7: 503-524.

Resh, V.H. et al. (including Wallace) 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7: 433-455.

Schowalter, T.D., W.W. Hargrove, and D.A. Crossley. 1986. Herbivory in forested ecosystems. Annual Review of Entomology. 31: 177-196.

ute Dynamics Working Group (includes Webster, Meyer, D'Angelo and Munn from Coweeta). Submitted. Concepts and methods for assessing solute dynamics in stream ecosystems. Journal of the North American Benthological Society.

Swank, W.T. 1986. Biological control of solute losses from forest ecosystems. pp. 85-139 in: S.T. Trudgill (ed.) Solute Processes. John Wiley and Sons.

Swank, W.T. and D.A.Crossley Jr. 1986. Coweeta Hydrologic Laboratory: Background and Synthesis. pp. 23 - 32 in: M.I. Dyer and D.A. Crossely, Jr. (eds.) Coupling of Ecological Studies with Remote Sensing: Potentials at Four Biosphere Reserves in the United States. Dept. of State Publ. 9504. Bureau of Oceans and International Environmental and Scientific Affairs.

Wallace, J.B. 1989. Structure and function of freshwater ecosystems: assessing the impact of pesticides. Occ. Pap. Ent. Soc. Am. In press.

Wallace, J.B., J.R. Webster and R. Lowe. In press. High-gradient streams of the southeast. In:W. Martin (ed.) Southeastern Communities. Wiley and Sons.

Webster, J.R., S.W. Golladay, E.F. Benfield, D.J. D'Angelo, and G.T. Peters. Submitted. Effects of forest disturbance on particulate organic matter budgets of small streams. Journal of the North American Benthological Society.

Webster, J.R. and E.F Benfield. 1986. Leaf breakdown in aquatic ecosystems. Annual Review of Ecology and Systematics 17: 567-594.

These are summarized in Table 25, and the numbers in the following discussion refer to entries in that table.

1) The workshop on atmospheric chemistry will be held in 1990 or 91 with the primary objective being to synthesize and characterize atmospheric chemistry data across LTER sites. Emphasis will be placed on intrasite analysis, but opportunities to examine intersite trends will also be addressed. It is intended that results be published as a Forest Service Technical Report in a format similar to the climate document. A secondary objective of the workshop will be to identify gaps in the current atmospheric measurement programs at LTER sites along with recommendations for a minimal level of effort in this area and a strategy of how to provide for these needs.

2) The project on comparative long-term successional patterns will include interactions with Phil Sollins (AND) and Tim Fahey (HBR) to compare successional patterns after clearcutting at these three sites. We hope to incorporate this comparative information in our planned volume on recovery from cutting (Table 20).

3) PROSPER will be used to estimate evapotranspiration and soil water flux in what is now early successional tropical forest. Soil water flux will be coupled with soil solution chemistry to quantify nutrient flux.

4) Preliminary field evidence suggests that microarthropod densities on the forest floor are much lower at Luquillo (LUQ) than at Coweeta. We intend to submit a proposal to examine the consequences of this for forest floor processes at the two sites.

5) Several research efforts have addressed changes in populations or processes as a function of disturbances or perturbation. The proposed intersite project on gradient analysis of soil organic matter quality in response to perturbation will follow up on important changes in soil organic matter quality in agroecosystems and forest sites across a continental gradient. We will analyze soil organic matter samples by GC/MS and other techniques to determine changes in organic matter quality as a function of gradients in elevation, latitude and disturbance.

6) The comparison of stable isotope patterns will be a descriptive study of C and N natural abundances in soils and vegetation at these two LTER sites using new analytical facilities soon to be available at the Institute of Ecology (described in Section IV.4).

7) The remote sensing work is described in section IV.10. of this proposal.

8) In the study on mycorrhizal fungal biomass estimates we propose to measure mycorrhizal fungal mat biomass and labile nutrient content (inorganic and organic N, S, and P) using modifications of the Jenkinson and Powlson (1976) chloroform fumigation incubation method. We will employ the procedure of Vance et al. (1987), which uses a chloroform fumigation, followed by extraction using 1 M K_2SO_4. We will determine microbial N, S, and P by techniques developed by Voroney and Paul (1984), Saggar et al. (1982) and Hedley and Stewart (1982) for

Table 22: Modeling activites at Coweeta Hydrologic Laboratory.

Past areas of modeling emphasis

Empirical models of watershed hydrology (e.g., statistical models of streamflow responses to forest cutting)

Statistical models of climatology (e.g. analyses of recurrence intervals for storms of given size and duration)

Process models of select components of forest hydrologic cycle (e.g., PROSPER model of forest evapotranspiration)

Process models of ecosystem biogeochemistry and productivity (e.g. forest N-cycle model with management applications, model of organic matter processing in headwater streams)

Theoretical models of ecosystem organization (e.g., model-based analyses of ecosystem stability)

Current and proposed areas of modeling activities

Models of long-term responses of Coweeta watershed (WS 34, 36) to atmospheric deposition (cooperative USFS effort funded by EPA Direct/Delayed Response Project, using 3 models: ILWAS, MAGIC and ETD)

Modeling study of long-term response of Coweeta forests to chesnut blight (cooperative study with ORNL, using FORET model of stand dynamics)

Model analyses of recent (1984-88) drought (stochastic model analyses of hydrologic drought in terms of magnitude, duration, and recurrence interval)

Development of model of soil temperature (funded by USFS, implemented on microcomputer, requiring inputs of easily measured climatic variables)

Development of process model of sulfur cycle in forest soils (USFS/UGA, based on extensive research data available for Coweeta)

Development of top-down model of coniferous forest growth in response to altered environmental conditions

Development of geographic information system (geo-referenced data base) and remote sensing capabilities for Coweeta Basin (cooperative studies with UGA and NASA/NSTL)

Development of model linking hydrological processes with vegetation dynamics within a forested catchment (cooperative agreement between USFS and U. Va.)

Individual-based models of vegetation dynamics along an environmental gradient (Huston, Section III.1, this proposal)

Development of models for nutrient dynamics in streams (Webster, D'Angelo Va. Tech, Section III.2, this proposal)

Development of organic matter dynamics models for first through fourth order streams (Webster, Va Tech, Section III.2, this proposal)

Models for water movement and chemical flux through riparian (Dowd, UGA, Section III.3, this proposal) the respective elements. We will also assay for calcium oxalates to see if they are in the high amounts measured by Cromack et al. (1988) in Pacific Northwest forests.

9) We intend to write a proposal to fund a workshop on decomposition in aquatic systems. The purpose of this workshop would be to design an intersite experiment that will allow a comparison of the relative importance of biotic and abiotic factors regulating leaf decomposition in different aquatic ecosystems. This experiment would complement the experiment underway studying terrestrial decomposition across sites.

10) Plants acquire nutrients, light, water, and fix carbon; they allocate these resources to roots, stems, leaves and reproductive parts. At Luquillo and Coweeta LTER sites, we plan a study along a successional gradient to determine the response curves of early-, mid-, and late-successional plant species to light, nutrients, and water, and how these resources are allocated. This will be an important contribution to our understanding of plant resource allocation strategies and to our modeling efforts.

11) The description of this project on development of soil temperature models is in Section IV.10 under New Techniques for LAI Measurements.

12) In the project on effects of site disturbance and regrowth on soil microbial activity, microbially mediated processes will be measured during regrowth of the tropical forest at LUQ following hurricane disturbance. Nitrogen transformations including nitrification, denitrification and mineralization will be estimated. Microbial activity and biomass will be evaluated using CO_2 evolution and ATP extraction techniques. These data will provide information comparable to that currently available on these processes during succession at Coweeta and therefore offer an opportunity to compare soil microbial processes over succession at two latitudes.

Coweeta has been an active participant in intersite research in the past and we intend to continue this in the future, as is evidenced by the projects described above and the commitment to intersite research agreed upon by all Cohort I sites, which is included as Section V.6. of this proposal.

7. Related research projects

The scope and diversity of research has continued to expand at Coweeta during the past 5 years as partially reflected by more than 25 active cooperative agreements between the Forest Service and other agencies and institutions listed in Section V.7. Studies range from single investigator efforts to national projects involving numerous investigators and multiple sites. Most of these studies have both utilized and contributed to LTER research at Coweeta.

The Integrated Forest Effects project funded by the Electric Power Research Institute is in the synthesis stage. Forest Service collaboration with investigators at nine sites in the United States, Canada, and Norway has focused on quantifying atmospheric deposition to forest ecosystems and subsequent effects on nutrient cycling processes. Although Coweeta is the only LTER site participating in the project, findings provide an outstanding opportunity to interpret and extrapolate

Table 23: Intersite research activities (1985 - 90) involving Coweeta CoPIs.

Project	Coweeta PI's	Other Sites Involved
1. Analysis and interpretation of regional drought	Swank	NIN
2. Atmospheric deposition, nutrient cycling, and hydrologic processes	Swank	NIN
3. Comparative climatology	Swift	LTER Network
4. Standards for LTER meteorological data stations	Swift	LTER Network
5. Long-term pattern of trace elements in tree rings	Ragsdale	LTER Network (with Blood at NIN)
6. Hillslope hydrology	Dowd	HBR
7. Sulfur gas emissions	Haines	LUQ, La Selva
8. Sulfur processing in soils and litter	Fitzgerald	NIN, LUQ, and 4 non -LTER sites
9. Substrate-specific solute retention in streams	Meyer	AND
10. Modelling solute transport in streams	Webster, Meyer	AND, LUQ, HBR, KNZ, non-LTER sites
11. Wood breakdown and movement in streams	Webster, Meyer Wallace	LUQ, AND (Covich project)
12. Modelling forest-stream interactions	Meyer, Swank	NIN, AND (McKellar project)
13. Developing intersite models linking soil and vegetation	Swank, Meyer Boring, Haines	AND, KNZ, VCR, CPR (Shugart, Parton, Lauenroth project)
14. Developing models of biogeochemical cycles	Haines, Swank	LTER Network (S. Bledsoe project)
15. Hardwood forest hydrology, productivity and biogeochemistry model	Swank	VCR (Yeakley/Shugart project)
16. Biomass accumulation in terrestrial secondary succession	Haines	LUQ
17. Plant responses to light and nutrient gradients on disturbed sites	Haines	LUQ
18. Nutrient limitation of aquatic productivity	Swank	LTER Network (Tate project)

(con't. on next page)

site-specific processes across a wide range of forest ecosystems. The current data synthesis will be produced in book form. Another major project has been initiated to assess on-site and off-site effects of prescribed burning as a site preparation tool in hardwood forest ecosystems. Studies are being conducted on nearby watersheds located on National Forest land and involve collaborative studies between several Forest Service Research Work Units and university scientists. The research is partially funded by the Man and Biosphere program and also by EPA and is a logical extension of past and current LTER related research on nutrient cycling.

CoPI's at UGA and Virginia Tech have been and are currently funded for research at Coweeta that complements their LTER-funded research. For example, Crossley is funded to look at the effects of resource quality and microarthropods on forest floor nitrogen dynamics, which will extend our understanding of decomposition and N cycling at Coweeta. Wallace and Webster are funded to examine the impact of macroinvertebrates on ecosystem processes in Coweeta streams using experimental manipulations. These studies have produced valuable information on processes controlling litter decomposition and particulate export in streams, and enabled Wallace (in press) to compare the influence of macroinvertebrate removal vs. drought on organic matter dynamics in streams. Boring was funded by UNESCO Man and Biosphere program to represent Coweeta for a US/USSR bilateral research exchange on biological diversity during August 1989.

Faculty investigators that are not funded through the Coweeta-LTER program are conducting research at Coweeta. For example, Carolyn Thomas (Ferrum College) has recently completed a funded project to examine fungal dynamics during litter decay and nutrient control of leaf decomposition in Coweeta streams. Alan Covich (U. of Oklahoma) is currently funded by NSF's mid-career fellowship program to do stream research at Coweeta on transport of woody debris, which was discussed more completely under intersite research. Several additional projects have been proposed by other investigators and are awaiting notification of funding.

A variety of extramural LTER modeling efforts are in progress with ORNL, universities, and other Federal agencies and are supported by grants from various sources. An indication of the level of cooperative effort at Coweeta on just one topic is illustrated in Figure 20. It is clear that LTER objectives and research activities serve as a catalyst to attract additional support and science which interfaces with the core LTER program.

8. Archives and inventories

A herbarium of all Coweeta plant species is maintained at Coweeta with duplicates at the Western Carolina University Herbarium and a subset of species at the UGA Herbarium. Recently updated (1985) soil survey maps (1 : 7200 scale) are available for the site. Archived soil samples are currently stored in the second floor of the laboratory building at Coweeta, but we plan to move them to more secure storage in the building formerly used to store Coweeta records. Representatives of insects collected at Coweeta are cataloged in the museum at UGA, and unsorted

Table 23, con't.: Intersite research activities (1985-90) involving CWT CoPIs.

19. Variability in ecosystems	Ragsdale, Berish	LTER Network (NTL project)
20. Trans-biome comparison of productivity, life forms, and resources	Vose	LTER Network (Tilman project)
21. Workshop on tree mortality (4/90)	Swank, Boring	LTER Network
22. Workshop on organic matter decomposition (5/89) (CWTsupplied large amounts of one of six main litter types for intersite decomposition experiment.)	Crossley	LTER Network
23. Organized workshop on techniques in soil ecology (9/89)	Crossley, Coleman	LTER Network and other sites
24. Workshop on Remote Sensing (11/89)	Crossley	LTER Network
25. Workshop on Stable Isotopes (10/89)	Boring	LTER Network
26. Workshop on Global Change (11/89)	Boring	LTER Network and others
27. Data Managers Workshops (e.g. 8/89)	Haines	LTER Network
28. GIS workshop (9/89)	Saari, Smith	LTER Network
29. Network Connectivity Committee (meetings and tour of site during their visit)	Haines, Meyer	LTER Network
30. LTER Coordinating Committee Meetings	Meyer, Crossley and others	LTER Network

terrestrial insect samples for use in future analyses are stored in North Carolina State Museum. Vegetation samples are archived at Coweeta. Xerox images of leaves taken over the past 10 years for analysis of leaf area and leaf area removed are archived at UGA. Archived samples of aquatic insects and fishes are stored in laboratories at UGA.

The library at Coweeta contains copies of all theses and dissertations done at Coweeta as well as reprints of all papers published that have used data from the site. An annotated site bibliography covering the period 1934 - 1984 was published (Gaskin et al. 1984) and is updated annually. The Coweeta-LTER Data Manager is currently putting this bibliography on-line. It currently contains 724 publications.

9. Leadership, management and organization

As PI's, Meyer and Swank are responsible for overall direction and management of the project. They communicate weekly by phone or BITNET. A recent NSF review of the Coweeta-LTER suggested instituting an executive committee, which we will do in 1990. The executive committee will be composed of five people: the two PI's and three others selected by the group to represent major research interests. The executive committee will assist the PIs in decisions on site use and in formulating policies for approval of the group as a whole. In the event that "conflict of interests" on site use, disturbance experiments, or other agency/cooperator decisions cannot be resolved by the PIs or executive committee, the ultimate decision resides with the Director of the Southeastern Forest Experiment Station, as provided in the basic cooperative agreement. It is important to note that this administrative tool has never been needed despite the numerous cooperative studies conducted at Coweeta over the past 25 years.

Scientific decisions are made by group consensus. This process has worked well for the two decades we have been doing interdisciplinary research at Coweeta. For example, the recent transition in leadership was accomplished smoothly and by group consensus. After 20 years as PI on interdisciplinary projects at Coweeta, Crossley wished to devote more attention to his research on canopy consumers and forest floor processes and biota. The addition of Dr. Jim Vose (Forest Ecologist) and Dr. Jennifer Donaldson (Soil Scientist) to the permanent staff at Coweeta will provide opportunities for future leadership development through the Forest Service. Swank has provided this leadership since 1968 but a transfer of responsibility is planned during the latter stages of the next funding period. We believe that periodic changes in project leadership are consistent with the long-term nature of LTER projects.

All Co-PIs at the UGA campus meet monthly for informal discussions and planning sessions over lunch. Semi-annual meetings include all investigators (Co-PIs, students, and technicians), and facilitate exchange of research results as well as planning and coordinating future research. The experience of our group has shown that this frequency is adequate to provide the overall communication needed for integration and interaction between investigators. We will also continue

Table 24: Publications summarizing intersite research conducted by Co-PI's.

Blood, E.R., W.T. Swank, and T. Williams. In press. Precipitation, throughfall and stemflow chemistry in a coastal loblolly pine stand. In: R.R. Sharitz and J.W. Gibbons (eds.) Freshwater Wetlands and Wildlife -- Perspectives on Natural, Managed, and Degraded Ecosystems. Savannah River Ecology Laboratory.

Haines, B.L., M.S. Black, J. Fail, L. McHargue, and G. Howell. 1987. Potential sulfur emissions from a tropical rain forest and a southern Appalachian deciduous forest. In: T. C. Hutchinson and K. Meema (eds.). Effects of atmospheric pollutants on forests, wetlands and agricultural ecosystems. Springer-Verlag, New York.

Munn, N.L. and J.L. Meyer. Submitted. Substrate-specific retention in two small streams: an intersite comparison. Ecology.

Solute Dynamics Workshop (includes J.L. Meyer, J.R. Webster, N.L. Munn and D. J. D'Angelo from Coweeta). Submitted. Concepts and methods in assessing solute transport in streams. Journal of the North American Benthological Society.

Stanko, K.M. and J.W. Fitzgerald. 1989. Sulfur processing in forest soils collected along an elevational gradient. Soil Biol. Biochem. in press.

Stanko, K.M. and J.W. Fitzgerald. 1989. Sulfur transformations in tropical forest soils. Canadian Journal of Forest Research. Submitted.

Swift, L.W. Jr. and H.L. Ragsdale. 1985. Meteorological data stations at long-term ecological research sites. pp. 25 - 37. In: B. A. Hutchinson and B.B. Hicks, eds. The Forest-atmosphere Interaction: Proceedings of the Forest Environment Measurements Workshop. Oak Ridge, TN. D. Reidel Publishing Co.

Swift, L.W. Jr. 1987. Coweeta Hydrologic Laboratory, N.C. pp. 28-33. In: D. Greenland (ed.) The Climates of the Long-term Ecological Research Sites. Occas. Pap. 44. Institute of Arctic and Alpine Research, University of Colorado, Boulder CO.

Swift, L.W. Jr. and E.R. Blood. 1987. Drought impact research at two LTER sites. pp. 102 -105. In: Southeastern Drought Symposium Proceedings, March 1987, Columbia SC. SC state Climatology Office Publication G-30. SC Water Resources Commission, Columbia SC.

Swift, L.R., and G.B. Cunningham. 1986. Routines for collecting and summarizing hydrometeorological data at Coweeta Hydrologic Laboratory. pp. 301-320 In: W.K. Michener (ed.) Research Data Management in the Ecological Sciences. University of South Carolina Press.

Watwood, M.E., J.W Fitzgerald, W.T. Swank and E.R. Blood. 1988. Factors involved in potential sulfur accumulation in litter and soil from a coastal pine forest. Biogeochemistry 6: 3-19.

Watwood, M.E., J.W. Fitzgerald and J.R. Gosz. 1986. Sulfur processing in forest soil and litter along an elevational and vegetative gradient. Can. J. For. Res. 16: 689-695.

to use our LTER advisory committee for research program guidance with 2- to 3-day meetings scheduled at 18- to 24-month intervals.

A site use form provides a formal mechanism for reviewing, approving and tracking new studies. We will continue to use this procedure as a management tool. All substantive research projects conducted at Coweeta are under formal cooperative agreement with the Southeastern Forest Experiment Station (list of cooperative agreements in Section V.7). This legal form of management will be continued.

10. New projects and technologies

Geographic Information System (GIS): A Sun workstation (Sun SPARCstation1 running at 12.5 MIPS) and ARC/INFO software arrived at UGA during January 1990. Additions made to the base configuration to increase processing power and the ability to handle large data sets include an additional 8 Mbytes of RAM for a total of 16 Mbytes, an accelerated color graphics adapter, and 700 Mbytes of disk storage. The SPARCstation with the added hardware is the ideal work station for a one-user ARC/INFO package. In addition to the ARC/INFO base license, NETWORK, TIN and COGO modules have been ordered. For data input and output, a digitizer (Calcomp 95000: 36" x 48") and plotter (HP Draftmaster) have been ordered. The large input/output devices will allow for full size digitizing and map production. These improvements in equipment were made possible by LTER supplemental funds.

The USFS lab at Coweeta is currently using an IBM-PC-based ARC/INFO system for GIS. The hardware includes an IBM-PC (70/386) with 1 MB memory, 1024K extended memory, 80387 math co-processor, 60 MB hard drive and 2 floppy disc drives, VGA High Resolution Monitor, HP-7475A Graphics Plotter, HP Paint Jet Printer, and CalComp 9100 Digitizer. Software includes PC ARC/INFO Starter, Grid Conversion, Overlay, ArcPlot, ArcEdit, Network and INFO.

All current baseline digital GIS data have been converted by or for the USFS, although future layers will also be digitized by the LTER GIS manager now that we have the equipment at UGA. The following base layers are common basin-wide coverages: base map of Coweeta basin with watersheds, streams roads and weir locations; 50 ft contours; bedrock (parent material) and surficial deposits; soil series map. Coverages to be digitized in the future include vegetation stands (1940, 1960, 1980), vegetation transects (1934 strip plots), rain gauges, Coweeta-LTER databank site locations, existing canopy gaps, WS7 forest composition, expansion of *Rhododendron* cover over time, geomorphic data on Ball Creek, and location and movement of large woody debris in streams. These coverages will be essential in our proposed research on environmental gradients (Section III) and in our proposed synthesis of studies on WS 7 (Table 20).

Our plans for use of GIS at Coweeta are diverse. We will use it as a tool in site management, allowing us to more carefully oversee placement of experimental plots and study areas. We intend

Table 25: Intersite research projects to be initiated during 1990-96. Research projects 1 - 15 described in Table 23 will be continued. Projects described below are in addition to these ongoing intersite research efforts.

Planned New Intersite Research Projects	Coweeta PIs	Other Sites Involved
1. Workshop to synthesize data on atmospheric chemistry	Swank	LTER Network
2. Comparative long-term successional patterns	Boring, Haines	LUQ, AND, HBR
3. Use of PROSPER to estimate water and nutrient fluxes	Swank, Vose	LUQ
4. Impacts of litter microarthropods on decomposition	Crossley	LUQ
5. Gradient analysis of soil OM quality in response to perturbations	Coleman	KBS, LUQ
6. Comparative terrestrial stable isotope patterns	Boring	NIN
7. Remote sensing: estimating canopy resistance for ET models and validation at > km^2 scale	Swank	AND
8. Mycorrhizal fungal mat biomass estimates using CFIM	Coleman	AND
9. Intersite comparison of leaf decomposition in streams	Meyer	LTER Network
10. Comparison of resource acquisition and allocation by early, mid, and late successional plants in regenerating forests	Haines	LUQ
11. Soil temperature models driven by solar radiation inputs estimated using pyranometer & hemispherical canopy photography	Haines, Vose	LUQ, La Selva
12. Effects of site disturbance and regrowth on soil microbial activity	Donaldson, Swank	LUQ

to overlay coverages from basin wide topographic maps, soil maps, exposure to radient energy, soil solution chemistry and vegetation to search for positive or negative relationships between the variables. We plan to utilize GIS to "scale up" estimates of processes from plot and watershed data to larger landscape areas and to examine the spatial patterning of critical mineral cycling processes based on the extensive data base that exists at Coweeta. An example of the use of GIS in "scaling up" was presented earlier in the proposal (Section II). GIS will facilitate studies of long-term changes in vegetation and be an integral part of our proposed vegetation modeling activities (Section III.1). In our hydrologic work, GIS will be used to link spatially variable watershed data to a physically based flow map. Spatial variability of insect damage to vegetation will also be examined with GIS, to isolate factors of slope, aspect and elevation from phenomena associated with drought-associated gap dynamics.

Local Area Network (LAN): To facilitate communication and exchange of data between PIs at UGA and better integration of data management, GIS work and PI's, we are in the process of installing a LAN as diagrammed in Figure 21. Electronic mail communication with all CoPI's is accomplished via BITNET.

Remote sensing studies: Forest Service CoPI's are currently cooperating with three different groups in the conduct of remote sensing research. One project is with Dr. Jeff Luvall, NASA at Stennis Space Center, Mississippi, where the objective is to develop methods for estimating regional forest evapotranspiration using remotely sensed data. Initial results show good agreement in evapotransipration estimates between traditional energy budget methods and estimates derived from the Thermal Infrared Multispectral Scanner. Future studies will utilize data from the calibrated Airborne Multispectral Scanner and Landsat TM.

A cooperative study between the USFS and Dr. Steve Running, University of Montana, is also focusing on the development of methods for estimating forest evapotranspiration using Landsat imagery. However, the underlying approaches and scale of resolution differ from Luvall's approach. Similar NSF-funded research is being conducted at H.J. Andrews. Data sets and hydrologic models at Coweeta will be used to test and refine remote sensing models.

A third study is in progress with Dr. Carolyn Hunsaker, Oak Ridge National Laboratory, with the objective to develop methods for the analysis of landscape processes that are important to water quality at different geographic scales. Both remote sensing and GIS techniques are being applied to link forested basin characteristics (<10 km^2) with the broader land use mosaic represented within the Little Tennessee River Basin.

New techniques for LAI measurements: Vose and Swank are evaluating the ability of the Sunfleck Ceptometer to non-distructively quantify LAI and seasonal LAI dynamics in hardwoods and pines. Operationally, the Ceptometer measures mean PAR beneath the forest canopy with 80 sensors located at 1 cm intervals. PAR measurements below the canopy and in the open are

We are also using GC/MS to analyze organic matter quality in the Coweeta landscape. We hypothesize significant differences in the rates of production, turnover and fates of litter and root-derived organic matter in the riparian zone as contrasted to upland forest floor or streams (sections II.2, 3, and 4). To assist us in this research we are extracting lipids and waxes from samples, reducing them with lithium hydride and/or deuteride, and determining aromatic and aliphatic moieties using GC/MS in collaboration with Dr. K Espelie at UGA. In the OA and OE horizons, we have already been able to discern various triols and tetrols which are more characteristic of root-derived compounds.

11. Dissemination of information

LTER and other cooperative research activities conducted at Coweeta are disseminated through a variety of mechanisms in addition to technical presentations and publications. The Forest Service utilizes a formal technology transfer plan, revised annually as a framework for this dissemination. Foremost among methods are the numerous tours conducted on site, which averages about 1200 visitors per year. A broad audience is reached as indicated in Table 26, which provides a summary of visitors during 1988. An excellent 18-minute slide-tape show has been developed to inform visitor groups about the history of Coweeta, major research findings, and the current research program. A partially enclosed Visitor's Center was recently constructed to serve the weekend and non-technical visitor. Also available are an interpretive folder for a self-guided tour and a "Guide to the Research Program" booklet written for the lay audience. New and revised brochures summarizing Coweeta will be prepared next year.

The news media is also a primary medium for dissemination. Research findings and activities during the past year appeared in 20 separate newspaper articles at local, regional and national levels. The Institute of Ecology at UGA has a staff member who coordinates publicity and media contacts, and the UGA Research Reporter has had several feature stories on Coweeta research. including one on the drought. We planned and executed newspaper coverage of the recent drought workshop through reporter contacts. Television coverage was provided on three occasions and a forest environment documentary intended for PBS was taped during the year. Information has also frequently been provided to Congressmen and their staff.

Use of these media will continue in concert with the new research proposal. However, we plan to expand dissemination efforts in several areas. The Forest Service is working to obtain a technology transfer specialist for the work unit, and a major responsibility of this individual would be to communicate the LTER program to the public. Long-range planning between the Forest Service, UGA and other cooperators includes the development of a program and facilities for the conduct of short courses. Components and products of the LTER programs would be included in both the field and classroom instructional material. The clientele would consist of US and foreign

Figure 20: Components of atmospheric deposition research at Coweeta Hydrologic Laboratory.

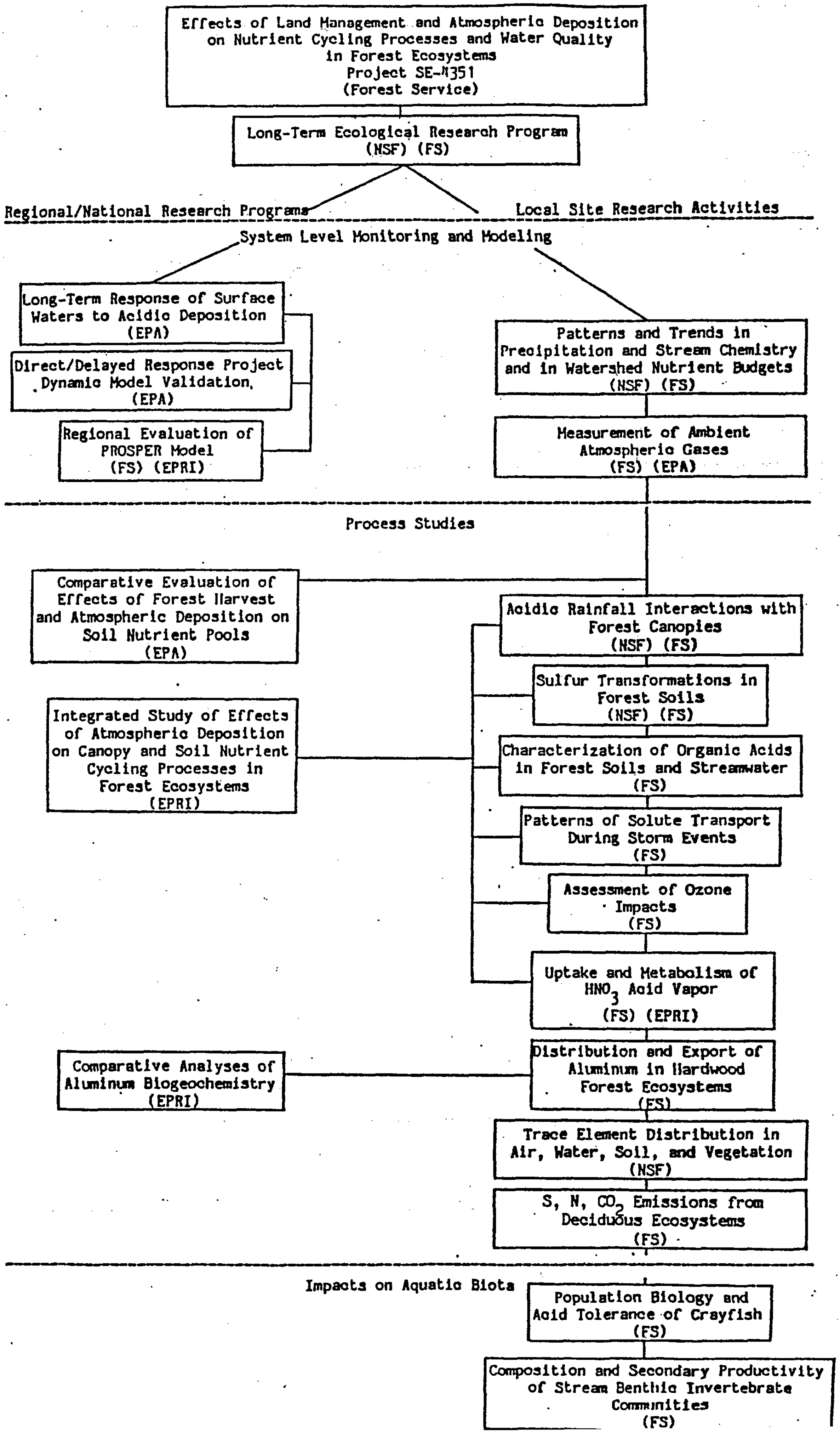

Table 26: Visitor record for a typical year (1988) at Coweta Hydrologic Lab.

Group	No. of Groups	Individuals in Group
Foreign Visitors	6	24
University Classes	24	337
Technical Schools	2	42
Secondary Schools	9	287
Forest Service, State, and Other Scientists	43	250
News Media	5	6
Special Interests	6	50
Drop-ins		236*
Totals	95	1,232

*Estimated from actual records

forest resource managers, planners and policymakers, environmental groups, secondary education students, graduate students and other specialized groups.

12. Contribution to education and human resources

As is apparent from the long list of theses and dissertations completed at Coweeta (117 at last count), research by graduate students has been a critical component of our research effort in the past and will continue to be in the future. During the last five years of LTER funding 40 students completed M.S. or Ph.D. degrees based on LTER-related research at Coweeta; 38% of these were women. We commonly employ undergraduates as field and laboratory assistants, and for many of these students this provides their first opportunity to be part of real scientific research. Many of these students have gone on to pursue advanced study in the sciences. LTER CoPIs regularly take their undergraduate classes on field trips to Coweeta, where students see on-going LTER research projects. For many of these students, this is their first exposure to experimental research in the field; it opens their eyes to the fact that experiments can and should be done in nature and on whole ecosystems, and not just in beakers in the laboratory.