

## Forest Patch Size, Land Use, and Mesic Forest Herbs in the French Broad River Basin, North Carolina

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### ABSTRACT

The effect of forest fragmentation on cove-forest herbs was studied in the Southern Blue Ridge Province. Patches of mesic forests were sampled with 4 ha study plots. The coverage and density of herb species were greater in large patches (>200 ha) than in small patches (<10 ha). Several ant-dispersed species, such as *Disporum maculatum* and *Uvularia grandiflora*, were more likely to be absent from small patches than from large patches. Wind-dispersed species, such as ferns and composites, were not affected by patch size and isolation. Small patches had reduced amounts of organic matter in the soil, suggesting that small patches have experienced more disturbance than large patches. Otherwise, there were no other differences in soil characteristics between patch sizes. Mechanisms hypothesized to have affected these populations include (a) disruption of population dynamics due to habitat fragmentation, (b) habitat degradation, and (c) anthropogenic disturbance via land use. Disturbances may have affected herb populations directly by increasing mortality rates and by degrading habitat. These habitat changes were confounded by the small size and isolation of small forest patches.

### INTRODUCTION

Land use is the leading cause of landscape change. Landscape-level changes often result in habitat loss and fragmentation (Skole et al. 1994, Turner et al. 1994, Sinclair et al. 1995). Both worldwide and in the United States, land cover is altered principally by direct human use-through agriculture, pasture, forestry, and development (Meyer and Turner 1992). Land use patterns affect both terrestrial and aquatic systems (Reiners et al. 1994, Cooper 1995) and influence biodiversity for several reasons (Turner et al. 1997). First, land-use activities may alter the relative abundances of natural habitats and result in the establishment of new land-cover types. Species richness may be enhanced by the addition of new cover types, but natural habitats are often reduced, leaving less area available for native species (Walker 1992). Exotic species may become established and outcompete the native biota. Second, the spatial pattern of habitats may be altered, often resulting in fragmentation of once-continuous habitat. Species using a particular habitat may respond individually to these changes. Species that differ in their patterns of survival, fecundity, and dispersal, as well as in habitat needs, will likely differ in their response to habitat loss and fragmentation. Species having specialized habitat needs, requiring a large area for home range, or having limited vagility, will be impacted more than generalist species that disperse well and can live in small isolated patches (Terborgh 1992, Dale et al. 1994). Clearly, the conservation of native species and their habitats requires a landscape-level solution (Franklin 1993, 1994; Tracy and Brussard 1994).

Ecologists are beginning to develop techniques for assessing the complex impacts of landscape changes on biodiversity. Generalizations are difficult to obtain because habitat fragmentation affects species in different ways (Pearson et al. 1996). Assessing spatial and temporal changes in biodiversity by monitoring a suite of species having different habitat requirements has emerged as a useful technique. For example, patterns of deforestation in Rondonia, Brazil, were interpreted from the perspective of species having different area requirements and dis-

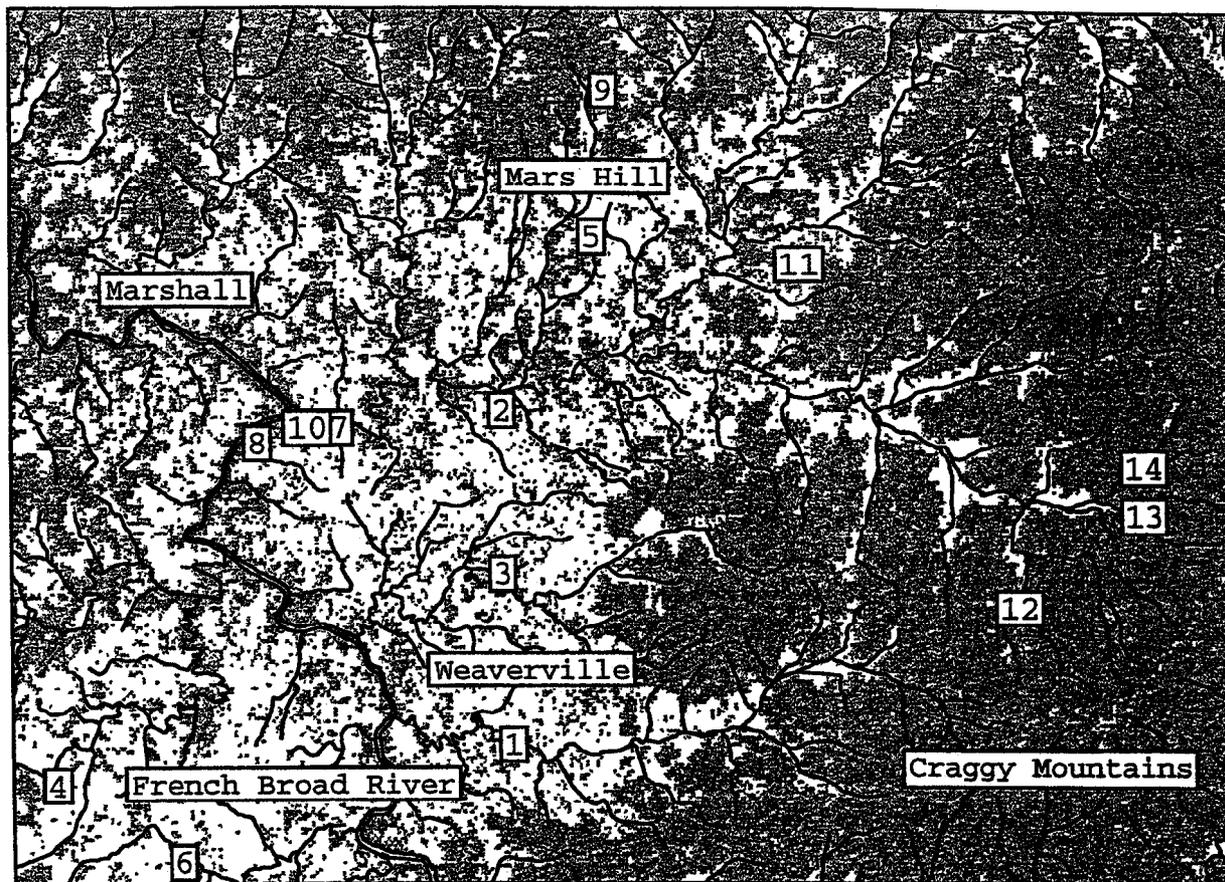


Figure 1. Forest cover in a portion of the French Broad River basin. The region shown is north of Asheville in northern Buncombe and southern Madison Counties, North Carolina. This map shows non-forest (white) and forest (grey) land covers for a 35.9 x 25.6 km region. Streams are shown as black lines. Numbers show locations of study plots. Plots 1-8 were located in small patches of forest. Plots 9-14 were located in large patches.

persal capabilities (Dale et al. 1994). In low- to mid-elevation forests in the Pacific Northwest, risk to bird species under four different management scenarios was evaluated by quantifying suitable habitat for each species by using habitat maps, species-habitat associations, and other life-history requirements (Hansen et al. 1995). Avian diversity has been used as an indicator of the vertical and horizontal structural complexity of vegetation over a broad region (Flather et al. 1992). Butterflies (Kremen 1992, 1994) and birds and butterflies (Debinski and Brussard 1994) have been used as indicators of biodiversity. While species' responses to landscape patterns are complex, the collective response of many species produces the patterns of biological diversity observed on landscapes. Moreover, landscapes have patterns that change in both space and time. Disturbance influences species diversity in many landscapes, and a better understanding of the interaction between spatial pattern and disturbance is needed (Roberts and Gilliam 1995).

While the southern Blue Ridge Province currently has a high percentage of forest cover (approximately 70% forested, SAMAB 1996), forest cover in some regions, particularly in large river valleys, is fragmented by agricultural and suburban land uses. The central portion of the French Broad River basin, North Carolina is one such region (Figure 1). The present-day landscape consists of a mosaic of forest patches interspersed with agricultural and suburban land uses. This region has experienced sustained agricultural use for more than 100 years (Eller 1982), and more recently has experienced a growth of urban and suburban land uses. This region has demonstrated the unlikely combination of increasing human population size and increasing forest cover since 1950. Agricultural land uses have declined since the turn of the century and land formerly in agriculture has reverted to forest, especially since 1950 (Wear

and Bolstad 1998 submitted). At the same time, suburban land uses **have increased** to **support** a growing human population. This landscape, as a whole, presently has more forest cover than earlier in this century. **In** some areas, forest cover has increased due to the abandonment of agricultural land formerly in pasture and cultivation and has decreased in other areas due to suburban development (Wear and Bolstad 1998 submitted). While recognizing these historical patterns, we seek to understand the consequences of the present-day patterns of forest cover on plant communities.

This research seeks to investigate the impact of habitat fragmentation on herbaceous species characteristic of cove forests found in this landscape. The study addresses the following question: Are the diversity and abundance of native forest herbs correlated with the **present-day** forest patch size in this landscape? The goal of this study was to determine whether forest herb communities differed between plots located in small and large patches of mesic forest. Soil characteristics were also measured to determine whether any differences in the plant community could be explained by **differences** in soils. To achieve this goal, we compared the **veg-**etation and soils sampled in a series of study plots located in either large or small patches of forest.

## METHODS

During 01 June-15 July 1995, 14 **4-ha** study plots were selected and **sampled** in forest patches ranging in area from 5 ha to **>10,000** ha. The sampling units for this study were the 4ha plot and 1-ha subplots within the larger study plot. The forests studied were located on both public and private lands in Madison and **Buncombe** counties of North Carolina. Three of the large forest patches were owned and managed by the USDA Forest Service. To control for coarse-level habitat variation, **all** plots were located in mesic forests at 600-920 m elevation. Plots located in forest patches **<25** ha in area were classified as being in small patches (**N** = 8). Plots in patches **>200** ha in area were classified as being in large patches (**N** = 6). Eight plots were classified as being in small patches, and each of these plots were located a different patch of forest. The mean  $\pm$  SE edge-to-edge distance to the nearest patch was  $42 \pm 8$  m for **all** patches in the study area. The nearest-patch distance for the small patches containing study plots was not **significantly different from** this mean. Three of the six large-patch plots were **located** in separate patches. The three remaining large-patch plots were located in the same forested patch that was **>10,000** ha in area (Sites 12-14, Figure 1). The minimum distance between these three plots was **>1.5** km, and **mesic** forest habitats were discontinuous between these plots. Therefore, these plots were treated as independent samples. Forest patch size was measured to the nearest ha using a land-cover map derived from a 1991 Thematic Mapper image (P. Bolstad and H. Pape-University of Minnesota, pers. **comm.**).

The same sized study plot (4, ha) was used to sample both large and small patches. This plot size covered a large percentage of the area of the small patches but only a minor portion of large patches. Nevertheless, keeping plot size constant allowed a more direct comparison of the communities found in the two patch sizes by eliminating the need to correct for species area effects due to **different** sized plots (Palmer 1991). Moreover, the patch size distribution of this landscape was highly skewed. Ninety-three percent of the patches in this landscape (Figure 1) were small (**<25** ha), and less than 2% were large (**>200** ha). In light of the **difficulties** of comparing the vegetation of entire patches, we chose to consider the vegetation of study plots as the sampling unit of comparison for this study.

By limiting our study to closed-canopy, mesic, deciduous forest, we attempted to control for environmental characteristics that might **affect herb** populations. We defined mesic forest as a community located on a north-facing or sheltered slope with forest canopy dominants of more *than* one of the following species: *Liriodendron tulipifera*, *Acer saccharum*, *Tilia americana*, *Aesculus octandra*, *Carya cordiformis*, and *Betula lenta*. *Fagus grandifolia*, *Quercus rubra*, *Acer rubrum* were also often present. Extensive *stands* of *Rhododendron maximum* and *Tsuga canadensis* were avoided although small stands of both species were encountered. Only **closed-**canopy forests with trees **>50** cm dbh were sampled. **All** plots were in second growth forest that had been disturbed before 1945 by logging and/or agriculture. We found no evidence that

any of the plots had been cultivated, but woodland grazing has been a common **practice in this region** (Owsley 1949). A detailed history of disturbance **was** not available for these **patches**; nevertheless, we attempted to control for disturbance history in the plot selection process by choosing sites with minimal evidence of recent anthropogenic disturbances. To assess the recent **history (within 20 years)** of anthropogenic disturbance, land owners were interviewed and physical evidence of disturbance (e.g., fences, stumps, road beds) were noted for each plot. Plots that had experienced recent timber harvest or intensive woodland grazing were rejected. It was impossible to locate plots in small patches with no evidence of disturbance. Therefore, plots were selected in large patches that roughly matched the level of disturbance observed in small patches. That is, we did not compare plots in small patches with plots in large patches of forest that could be classified as old-growth with minimal human disturbance.

### *Field Sampling*

The diversity and abundance of vascular plants were measured for each study plot. Each study plot was divided into four 1-ha subplots (four subplots per plot  $\times$  14 plots = 56 subplots). For each plot, herb and shrub diversity and abundance were measured using 40 **0.5-m<sup>2</sup> quadrats**. The herb/shrub **quadrats** were located using a stratified random sampling design with each 1-ha subplot receiving 10 **quadrats (Figure 2)**. **Quadrats** were located at least 20 m from forest edges; however, our **ability** to avoid the forest edge was limited in small forest patches. **Only** a small fraction of a **5-ha** patch was **>100** m from an edge. In the herb/shrub quadrats, the number of emergent stems for each species was recorded along with a visual estimate of each species' percent coverage within the **quadrat**. Coverage was estimated for foliage up to two m above the ground **surface**. The number of stems per **quadrat** for each species was used as an estimate of **density**.

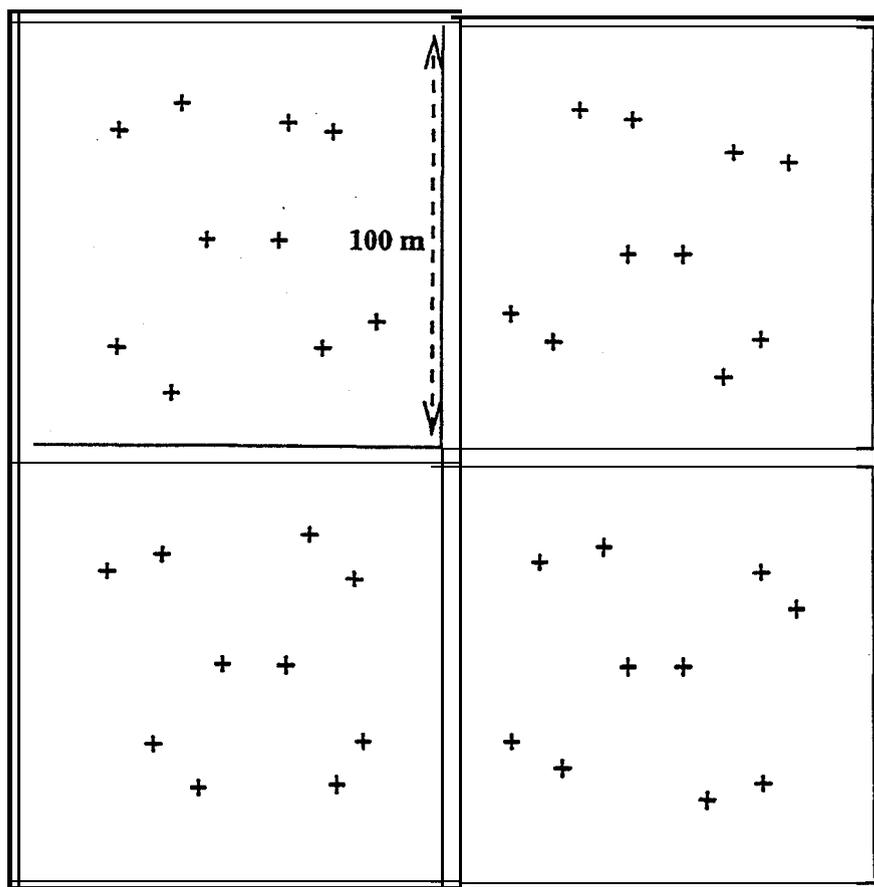
Soil samples were taken from each 1-ha subplot by collecting mineral soil to a depth of 15 cm. The soil was collected from a point adjacent to each of the 10 herb **quadrats** and combined to form a composite sample for the subplot. Samples were dried at **70°C** for 48 **hr** and mailed for testing to the Soil Testing Laboratory of the North Carolina Department of Agriculture, Agronomic Division. This laboratory measured aspects of soil chemistry, texture, nutrient availability, and organic matter relevant to agricultural and forestry uses (see Tucker 1996 for soil lab methods). Table 2 lists the 15 soil metrics analyzed for this investigation.

### *Data Analysis*

The soil **analyses** produced 15 measures of soil texture and chemistry for each 1-ha subplot. The covariance structure of these 15 **metrics** was **analyzed** using a factor analysis with a principal components solution and varimax rotation (**PROC FACTOR**, SAS 1989) in order to reduce the 15 soil metrics to five complex soil factors (Johnson and Wichern 1988). Based on the absolute value of the rotated factor loadings, specific soil metrics were associated with each factor. This data reduction effectively removed the covariance **structure** of the data set, producing **uncorrelated** factor scores. The factor scores for each subplot were used as independent variables to assess the effects of soil attributes on vegetation. A t-test for two samples with unequal variances was used **to** determine whether soils differed between plots located in large versus small patches (SAS 1989).

Seventeen herb species (Table 1) were selected as representative of cove-forest communities based on published descriptions of their habitat (e.g., Radford et al. 1968, **Weakley** 1995). For each species studied, the coverage and density estimates were summed for each 1-ha subplot to reduce the number of zero counts. Then, the coverage sums were **arcsin-square** root transformed and the **density** sums were square-root transformed to increase normality of the data (Sokal and **Rohlf** 1995). These values represent the coverage and abundance of herb species for each 1-ha subplot, the same scale as the soil measurements. Values for all 1-ha subplots (**N = 56**) were used in tests for the effects of soil chemistry on plants because soil chemistry often varied among subplots within a plot. However, to test for an effect of patch size, the values for the four 1-ha subplots for each plot were averaged (by calculating a mean) to obtain a single value that represented the plot for each species (i.e., **N = 14**). We also tested for the

## Study Plot



——— 4-ha study plot  
 ——— 1-ha subplot  
 + sample quadrat

Figure 2. The arrangement of plot, subplots and quadrats employed in the field sampling. Pairs of quadrats were randomly positioned in the center and four quadrants of each 1-ha subplot. Quadrats were at least 7 m apart.

effects of patch **size** and soils on the **total coverage** and **total density** of all seventeen species by summing the coverage and density values for all species **prior to** transformation. Both total coverage and total density were then square-root transformed.

The effect of patch **size** was tested by comparing the mean coverage and density of plots **from** small versus large patches for each species. A t-test for two samples with unequal variances was used (**PROC TTEST**, SAS 1989). To determine whether populations were more **variable** among large and small patches, **differences** in variance of coverage and density were tested using an F-test. For each series of tests, P-values were adjusted using a Bonferroni correction. To determine whether patch **size** affected the presence/absence of the selected species, a 2 X 2 contingency table was constructed for each species. The two factors in the contingency table were patch size (small or large) X population (present or absent) for each plot (**N = 14**). A Fisher exact test (**PROC FREQ**, SAS 1989) was used to test for a **significant** relationship between patch size and presence/absence.

Although the plot selection process controlled for general soil type, some fine-scale variation in soil chemistry was observed that may have affected species abundances. It was possible

**Table 1. Species chosen as characteristic of cove forests in southern Blue Ridge Mountains. Taxonomic nomenclature and authorities follow Kartesz (1994)**

Scientific Name	Common Name
<i>Adiantum pedatum</i> L.	Maidenhair fern
<i>Asarum canadense</i> L.	Wildginger
<i>Astilbe biternata</i> (Vent.) Britt.	False goatsbeard
<i>Botrychium virginianum</i> (L.) Sw.	Rattlesnake fern
<i>Cardamine diphylla</i> (Michx.) Wood	Toothwort
<i>Carex plantaginea</i> Lam.	Sedge
<i>Caulophyllum thalictroides</i> (L.) Michx.	Blue cohosh
<i>Cimicifuga racemosa</i> (L.) Nutt.	Black cohosh
<i>Disporum lanuginosum</i> (Michx.) Nichols.	Yellow mandarin
<i>Disporum maculatum</i> (Buckl.) Britt.	Spotted mandarin
<i>Sanguinaria canadensis</i> L.	Bloodroot
<i>Solidago flexicaulis</i> L.	Broad-leaved goldenrod
<i>Stellaria pubera</i> Michx.	Hairy chickweed
<i>Tiarella cordifolia</i> L.	Foam flower
<i>Trillium rugelii</i> Rendle	Southern nodding trillium
<i>Uvularia grandiflora</i> sm.	Bellwort
<i>Viola canadensis</i> L.	Canada violet

that some soil factors may have been correlated with patch size; therefore, we corrected the plant data for the effects of patch size before performing tests on the effects of soil factors. These corrections were accomplished by estimating a regression equation for the effects of patch size on measures of coverage and density for each plant species using a general linear model (PROC GLM, SAS 1989). The residuals from this regression represent variation in plant coverage and density, corrected for the effects of patch size. These residuals were then tested for the main effects of the five soil factors (see Table 2) using analysis of variance (PROC GLM, SAS 1989). Hypothesis tests were performed using the type III sums of squares (SAS 1989).

**Table 2. Rotated factor pattern for the soil metrics. Factor loadings shown in bold indicate the associations between soil metrics and factors**

Descriptive Label Soil Metric	pH-Cations Factor 1	Zn-Na Factor 2	C-Cu Factor 3	Mn-S Factor 4	Mg Factor 5
Humic Matter	-0.1062	0.0917	0.8747	0.0670	-0.2919
Weight : Volume	-0.0126	-0.1320	-0.2164	-0.7641	0.0991
Cation Exchange Capacity	0.534	0.3205	0.0323	0.0740	-0.1746
Base Saturation	0.9508	0.1004	-0.0330	0.0272	0.1123
Acidity	-0.7781	0.0938	0.2020	0.0622	-0.2266
pH	0.9580	0.1180	0.0598	0.0286	0.0344
P	0.4380	0.1414	-0.5843	-0.2232	-0.4491
K	0.6811	0.1156	-0.3343	0.0568	0.1435
Ca	0.9347	0.1562	0.0179	0.0439	-0.1872
Mg	0.0889	-0.9806	-0.0642	-0.0283	0.9297
Mn	0.3260	0.0641	0.1433	0.7215	0.2663
Zn	0.0793	0.9113	-0.0114	0.2613	-0.1189
cu	0.0263	0.0468	0.9050	0.1912	0.1483
S	-0.5369	0.1894	-0.0616	0.6323	-0.1843
Na	0.2490	0.6638	0.1185	-0.1887	0.0924
Percent variance explained	39.9	18.2	16.7	13.7	11.4

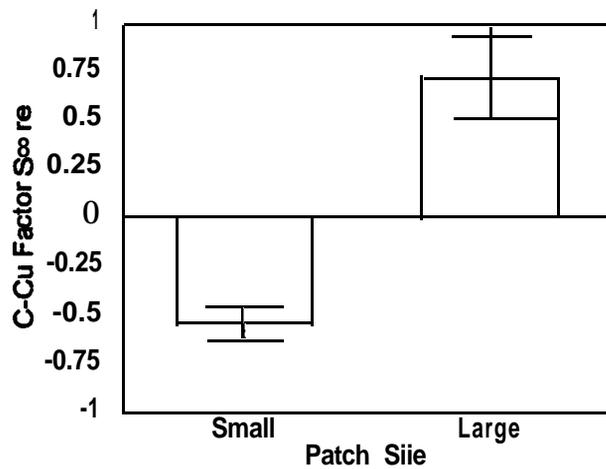


Figure 3. Soil **organic** matter is positively related to **patch** size. Mean and standard error of the C-Cu factor scores are plotted.

## RESULTS

### *Soil Metrics*

The factor analysis reduced the soil metrics to five soil factors (Table 2). The **first** factor (**pH-cations**) described variation in soil **pH** and the abundance of cations and anions. This factor accounted for most of the variation in the soil data and was negatively related to soil acidity. Factor 2 (**Zn-Na**) reflected the availability of **zinc** and sodium. Factor 3 (**C-Cu**) described the amount of **humic** matter (interpreted as stored carbon) and availability of copper. Factor 4 (**Mn-S**) reflected the availability of manganese and sulfur, and factor 5 (**Mg**) described the availability of magnesium. Hereafter, these soil factors will be referred to by the descriptive labels listed in Table 2.

A t-test revealed that only the C-Cu soil factor was **significantly** correlated with patch size ( $T = 5.99$ ,  $d.f. = 34$ ,  $P < 0.001$ ). The C-Cu **factor** scores for large patches were **significantly** greater than the score for small patches (Figure 3). There were no significant differences due to patch **size** in the other soil **factors** (all  $T < 1.6$ ,  $P > 0.13$ ).

### *Cove-forest Herbs*

Larger patches of forest tended to have a greater coverage and greater density of **cove-forest** herbs than small patches (Table 3). Eight of the 17 species were more abundant in plots in large patches. One species, *Stellaria pubera*, was more abundant in plots in small patches. In general, trends in percent coverage were matched by trends in plant density. Plots with higher coverage for a particular species tended to have greater density of individuals of that species. Three of the four **liliaceous** species (*Disporum lanuginosum*, *Disporum maculatum*, and *Uvularia grandiflora*) were less abundant in small patches; *Trillium rugelii* was the exception. *Trillium rugelii* tended to be more abundant in the large patches, but the trend was not statistically significant. There were no individuals of *D. maculatum* and *U. grandiflora* found in the small patches. *Stellaria pubera* was more abundant in small patches. *Caulophyllum thalictroides* tended to have greater coverage and density in large patches (Table 4); however, this species had a patchy distribution resulting in a great deal of variability among samples.

Patch **size** also **affected** the variance in species' **density** among patches. At the 4ha scale, **variances in coverage** and density estimates for *Adiantum pedatum*, *Botrychium virginianum*, *Carex plantaginea*, *Stellaria pubera*, and *Solidago flexicaulis* were greater for plots located in small patches than for plots in large patches (Table 4; F-test, all  $P < 0.05$ ). For species that were more abundant in large patches, variances in coverage and density tended to be greater for patch sizes with the greater mean (Tables 3, 4).

Patch **size** affected the probability that a given species occurred in a study plot (Table 5). *Asarum canadense*, *Astilbe biternata*, *C. thalictroides*, *Cardamine diphylla*, *D. maculatum*, and

**Table 3.** Effects of patch size and soil factors on the mean coverage and density of cove-forest species. Empty cells indicate that effects were not significant. A sign indicates the direction of effect and significance at the P < 0.05 level

Species	Coverage						Density					
	Patch Size	pH, Cations	Zn, Na	C, Cu	Mn, S	Mg	Patch She	pH, Cations	Zn, Na	C, Cu	Mn, S	Mg
<i>Adiantum pedatum</i>												
<i>Asarum canadense</i>	+	+					+	+				
<i>Astilbe biternata</i>	+		+	+			+		+	+		
<i>Botrychium virginianum</i>					+	+					+	+
<i>Cardamine diphylla</i>	+						+			+		
<i>Carex plantaginea</i>												
<i>Caulophyllum thalictroides</i>				+						+		
<i>Cimicifuga racemosa</i>		+	+	+				+	+			
<i>Disporum lanuginosum</i>	+			+			+			+		
<i>Disporum maculatum</i>	+			+			+			+		
<i>Sanguinaria canadensis</i>	+	+		+			+	+		+		
<i>Solidago flexicaulis</i>												
<i>Stellaria pubera</i>				+						+	+	
<i>Tiarella cordifolia</i>	+			+			+			+		
<i>Trillium rugelii</i>				+						+		
<i>Uvularia grandiflora</i>	+			+			+			+		
<i>Viola canadensis</i>				+						+		
Total (Sum of individual species)	+	+		+	-		+	+				

**Table 4.** Mean and standard error (SE) of coverage and density by patch size measured at 1-ha scale. Coverage was arcsine-square root transformed, and density was square-root transformed. Units are the summed percent coverage and density for ten 0.5 m<sup>2</sup> quadrats in a 1-ha plot. See Table 3 for effects of patch size on means

Species	Patch Size	Coverage (Mean ± SE)		Density (Mean ± SE)		Variance Test <sup>1</sup>
		small	Large	Small	Large	
<i>Adiantum pedatum</i>		0.20 ± 0.06	0.08 ± 0.02	3.36 ± 0.95	1.42 ± 0.40	S
<i>Asarum canadense</i>		0.04 ± 0.02	0.21 ± 0.07	0.63 ± 0.35	3.25 ± 1.06	L
<i>Astilbe biternata</i>		0.01 ± 0.01	0.17 ± 0.04	0.18 ± 0.11	6.42 ± 1.36	L
<i>Botrychium virginianum</i>		0.18 ± 0.04	0.11 ± 0.03	2.02 ± 0.50	1.58 ± 0.52	S
<i>Cardamine diphylla</i>		0.01 ± 0.01	0.10 ± 0.04	0.04 ± 0.04	0.89 ± 0.34	L
<i>Carex plantaginea</i>		0.04 ± 0.02	0.03 ± 0.01	0.71 ± 0.36	0.64 ± 0.26	S
<i>Caulophyllum thalictroides</i>		0.08 ± 0.07	0.19 ± 0.07	0.63 ± 0.48	1.82 ± 0.64	-
<i>Cimicifuga racemosa</i>		0.20 ± 0.04	0.19 ± 0.05	6.92 ± 1.53	6.46 ± 1.48	-
<i>Disporum lanuginosum</i>		0.03 ± 0.01	0.20 ± 0.06	0.89 ± 0.43	4.41 ± 1.29	L
<i>Disporum maculatum</i>		0.00 ± 0.00	0.08 ± 0.04	0.00 ± 0.00	0.79 ± 0.40	na
<i>Sanguinaria canadensis</i>		0.09 ± 0.03	0.57 ± 0.12	1.20 ± 0.40	7.81 ± 1.76	L
<i>Solidago flexicaulis</i>		0.16 ± 0.09	0.08 ± 0.05	2.11 ± 1.12	1.24 ± 0.76	S
<i>Stellaria pubera</i>		0.36 ± 0.07	0.08 ± 0.02	3.46 ± 0.67	1.06 ± 0.27	S
<i>Tiarella cordifolia</i>		0.02 ± 0.01	0.24 ± 0.08	0.19 ± 0.11	2.71 ± 0.88	L
<i>Trillium rugelii</i>		0.19 ± 0.07	0.30 ± 0.11	1.89 ± 0.71	2.90 ± 1.02	-
<i>Uvularia grandiflora</i>		0.00 ± 0.00	0.06 ± 0.02	0.00 ± 0.00	1.10 ± 0.48	na
<i>Viola canadensis</i>		0.09 ± 0.05	0.24 ± 0.05	0.88 ± 0.49	2.65 ± 0.60	-
Total		17.8 ± 2.38	30.71 ± 2.46	18.33 ± 2.51	31.66 ± 2.53	-

<sup>1</sup> The last column shows the results of an F-test (significant at P < 0.05) to determine whether patch size had a significant effect on variance in coverage and density. The results for coverage and density variances were similar. The symbols mean: S, small patches have significantly greater variance; L, large patches have greater variance; -, no significant difference; na, not applicable because mean and variance equal zero for small patches.

**Table 5.** Proportion of plots supporting extant populations of cove-forest species. The influence of patch size on the frequency of extant populations was tested with a contingency table analysis. Significance values (P) are reported for a Fisher exact test

Species	Patch Size		P <sup>1</sup>
	Small	Large	
<i>Adiantum pedatum</i>	0.62,	0.50	ns
<i>Asarum canadense</i>	0.25	0.83	0.05
<i>Astilbe biternata</i>	0.38	1.00	0.03
<i>Botrychium virginianum</i>	1.00	0.83	ns
<i>Cardamine diphylla</i>	0.12	0.67	0.06
<i>Carex plantaginea</i>	0.38	0.50	ns
<i>Caulophyllum thalictroides</i>	0.12	0.83	0.01
<i>Cimicifuga racemosa</i>	0.75	0.83	ns
<i>Disporum lanuginosum</i>	0.38	0.67	ns
<i>Disporum maculatum</i>	0.00	0.67	0.01
<i>Sanguinaria canadensis</i>	0.62	0.67	ns
<i>Solidago flexicaulis</i>	0.38	0.33	ns
<i>Stellaria pubera</i>	0.88	0.83	ns
<i>Tiarella cordifolia</i>	0.38	0.83	ns
<i>Trillium rugelii</i>	0.38	0.67	ns
<i>Uvularia grandiflora</i>	0.00	0.67	0.01
<i>Viola canadensis</i>	0.38	0.83	ns

<sup>1</sup> ns = not significant; P > 0.10.

*U. grandiflora* were all more likely to be present in large patches than in **small patches**. *Disporum lanuginosum*, *Tiarella cordifolia*, *T. rugelii*, and *Viola canadensis* tended to be **more frequent** in large patches, but these trends were not statistically **significant** (Table 5). No **species** were more likely to be found in small patches than in large patches. Although *S. pubera* was more abundant in **small patches**, it was equally likely to be found in plots in both **patch sizes**. Note that the same number and arrangements of **quadrats** were employed for plots in both small and large patches of forest. Therefore, these results were not due differences in sampling effort.

The relationships between soil factors and species coverage and density were mixed. The C-Cu factor **affected** 11 of 17 individual species and the total coverage of all cove-forest herbs (Table 3). All these species were more abundant at plots having greater amounts of soil **humic matter**. Soil **pH-cations** were positively associated **with** *A. canadense*, *C. racemosa*, *Sanguinaria canadensis*, and the total coverage and density of cove-forest herbs. The availability of Zn-Na was positively correlated **with** *A. biternata*, *C. mcemosa*, and *S. canadensis*. Both the availability of **Mn-S** and Mg was positively related to populations of *B. virginianum*. In contrast, **Mn-S** was negatively correlated to *C. plantaginea*, *C. racemosa*, *S. canadensis*, and the total coverage of all species. Thus, most species were positively related to higher levels of soil humic matter and nutrients with the exception of *C. racemosa*. This species showed a positive correlation with **pH** and Zn-Na, a negative response to **Mn-S**. At plots with more C-Cu, it had greater coverage but no differences in density.

## DISCUSSION

Cove-forest herbs were, in general, more abundant in larger patches of **mesic** forest. The reduction in coverage and density of these species could have been produced by several mechanisms. The following mechanisms might explain this **pattern**: (a) effect of habitat **fragmentation** on population dynamics, (b) habitat **differences** influenced by patch size, and (c) differences in the past disturbance regime among patch sizes.

### *Habitat Fragmentation and Population Dynamics*

Small patches harbored smaller populations of herbs that were demographically isolated from other populations; therefore, herb populations in small patches may have experienced higher probabilities of local extinction. Small populations **suffer** higher rates of extinction for many species (e.g., Berger 1990, Dennis et al. 1991), and the geographic isolation inhibits the arrival of propagules from other populations that could rescue a given population from extinction (Brown and Kodric-Brown 1977, Kadmon and Pulliam 1993). In this study, presence/absence data shows that several species were more likely to be present in larger patches (Table 5). Of these species, *A. canadense*, *A. biternata*, *D. maculatum*, *U. grandiflora*, *T. cordifolia* and *V. canadensis* have limited dispersal capabilities that may prevent them **from** reaching some isolated patches. For example, *A. biternata* and *T. cordifolia* produce numerous small seeds that fall a short distance **from** the parent plant while *A. canadense*, *D. maculatum*, *U. grandiflora*, *T. cordifolia* and *V. canadensis* are dispersed by ants (Beattie and Culver 1982, Smith et al. 1989). Moreover, species that disperse well were not **affected** by patch size. These species included the ferns, *A. pedatum* and *B. virginianum*, and the composite, *Solidago flexicaulis*; which are wind dispersed and should be able to recolonize isolated patches. Matlack (1994a) found that disjunct stands of successional forest had reduced numbers and abundances of forest herbs. Moreover, the probability of recolonization and migration rate by herb species was negatively related to distance to a source population and positively related to seed dispersal ability. Thus, dispersal-limited species may be more likely to go extinct in small, isolated forest patches.

### *Habitat Differences*

Small patches may have different physical habitats than large patches thereby affecting the occurrence and abundance of herb species. The analysis of soil measurements indicated that both patch sizes were similar with respect to the availability of soil nutrients, with the exception of soil humic matter and copper. The plot selection process also ensured that habitat

factors such as **overstory condition**, geological parent material, and topography were **similar** between patch sizes. We did not directly measure microclimatic variation in air temperature and water availability. These habitat parameters can be affected by patch size and could be important to the germination, growth, and survival of these species. Small patches are **likely** to experience **strong** "edge effects" due to their high perimeter-to-area ratio (Saunders et al. 1991). In the eastern United States, **microclimatic** parameters, such as temperature, litter **moisture**, humidity, and light, show that edge effects may extend at least 50 m from the edge into the forest interior although these effects are moderated on north-facing slopes (**Matlack** 1993). Populations of forest herbs may be correlated with distance to edge (**Matlack** 1994b). While we avoided sampling the immediate edge of **these** forest patches, effects that extended **>100** m from the forest edge would **have** affected all regions within a small patch. Such alterations of the forest microclimate may have reduced **habitat suitability** for species adapted to **mesic**, forest-interior conditions.

**Our** data show that soil humic matter, as measured by soil factor C-Cu, was positively correlated with patch size (Figure **3**), and humic matter affected the coverage and density of many species. **Humic** matter was the only habitat characteristic measured that varied between patch sizes, but it was also the factor most strongly related to species abundances. Soils with increased organic matter tend to have increased water retention, improved aeration and tilth, and have enhanced supplies of plant nutrients (Coleman and Crossley 1996). The organic **matter** also supports the growth of **decomposers** and symbiotic microbes which supply nutrients to growing plants and may even provide protection **from** pathogens (e.g., Chanway et al. 1991). Thus, if the ecology and history of a small patch influences the organic matter of its soils, that patch's ability to support populations of forest herbs will likewise be affected.

### **Disturbance**

The disturbance regimes of small patches may have been different **from** large patches. **Anthropogenic** disturbance can **affect** herb populations by directly **killing** individuals and degrading habitat (Meier et al. 1995). Catastrophic disturbances such as clearcutting may extirpate a population or dramatically reduce coverage and abundances. Recovery after an intense disturbance may take a long time (**Duffy** and Meier 1992). Long-term, chronic disturbances, such as grazing, may interfere directly with the reproduction and survival of herb species (**Lubbers** and **Lechowicz** 1989, Anderson 1994, **McIntyre** et al. 1995).

Despite our efforts to control for disturbance history, the correlation between soil humic matter and patch size suggests that small patches have been disturbed more frequently and/or more intensely in the past. Land uses such as grazing and logging can result in the loss of stored C in soils and can promote erosion (e.g., Black and Harden 1995). All of the plots studied had been logged during the early part of the century and were second growth timber. Timber management can affect the diversity and abundance of forest herbs (Meier et al. 1995), and the diversity **of** the herb layer is connected to the diversity and condition of the overstory (**Gilliam** et al. 1995). A full recovery of the herb community depends on the development of ecosystem characteristics associated with old, mature forests (**Halpern** and Spies 1995).

Agricultural uses of forests could be an important source of anthropogenic disturbance. There is no evidence that any of our study plots had been cultivated during the last 75 years. However, small patches were often adjacent to land presently or formerly in agricultural use. A **woodlot** on the property of a farm family is more likely to have been used for grazing and for a source of forest products than a plot nested within a larger landscape **dominated** by forest. **Woodlots** were often burned, either intentionally or accidentally, for a variety of reasons. We frequently observed the remnants of barbed wire fences in the small patches, and a number of potential study plots in the landscape were rejected because they were being actively grazed or the landowner informed us that the **woodlot** had been used for grazing within the past two decades. There are several ways grazing could reduce soil C. Soil is disturbed by cattle walking on slopes, resulting in losses of organic matter due to erosion and enhanced decay. Livestock also actively crop and browse living biomass thereby intercepting organic matter that would normally end up in the soil. Cattle regularly graze on herbs, particularly liliaceous species.

Therefore, it is plausible that these small patches have experienced more **anthropogenic disturbance**.

Disturbance can interact with habitat **fragmentation** to decimate or reduce populations. Once a disturbance destroys a population in a isolated patch, opportunities for recolonization would be reduced due to patch isolation for species with limited dispersal capabilities. Disturbances that degrade habitat may convert patches from **self-sustaining** source populations to sink populations in which local reproduction does not keep up with mortality (Pulliam 1988). Then, patch isolation would **interfere** with immigration necessary to maintain sink populations. Many of the species studied here are long-lived, and the demise of a sink population might take decades. Thus, there may be more than one **mechanism affecting** the herb communities in these forest patches. It is likely that some interaction between habitat fragmentation, habitat quality, **and anthropogenic** disturbance was responsible for the patterns observed in these data.

### *Soil Factors and Vegetation*

Of the soil characteristics studied, soil **C-Cu** had the greatest impact on these herb species. In our data, the **pH-cations** factor was positively correlated with the coverage and **density** of several species and the total coverage and density of all species combined (Table 3). This factor serves as a good indicator of the overall site fertility. Two species, *C. thalictroides* and *S. canadensis*, were correlated with several soil **factors** suggesting that these species respond to differences in nutrient availability measured at the 1-ha scale. Soil **pH-cations** has been identified as an important factor in other studies of plant communities in **this** region. McLeod (1933) demonstrated that **pH** and soil nutrients were associated with gradients in moisture and elevation that **affect** the geographic location of community types in the Black and Craggy Mountains in the southern Blue Ridge. **Other** authors (e.g., Cole and Ware 1997) have shown the **effect** of edaphic factors on successional dynamics and climax vegetation. Most studies analyze data taken **from** a wide range of **community** types or from across physiographic regions. However, this study, by selecting plots according to criteria designed to control for edaphic variation, collected data **from** a very restricted range of natural variation. Therefore, the effects of soil nutrients on the herbs we studied were not consistently important between species. The soil sampling technique used for this study provides a estimate of the average soil conditions at the scale of 1 ha. Thus, this sampling was appropriate for testing for an effect of patch size. However, this spatial resolution may have been too coarse to capture variation in soils relevant to herb populations with variations. at finer spatial scales (Palmer 1991). Sampling at the scale of **0.05–0.10** ha would be more appropriate for discovering **finer** scale relationships.

### *Conclusion*

These data show that forest patch size is correlated with populations of cove-forest herbs in the French Broad **River** basin. These herb species had lower density and coverages in small patches of mesic forest as compared to large patches. **Of** the soil **characteristics** tested, **humic** matter was positively correlated with the abundance of most species and with patch size. These soil results suggest that small patches may have been more disturbed than large patches of forest. The land use **history** of this landscape is complex. **Present-day** communities are likely **affected** by the current and historical patterns of habitat **availability** and habitat **quality**. We hypothesize that past disturbances could have affected herb populations directly by increasing mortality rates and by **degrading** habitat. Moreover, these habitat changes could have been confounded by the small size and isolation of small forest patches. Land uses have **affected** the spatial pattern and **quality** of habitats in the French Broad **River** Basin. Patterns of forest **fragmentation** and the land use history of forest patches have likely **affected** the abundance and community composition of cove-forest herbs inhabiting patches of mesic forest in this landscape.

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