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Understory vegetation indicators of anthropogenic disturbance in longleaf pine forests at Fort Benning, Georgia, USA

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Abstract

Environmental indicators for longleaf pine (*Pinus palustris*) ecosystems need to include some measure of understory vegetation because of its responsiveness to disturbance and management practices. To examine the characteristics of understory species that distinguish between disturbances induced by military traffic, we randomly established transects in four training intensity categories (reference, light, moderate, and heavy) and in an area that had been remediated following intense disturbance at Fort Benning, GA. A total of 134 plant species occurred in these transects with the highest diversity (95 species) in light training areas and the lowest (16 species) in heavily disturbed plots. Forty-seven species were observed in only one of the five disturbance categories. The variability in understory vegetation cover among disturbance types was trimodal ranging from less than 5% cover for heavily disturbed areas to 67% cover for reference, light, and remediated areas. High variability in species diversity and lack of difference in understory cover led us to consider life-form and plant families as indicators of military disturbance. Life-form successfully distinguished between plots based on military disturbances. Species that are Phanerophytes (trees and shrubs) were the most frequent life-form encountered in sites that experienced light infantry training. Therophytes (annuals) were the least common life-form in reference and light training areas. Chamaephytes (plants with their buds slightly above ground) were the least frequent life-form in moderate and remediation sites. Heavy training sites supported no Chamaephytes or Hemicryptophytes (plants with dormant buds at ground level). The heavy, moderate, remediated, and reference sites were all dominated by Cryptophytes (plants with underground buds) possibly because of their ability to withstand both military disturbance and ground fires (the natural disturbance of longleaf pine forests). Analysis of soils collected from each transect revealed that depth of the A layer of soil was significantly higher in reference and light training areas which may explain the life-form distributions. In addition, the diversity of plant families and, in particular, the presence of grasses and composites were indicative of training and remediation history. These results are supported by prior analysis of life-form distribution subsequent to other disturbances and demonstrate the ability of life-form and plant families to distinguish between military disturbances in longleaf pine forests.

Keywords: Longleaf pine; Indicators; Life-form; Disturbance; Family diversity

1. Introduction

Resource managers need a basic understanding of potential effects of human activity on ecological conditions. Human activity may influence a variety

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of ecological attributes including the presence of species, populations, and communities as well as the occurrence, rate, or scale of processes (Angermeier and Karr, 1994). Understanding the implications of anthropogenic disturbances on an ecological system is complicated by variability in ecological response. Identification of indicators which capture key ecological responses to human actions provides a useful tool for improving understanding of ecological effects and for monitoring and management.

Longleaf pine (*Pinus palustris*) forests are a system in which understanding effects of anthropogenic activity is necessary for resource management. Forests of the southeastern United States comprise a landscape that has experienced significant anthropogenic activity in the form of land development, resource utilization, and changes to the natural disturbance regimes. Anthropogenic activity within a landscape is typically expressed as a complex gradient of altered ecological components and changes in natural disturbance dynamics and succession patterns (Guntenspergen and Levenson, 1997). Prior to European settlement, longleaf pine forests covered 25–35 million hectares (ha) of the southeastern Coastal Plain landscape (Frost, 1993). By the 1900s, less than 10% of the original stands remained (Frost, 1993). Today only two million hectares of the pre-settlement forest endures (Quicke et al., 1994). The loss and degradation of the longleaf pine forest is mainly attributed to land-use change, timber harvest, and fire suppression (Haywood et al., 1998; Gilliam and Platt, 1999). Since the longleaf pine forests are a fire-adapted system, it is the absence of regular light ground fires that is a disturbance to these forests. Fires reduce the growth of hardwoods into the overstory.

The need for a clear understanding of human impacts on longleaf pine forests takes on even greater importance when considering the fact that much of the remaining longleaf pine forest supports not only critical ecological processes but also a multitude of ecosystem services (Noss, 1989). For example, the federally endangered red-cockaded woodpecker (*Picoides borealis*) is a nonmigratory bird endemic to the longleaf pine forests in the southeastern United States. A prime cause of decline in red-cockaded woodpecker populations is the loss and degradation of longleaf pine forests. Reduction of the woodpecker population would also induce decline of the 23 species that inhabit holes in living trees uniquely created by these birds (Dennis, 1971).

One way to maintain the diverse ecological services of the longleaf pine forests entails reducing the amount of hardwood in-growth that, at first, compromises the understory and, eventually, alters overstory composition. As the hardwood trees grow into the canopy, the red-cockaded woodpeckers and other species unique to these forests tend to abandon the stands (Noss, 1989). Thus, the status of the understory composition and structure is a critical indicator of future condition of the longleaf pine forest (James et al., 2001). Unfortunately, the attributes and dynamics of this forest layer are not well-known, particularly for those systems that do not support the wire grass (*Aristida stricta* Michx.) community typical of the understory of some longleaf pine forests (Noss, 1989). Although an understanding of the cause and effect relationships of human modifications and alterations of longleaf pine systems is developing (Platt et al., 1988a,b; Frost, 1993; McCay, 2000), much still remains to be learned about human impacts on the understory in order to predict how human activities affect the ecological system.

Approximately, 75% of the longleaf forest is in private ownership serving a diversity of purposes including recreation and resource extraction. The remaining land is public. Almost without exception, the larger patches of longleaf pine forest are under federal ownership, a significant portion of which is on Department of Defense (DoD) lands (Walker, 1999). These large patches of intact forest best represent the ecological condition of the longleaf pine forest and tend to support the highest number of native species (Noss, 1989).

The longleaf pine stands on military installations are not only important forest reserves; they also provide suitable terrain for military training. In order to continue to meet the joint but seemingly incongruous needs of habitat reserves and military training, a means to monitor impacts of training should be developed and implemented. A critical challenge is to construct management procedures based on cost-effective monitoring plans that allow multiple land-use activities to take place while at the same time maintaining the ecological services of natural resources for the majority of the installation. There is a need on most military lands for the designation of sacrifice areas where training activities involving tracked vehicles and range practices must take place at the expense of ecological integrity. However, some attempts are made to minimize impacts through soil conservation measures. In contrast, dismounted training that also occurs on the installation appears to have minimal immediate impact on the forest stands. Differences subsequent to military foot traffic occur in soil infiltration rates, erosion, above ground biomass, and litter (Whitecotton et al., 2000). Yet, effects of foot traffic on the understory vegetation and over the long-term are not well-known.

Our perspective is that a suite of indicators ranging from microbiologic to landscape metrics is necessary to capture the full spatial, temporal, and ecological complexity of impacts that should be measured. Potential indicators should be considered in a spatially hierarchical fashion and for all gradients deemed important at a site. Placing potential indicators on a spatial axis (e.g. Fig. 1) provides a means to ensure that information is considered across spatial scales. Alternatively, it is important to include indicators that encompass the diversity of responses over time (so that one is not just measuring short-term responses of the system). In a similar fashion, as depicted in this figure, all major gradients should be included in the analysis of potential indicators. Thus, it is useful to consider the representativeness of indices across major physical gradients (e.g. soils, geology, land-use) and across gradients in disturbance regimes.

This study is part of a larger project designed to investigate indicators that would be useful to augment current sampling regimes at military bases and typical of other actively managed sites. Current ecological monitoring on military lands, the land condition trend analysis (LCTA) (Diersing et al., 1992), does not incorporate the diversity of indicators that are necessary for monitoring changes and responses to land as shown in Fig. 1. We hypothesized that understory conditions are a key element in the suite of indicators that can reflect differences in military training intensity. While some of the indicators from the proposed suite are designed to measure changes that occur over the long-term, understory vegetation is the element representing ecological changes that may occur over a few years to decades. Before such a suite can be adopted, it is necessary to evaluate how effectively the component indicators represent changes and susceptibility of ecological systems to military training. The purpose of this paper is to examine the ability of understory vegetation to indicate differences in disturbance regimes.

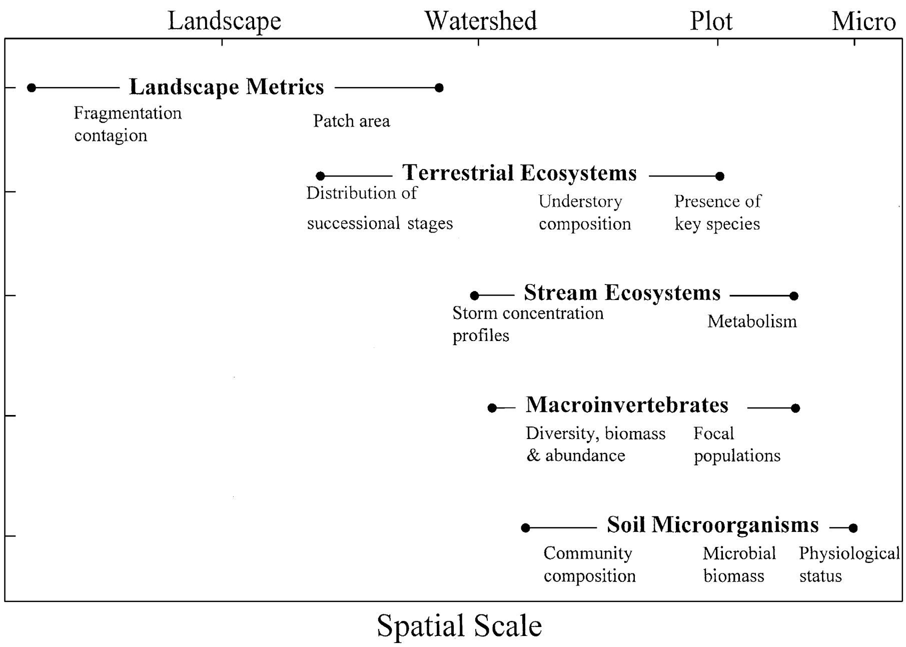

Fig. 1. Spatial hierarchical overlap of a suite of ecological indicators for Fort Benning, GA.

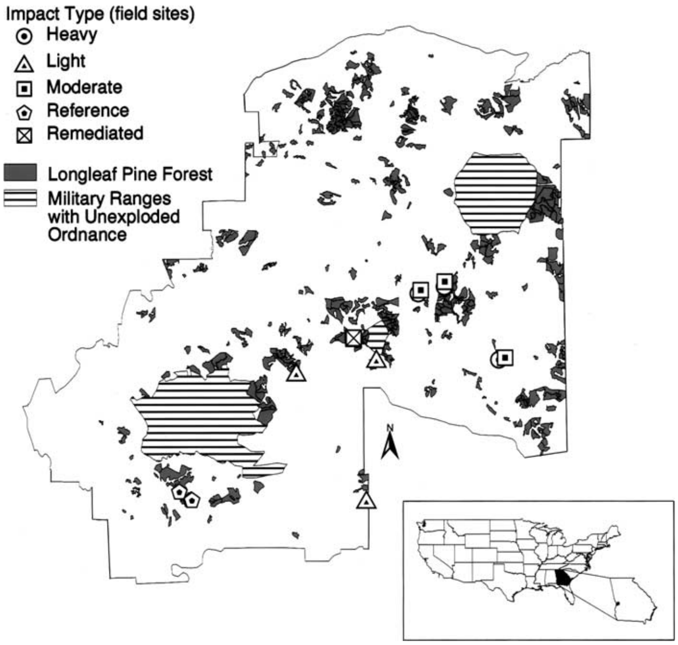

Fig. 2. Map of Fort Benning showing the location of field sites in relation to longleaf pine forest and military ranges that contain unexploded ordnance. Not that several sites are so close that the symbols overlap. The inset depicts the location of Fort Benning in western Georgia and Georgia in the southeastern United States.

2. Study site

The study was conducted at the Fort Benning Army Installation which occupies 73,503 ha in Chattahoochee, Muscogee, and Marion Counties of Georgia and Russell County of Alabama (Fig. 2). The climate at Fort Benning is humid and mild with rainfall occurring regularly throughout the year. The warmest months are July and August with average daily maximum and minimum temperatures of 37 and 15 °C, respectively. The coldest months are January and February with an average daily maximum and minimum temperature of 15.5 and −1 °C, respectively. Annual precipitation averages 105 cm with October being the driest month.

Fort Benning is located within the southern Appalachian Piedmont and Coastal Plains and is considered part of the southeastern Mixed Forest Province of the subtropical division (Bailey, 1995). The northern boundary of the installation lies along a transition zone between the Piedmont and Upper Coastal Plain. The installation is comprised of five major geologic formations: undifferentiated alluvium and mixed terrace deposits; Cusseta formation, which is mostly micaceous sand; Bluffton formation, a layered micaceous sand; Tuscaloosa formation; and the Eutaw formation (Roemer et al., 1994). The soils are constituted of a combination of clay beds and weathered Coastal Plain material as well as alluvial deposits from the Piedmont. Eight soil associations form the majority of the soil on the installation. Lakeland–Troup, Orangeburg–Dothan–Ailey, and Raanoke–leaf soil associations occupy the higher elevations. Bibb–Chewacla–Rains, Ochloknee–Toccoa, Augusta–Ocholocknee, and Susquehanna–Duplin–Esto are located on the alluvial flood plains and terraces. Undifferentiated rough gullied land occurs in the southeast portion of the installation (Elliot et al., 1995).

Historically, the land was cleared and actively farmed first by native American and later by European settlers (Kane and Keeton, 1998). Fort Benning was established in 1918, and all farming stopped as landowners were relocated (which occurred up to 1945). Military training ensued for the following eight decades with heavy training land impacts occurring only in selected portions of the installation. Some timber harvesting and thinning continued, and the longleaf pine forests were subjected to regular low level fires for management purposes (Jack Greeley, personnel communication 1999, Fort Benning, GA).

Fort Benning contains several unique environmental features probably because the Fort Benning army installation was protected from farming and urban development which occupies much of the surrounding region. The presence of the federally-listed red-cockaded woodpecker is one reason why this study focused on the longleaf pine ecosystem. However, there are other rare species and habitats at Fort Benning, including the gopher tortoise (*Gopherus polyphemus*) and relict trillium (*Trillium reliquum*). Minimizing conflicts between the rare species and military land-use is a key goal of land management activities at the installation.

The presence of natural vegetation enables realistic training scenarios involving cover, concealment, or line-of-sight firing constraints. In order that Fort Benning can meet its mission needs now and into the future, the natural resources that provide the training context must be managed such that they are ecologically sustainable. With appropriate measurements and management, the retention of the training mission will also protect rare habitats and species at Fort Benning and other military installations.

The installation is a center for both dismounted and mechanized training, and, therefore, land-use focuses on military training (Waring et al., 1990). Maneuver areas are subject to a range of training activities such as dismounted infantry, mechanized forces, munitions detonation, biovac sites, landing strips and pads, and drop zones for airborne training (USAIC, 2001). Impacts of maneuver training activities on natural resources vary from direct removal or damage of vegetation, digging activities, ground disturbance from vehicles, soil compaction, soil erosion, and sedimentation. The degree and extent of the impacts of training activities depend on the type of training activity, time of year, intensity (e.g. the number of solders or vehicles per area per unit time), and how frequently the area is exposed to training activity. Further, different types of training typically occur irregularly over the landscape, and in many cases overlap, creating localized gradients of impacts. This study was limited to maneuver training areas and, thus, does not include firing ranges, ordinance impact areas, or cantonment areas. Our goal was to develop valid and repeatable measures of impacts of training on understory of longleaf pine forests.

3. Experimental design

Study site locations were on land suitable for longleaf pine growth. Determination of potential site locations was achieved through a combination of existing forest stand information (Bob Larimore, personal communication, 1999, Fort Benning, GA) and county soil surveys of the United States Department of Agriculture Natural Resource Conservation Service (USDA NRCS, 1924, 1983, 1993, 1997). We overlaid an image of the United States Forest Service forest stand classification onto USDA NRCS soil maps for the area of land within the Fort Benning boundary. A final map was then created depicting locations of soils associated with longleaf pine within the installation boundary, and study sites were selected from those areas. Longleaf pine stands currently comprise approximately 5800 ha of the total area of Fort Benning (USAIC, 2001). Soils favorable to the establishment and growth of longleaf pine make up approximately 65,900 ha (about 90% of the total area).

The study was designed using a stratified sampling methodology. The sampling sites were blocked into five training intensity categories: reference, light, moderate, heavy, and remediation. Reference areas experience little to no training activities and are often in exclusion zones around firing ranges. Light impact areas are limited to dismounted training and individual orienteering activities. Moderate impact areas occur adjacent to tank training zones and are, thus, exposed to some tracked vehicle maneuvers, as well as limited vehicle and infantry traffic. Heavy impact areas are used exclusively for wheeled and tracked vehicle training exercises. The classification of each site was primarily based on historical records of training activity; however, due to the variability of training intensity over space, final site selection was achieved through field reconnaissance and discussions with the Fort Benning natural resource personnel.

The remediation area is located in the uplands of the McKenna Drop Zone that was cleared in 1988 and subsequently rehabilitated (but was not used for training). It is currently off-limits to military training and testing. Revegetation efforts involved liming, fertilizing, and seeding with mixtures of grasses and legumes selected to increase vegetative cover and reduce run-off rates [e.g. giant reed (*Arundo donax*), bermuda grass (*Cynodon dactylon*), little bluestem (*Adropogon scoparius*), maidencain (*Panicum hemitomom*), pensacola bahiagrass (*Paspalum notatum*), alamo switchgrass (*Panicum virgatum*), weeping lovegrass (*Eragrostis curvula*), lespedeza sericea (*Lespedeza cuneta*, var. *Sericia*) and lespedeza interstate (*Lespedeza cuneta*, var. *Interstate*)].

Three transects were located in each of the reference, light, moderate, and heavy training classifications, and two transects were located in the remediation areas. Each of the 14 transects was established at a random distance and direction from a selected location.

Five circular plots were established along each transect at intervals of 15 m between the centers. The circular plot size of 5 m radius was determined based upon a species–area curve constructed for the reference site using the technique described by Barbour et al. (1980). At that size plot, 31 understory species occurred. Within each plot, all species of understory vegetation (less than one meter in height) were identified and assigned a cover class using a modified Braun-Blanquet (1932) cover system (based on Clarke, 1986) (Table 1).

Bråkenhielm and Qinghong (1995) have demonstrated that visual estimates provide the most accurate, sensitive, and precise measure of vegetation cover compared to point frequency and subplot frequency methods. Thus, visual estimates of understory cover were used in this study. We came to a clear agreement in the field as to the appearance of each cover class. Individual species cover scores could not exceed 100%; however, cumulative cover scores for all species associated with an individual plot could be larger than 100%. All species were also classified using Raunkiaer's life-form classification system (Kershaw and Looney, 1985) based on the height of perennating buds.

Table 1
Key of the modified Braun-Blanquet (1932) cover classification system[a]

Cover-abundance class	Species cover and distribution characteristic
0	No plants present
1	Less than 1% cover; 1–5 small individuals
2	Less than 1% cover; many small individuals
3	Less than 1% cover; few large individuals
4	1–5% cover
5	5–12% cover
6	12–25% cover
7	25–50% cover
8	50–75% cover
9	75–100% cover

[a] Modified from Table 2.3; Clarke (1986).

Understory vegetation included all shrubby and herbaceous vegetation as well as trees under 5 cm diameter at breast height (DBH). In addition, canopy cover, canopy species, size of trees greater than 5 cm DBH, evidence of human disturbance, and depth of soil A horizon were recorded for each plot. The soil depth was meant to provide a quantitative measure of disturbance. In order to establish maximum stand age, we obtained two tree cores from each of the four largest trees in the immediate vicinity of each transect.

All species identification and characteristic descriptions were based on Godfrey (1988) and Radford et al. (1968). In a few cases plants could only be identified at the genus level. Understory oak had great plasticity, and distinguishing between saplings of the eight oak species was difficult. In addition, three distinct species of *Prunus* were observed, but due to a lack of a terminal inflorescence, two of the species were unidentifiable. Finally, one species of *Desmodium* was identified as clearly distinct from all other *Desmodium* species found within the study plots but was bearing no fruit, therefore rendering it impossible to identify.

Statistical analysis was performed to test for differences between the training intensities. Analysis of variance (ANOVA) was used to examine for differences in the mean cover scores for all species found within the plots (i.e. zeroes were eliminated). One-way ANOVA and Cochran–Mantel–Haenszel statistical test (Cochran, 1954; Mantel and Haenszel, 1959; Mantel, 1963) were conducted to see if there were differences in the frequency of cover ranks by life-form within a training category. We note that the ANOVA is asymptotically equivalent to the Kruskal-Wallis test. Then a two-way ANOVA was conducted to examine for differences in cover ranks considering both life-form and training category. The cover ranks were normally distributed by training category except for the heavy training sites.

4. Results

Highest understory plant species diversity occurred in light training sites and reference areas which also contained the oldest trees (Table 2). However, richness was also high in moderate training and remediation areas. Both diversity and understory plant cover were lowest in the heavy training areas which did not have a developed overstory. The moderate training areas had about two-thirds the amount of understory cover as did reference, light training, and remediation sites, and understory cover for those three areas was not distinguishable. Tree cover was highest in reference and light training areas, absent in heavy training areas, and very low in moderate training and remediation sites (Table 2).

A total of 134 understory plant species representing 36 families were identified in different training regimes at Fort Benning (see Appendix A). Many species had high variation in cover over all the training types, and we were unable to separate training types by species using multivariate analyses. Most species contributed an average of less than 1% cover. Little bluestem (*Andropogon scoparius*) had the highest mean cover (2.64%). Three awn grass (*Aristida oliganthum*) was the only species that occurred in all five training categories. Eight species were found only in reference and light training sites. Some species were found in only one training type: 11 in reference sites, 13 in light training, 14 in moderate training, and 4 in remediated sites. However, there were no species that occurred only in heavy training sites. Moderate training supported eight species which also occurred in sites with heavy training.

Families that contributed greater than 1% cover to the understory also differed by training category (Fig. 3). Grasses (Graminae) had the most cover for all categories. The heavy training had very little grass cover (2%), but grass cover exceeded 45% for moderate and reference areas and was greater than 75% for remediated areas. The reference sites had more than 30% cover of composites (Asteraceae) compared to 17% composite cover for light training areas and less than 5% for other training categories. Light training areas had the broadest taxonomic representation with 10 families contributing more than 1% cover as compared to one family (Graminae) for heavy training, four for moderate training, and six each for the reference and remediated sites.

Raunkiaer's life-form accounted for some differences between disturbances (Fig. 4). Over all samples, 12 species were Chamaephytes (plants with buds that are 0.1–0.5 M above ground), 38 species were Cryptophytes (plants with below ground dormant tissue), 32 species were Hemicryptophytes (plants with buds that at the ground surface), 34 species were Phanerophytes (trees or shrubs with buds greater then 0.5 m above ground), and 18 species were Therophytes (annuals) (see Appendix A). The frequency distribution of these species by life-form and training intensity is shown in Table 3. Crypotophyes were the most frequent group of species for reference, moderate, heavy, and remediation areas. In contrast, Phanerophytes were the most frequent life-form for light training areas. Therophytes (annuals) were least frequent for reference and light training areas, whereas Chamaephytes were least frequent for moderate and remediation sites. Heavy

Table 2
Mean and standard deviation (in parentheses) of vegetation characteristics of the different training intensities and remediated plots

Characteristic	Training category				
	Reference	Light	Moderate	Heavy	Remediation
Understory species richness	82	95	78	16	69
Percent understory cover	67.00	67.87	44.40	4.73	67.00
	(10.79)	(12.86)	(18.21)	(4.50)	(17.24)
Percent tree cover	36.19	26.10	0.53	0.00	1.92
	(4.01)	(5.59)	(0.92)	(0.00)	(2.72)
Stand age (years)	56.50	83.67	NA[a]	NA[a]	7[b]
	(24.83)	(22.40)			

[a] NA: not applicable because there were no overstory trees in the plots.
[b] Tree age was estimated from planting history.

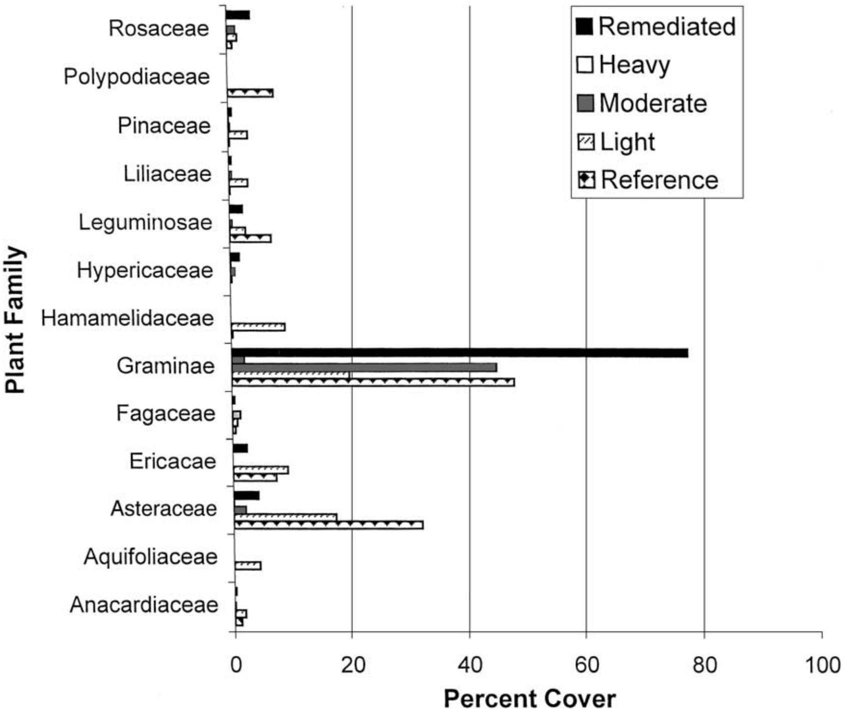

Fig. 3. Percent cover of plant families (for those families with greater than 1% cover) by training category.

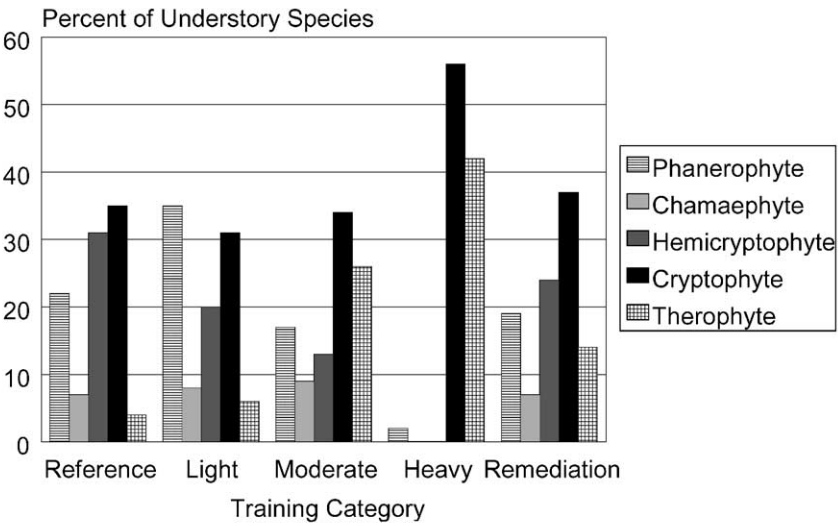

Fig. 4. Life-form distribution by training categories for understory species.

Table 3
Percent of understory species representing major life-forms in training categories (repetitions of species can occur across plots)

Life-form	Training category (number of plots)					Total number of times that species of each form were encountered
	Reference (15)	Light (15)	Moderate (15)	Heavy (15)	Remediation (10)	
Phanerophyte	22	35	17	2	19	339
Chamaephyte	7	8	9	0	7	105
Hemicryptophyte	31	20	13	0	24	309
Cryptophyte	35	31	34	56	37	490
Therophyte	4	6	26	42	14	165
Total number of times that species of each form were encountered	429	436	268	48	227	1408

Table 4
Comparisons of the frequency of understory plants in vegetation cover classes by life-form for five training categories using the Cochran–Mantel–Haenszel statistic (based on rank scores) and single-factor ANOVA

Statistic	Training category (number of plots)				
	Reference (15)	Light (15)	Moderate (15)	Heavy (15)	Remediation (10)
Cochran–Mantel–Haenszel Statistic	47.39	57.959	76.484	75.738	18.141
F	–	–	–	–	–
P	0.001	0.001	0.001	0.001	.0001
ANOVA					
F	6.75	7.28	13.92	0.98	11.28
P	0.0001	0.0001	0.0001	NS	0.0001

training sites supported no Chamaephytes or hemicryptophyes.

Differences in the ranks of the cover scores for all life-forms found in the plots (i.e. zeroes were eliminated) was examined using ANOVA and the Cochran–Mantel–Haenszel statistic (Table 4). All training types had fewer species in the higher cover classes than in categories with low cover. There were significant differences in cover ranks by life-forms within reference, light, moderate, and remediation sites, but not within heavy sites. The lack of difference in the heavy training sites likely reflects the paucity of plants found there. The two-way ANOVA revealed significant differences in cover ranks considering both life-form and training intensity (Table 5).

Depth of the soil A horizon, which is used as a measure of impact of military training, differed significantly between categories of training intensity ($F_{4.65} = 24.3$, $P < 0.001$). Light and reference areas had the greatest depth and also the highest variability (Fig. 5). Depth of the A horizon for heavy, moderate, and remediated sites was consistently small.

Table 5
Two-way analysis of variance of the plant frequency by life-form and training category when reference, light, moderate and heavy training are considered

	Degrees of freedom	*F*	*P*
Training category	3	7.50	.0001
Life-form	4	16.15	.0001
Interaction	7	12.44	.0001

5. Discussion

Except for distinguishing heavy training areas, these data suggest that neither understory cover nor plant diversity are useful indicators of past training. This inability to discriminate may have occurred because

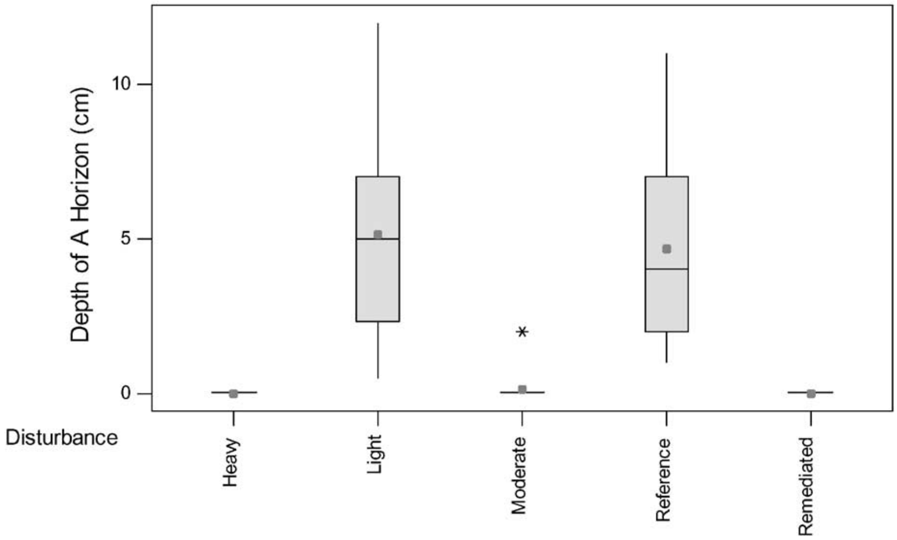

Fig. 5. Boxplot of the depth of the A soil horizon by training intensity type. The bottom and top edges of the box are located at the sample 25th and 75th percentiles. The center horizontal line occurs at the sample median. Means are indicated by solid squares; an outlier value is indicated by an asterisk.

the training areas differed in canopy cover with the light and reference areas being the only ones having significant overstory cover. In those stands, the average age of the trees was 56 years for the reference sites and 83 years for lightly trained sites suggesting it had been at least five–eight decades since a disturbance large enough to induce tree replacement had occurred. However, the influence of canopy cover on understory diversity and cover was not strong. Neither moderate nor remediated sites had an established tree canopy; yet they supported 78 and 69 understory species, respectively, compared to 82 and 95 species for reference and light training areas.

Furthermore, understory cover of remediated areas was equivalent to that of reference and light training sites. Moderate sites averaged 44% understory cover, about two-thirds of that in light, remediated, and reference sites, suggesting that recovery still had to be achieved. Understory species richness and percent cover were quite low for the heavily-used training areas probably because most plants had been removed by repeated tank traffic.

The high diversity and large variation in understory cover of longleaf pine forests and reestablishing vegetation provided a challenge in the use of understory species to distinguish between training impacts in longleaf pine stands (see Appendix A). It was not surprising that little bluestem (*Andropogon scoparius*) contributed the highest mean cover over all sites, for it is a characteristic plant of longleaf pine forests (Dobrowolski et al., 1992; Kirkman et al., 2000). Species that were only identified from one type of training area sometimes were helpful in identifying characteristics of such sites. For example, bracken fern (*Pteridium aquilinum*) was only found in reference sites and is a typical plant of old growth longleaf pine stands. Prickly pear (*Opuntia compressa*) was only found in moderately disturbed sites and can likely withstand the stressful conditions of such sites. The high variability in understory vegetation cover over training categories probably led to the lack of separation by training category by species which required analyses based upon groupings of species into life-forms and families, which are measures of structure and composition (respectively).

In contrast to considering diversity and cover of all species, life-form offered a more effective indicator of past disturbances. Frequency of life-form occurrence distinguishes between military disturbance. Trees and shrubs (Phanerophytes), which may be less affected by foot soldier traffic than other life-forms, dominated cover in light training areas. However, in an extensive literature review of foot traffic impacts on vegetation, shrubs and trees suffered the longest lasting decrease (Yorks et al., 1997). Our analysis suggested that foot traffic impact on trees and shrubs may not be as intense as on other life-forms. This difference between duration and intensity of disturbance impacts is a necessary distinction (White and Pickett, 1985). Cryptophytes dominate in all other training categories possibly because they are common in the flora due to their ability to withstand ground fires, the natural disturbance of longleaf pine forests. Plants with underground buds are possibly the only vegetation able to withstand heavy tank traffic. In contrast, Therophytes, which are also found in the heavy training areas, likely seeded into sites after mechanized training ceased. Chamaephytes do not contribute more than 1% cover for any training treatment possibly because they are uncommon in the longleaf pine flora and because they are susceptible to all types of traffic.

Previous studies document that life-form reflects impacts following volcanic eruption, grazing, tree thinning, water additions, and soil disturbance (Adams et al., 1987; McIntyre et al., 1995; Stohlgren et al., 1999). In a comparison of treatments designed to reduce hardwood in-growth in longleaf pine forests, fire resulted in the greatest increase in understory species richness and herbaceous groundcover plant densities as compared to herbicide treatments (Provencher et al., 2001). This difference is likely attributed to the fire allowing the survival of plants with their buds below the surface much as dismounted training allows Cryptophytes to survive. Furthermore, life-form changed in the understory after thinning in Douglas fir (*Pseudotsuga menziesii*) plantations (Thomas et al., 1999). Studies from the inner Mongolia Plateau report that life-form is a greater determinant of ecosystem processes than is species richness (Bai et al., 2001).

Plant families are also a useful way to group understory vegetation to reflect differences in training regimes. Of those families that contribute more than one percent cover, light training areas had the highest diversity with 11 families represented whereas heavy training areas had only one family present. Anacardiaceae was the most abundant family in the light training sites (possible because foot soldiers may have avoided poison ivy, one of the common representatives of this family, giving it a competitive advantage over other species that were more readily tramped upon). Both remediated and reference sites each contained six families with greater than 1% cover, but three of these families were not the same. Ferns (Polypodiaceae) and, in particular, bracken fern (*Pteridium aquilinum*) were distinct to reference sites and can be assumed to be an indicator of the absence of military disturbance.

Graminae was the only family common to all training types. Yorks et al. (1997) report from their literature review of foot traffic impacts that graminoids were found to be most resistant. Grasses contributed very little cover in the heavily trained sites but provided more than 70% cover to the remediated sites. It is not surprising that remediated sites had such high cover of grasses, for recovery efforts of these areas included planting grass seed. The relevant management question is: does such planting bring impacted sites closer to the vegetative characteristic of naturally revegetating sites? We found no family that was distinct to remediated sites. Except for the low percentage of trees and shrubs, life-form distribution of remediated sites is similar to that of both reference and lightly trained sites with Cryptophytes being well represented (Fig. 4). Thus, this analysis suggests that the remediated sites are moving along the pathway toward established vegetation much like that of the reference or lightly trained areas.

Depth of the soil A horizon offers a means independent of observation and vegetative measures to distinguish between the impacts due to military training. The fact the A horizon depth for sites that experienced dismount traffic is not distinct from the reference sites suggests that foot soldier traffic has relatively little impact on the physical conditions of the longleaf pine understory. Yet, the increased percent of trees and shrubs species in the light training areas versus the reference sites cannot be explained by soil properties but is more likely a result of the movement of foot soldiers through the forest.

6. Conclusions

We hypothesized that understory diversity and cover sampled from an anthropogenic disturbance gradient within the longleaf pine forests would reveal significant compositional and structural differences that occurred as a result of military training intensity. The confirmation of life-form distribution and plant family cover as distinguishing features suggests that monitoring programs for longleaf pine forests should include understory vegetation as an ecological indicator. These metrics can serve as surrogate measures of disturbance to the longleaf pine system. Both life-form distribution and plant family cover appear to be useful ways to group the large number of species which occur in the understory of these longleaf pine forests.

Indicators of disturbance that are used for resource management need to be easy to measure, sensitive to stresses, and predictable as to how they respond to stress (Cairns et al., 1993; Stewart and Loar, 1994, Dale and Beyeler, 2001). Selecting indicators for the understory of longleaf pine forests is complicated by the high species diversity. Field classification of understory plants according to life-form and family is relatively straightforward compared to species identification. Both of these attributes are relatively easy and time efficient to measure and interpret. Thus, we recommend that the suite of indicators used for monitoring longleaf pine ecosystems include these metrics.

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Appendix A

Characteristics of understory species found in longleaf pine forests at Fort Benning, GA.

Botanical name	Family	Raunkiaer life-form (as discussed by Kershaw and Looney, 1985)		Growth-form	Cover		Common name	Location by impact (R = reference, L = light, M = moderate, H = heavy, D = remediated)
					Mean	S.D.		
Agalinis purpurea	Scrophulariaceae	Therophyte		Forb	0.17	0.45	Gererdia	LMD
Albizia julibrissin	Leguminosae	Phanerophyte	Deciduous	Tree	0.01	0.12	Silk tree	L
Ambrosia artemisiifolia	Asteraceae	Therophyte		Forb	0.01	0.12	Annual ragweed	M
Andropogon scoparius	Graminae	Cryptophyte	Geophyte	Graminoid	2.64	2.78	Little bluestem	RLMH
Andropogon ternarius	Graminae	Cryptophyte	Geophyte	Graminoid	1.20	2.04	Splitbeard bluestem	RLD
Aristida oligantha	Graminae	Cryptophyte	Geophyte	Graminoid	0.86	1.72	Threeawn grass, wire grass	RLMHD
Aristida purpurascens	Graminae	Cryptophyte	Geophyte	Graminoid	1.27	2.07	Arrowfeather threeawn grass	RMHD
Aster concolor	Asteraceae	Cryptophyte	Geophyte	Forb	0.26	0.63	Eastern silver aster	R
Aster dumosus	Asteraceae	Cryptophyte	Geophyte	Forb	0.37	0.71	Rice button aster	RLD
Aster patens	Asteraceae	Cryptophyte	Geophyte	Forb	0.06	0.23	Spreading aster[a]	RLMD
Aster tortifolius	Asteraceae	Cryptophyte	Geophyte	Forb	0.77	1.49	White-topped aster	RLMD
Bulbostylis ciliatifolia	Cyperaceae	Therophyte		Forb	0.16	0.71	Bulbos rush[a]	M
Cacalia lanceolata	Asteraceae	Hemicryptophyte	Rosette	Forb	0.04	0.20	Indian-plantain	R
Cacalia muhlenbergii	Asteraceae	Hemicryptophyte	Rosette	Forb	0.14	0.43	Great Indian- plantain	RD
Carya tomentosa	Juglandaceae	Phanerophyte	Deciduous	Tree	0.14	0.55	Mockernut hickory	LD
Cassia nictitans	Leguminosae	Therophyte		Forb	0.89	1.29	Partridge pea	RLMD
Cenchrus longispinus	Graminae	Therophyte		Forb	0.20	0.77	Sandspurs	M
Conyza canadensis	Asteraceae	Therophyte		Forb	0.46	0.85	Horseweed	MHD
Coreopsis major	Asteraceae	Cryptophyte	Geophyte	Forb	0.24	0.65	Greater tickseed	R
Crataegus flava	Rosaceae	Phanerophyte	Deciduous	Tree	0.47	1.10	Yellow hawthorne	RLMD
Crataegus pulcherrima	Rosaceae	Phanerophyte	Deciduous	Tree	0.06	0.38	Handsome hawthorne[a]	LD
Crataegus spathulata	Rosaceae	Phanerophyte	Deciduous	Tree	0.01	0.12	Little hop hawthorne	R
Croton glandulosus	Euprorbiaceae	Therophyte		Forb	0.06	0.23	Croton	MH
Cynodon dactylon	Graminae	Cryptophyte	Geophyte	Graminoid	0.61	1.54	Bermuda grass	MH
Desmodium sp.	Leguminosae	Cryptophyte	Geophyte	Forb	0.49	0.93	Ticktrefoil	RLM
Desmodium ciliare	Leguminosae	Cryptophyte	Geophyte	Forb	0.24	0.60	Hairy smallleaf ticktrefoil	RL
Desmodium floridanum	Leguminosae	Cryptophyte	Geophyte	Forb	0.10	0.35	Florida ticktrefoil	L
Desmodium lineatum	Leguminosae	Cryptophyte	Geophyte	Forb	0.37	0.80	Linear ticktrefoil[a]	RLM
Desmodium strictum	Leguminosae	Cryptophyte	Geophyte	Forb	0.11	0.40	Pinebarren ticktrefoil	L
Dichanthelium aciculare	Graminae	Cryptophyte	Geophyte	Forb	0.04	0.27	Needleleaf rosetta grass	D
Dichanthelium oligosanthes	Graminae	Cryptophyte	Geophyte	Forb	0.63	1.22	Bound rosetta grass[a]	RLMD

Appendix A. (*Continued*)

Botanical name	Family	Raunkiaer life-form (as discussed by Kershaw and Looney, 1985)		Growth-form	Cover		Common name	Location by impact (R = reference, L = light, M = moderate, H = heavy, D = remediated)
					Mean	S.D.		
Dichanthelium sabulorum	Graminae	Cryptophyte	Geophyte	Forb	1.11	1.86	Hemlock rosetta grass	RLMD
Digitaria violascens	Graminae	Cryptophyte	Geophyte	Forb	0.39	1.07	Crabgrass	MHD
Diodea teres	Graminae	Therophyte		Forb	0.81	1.27	Poorjoe	LMH
Diospyros virginiana	Ebenaceae	Phanerophyte	Deciduous	Tree	1.29	1.44	Common persimmon	RLMD
Elephantopus tomentosus	Asteraceae	Hemicryptophyte	Partial rosette	Forb	0.26	0.94	Devils grandmother	R
Eragrostis curvula	Graminae	Cryptophyte	Geophyte	Graminoid	0.09	0.72	Weeping lovegrass	M
Eragrostis capillaris	Graminae	Therophyte		Graminoid	1.00	2.11	Slender lovegrass	LMD
Eragrostis refracta	Graminae	Cryptophyte	Geophyte	Graminoid	0.64	1.65	Coastal lovegrass	MHD
Erianthus contortus	Graminae	Cryptophyte	Geophyte	Graminoid	0.16	0.61	Sugar cane	L
Eupatorium album	Asteraceae	Hemicryptophyte	Proto	Forb	0.41	0.89	White thoroughwort	RLMD
Eupatorium aromaticum	Asteraceae	Hemicryptophyte	Proto	Forb	0.37	1.02	Aromatic thoroughwort	RL
Eupatorium capillifolium	Asteraceae	Hemicryptophyte	Proto	Forb	0.64	1.17	Small dogfennel	RLM
Eupatorium coelestinum	Asteraceae	Hemicryptophyte	Proto	Forb	0.03	0.17	Mistflower	R
Eupatorium hyssopifolium	Asteraceae	Hemicryptophyte	Proto	Forb	0.69	1.28	Hyssopleaf thoroughwort	RLMD
Euphorbia corollata	Euphorbiaceae	Hemicryptophyte	Proto	Forb	0.16	0.40	Flowering spurge	RLD
Froelichia gracilis	Amaranthaceae	Therophyte		Forb	0.10	0.35	Cottonweed	MH
Galium hispidulum	Rubiaceae	Chamaephytes	Active	Forb	0.01	0.12	Coastal beardstraw	L
Gaylussacia frondosa	Ericacae	Phanerophyte	Deciduous	Tree	0.06	0.29	Dangleberry	R
Gelsemium sempervirens	Loganiaceae	Chamaephytes	Active	Vine	0.07	0.26	Yellow Jasmine	LM
Gymnopogon ambiguus	Graminae	Cryptophyte	Geophyte	Grass	0.17	0.45	Beard grass	RLD
Haplopappus divaricatus	Asteraceae	Therophyte		Forb	0.44	0.83	Haplopappus	LMHD
Helianthus longifolius	Asteraceae	Cryptophyte	Geophyte	Forb	0.13	0.68	Longleaf sunflower	D
Heterotheca graminifolia	Asteraceae	Hemicryptophyte	Partical Rossett	Forb	2.13	2.78	Narrowleaf silkgrass	RLD
Heterotheca subaxillaris	Asteraceae	Therophyte		Forb	0.04	0.20	Annual silkgrass[a]	M
Heterotheca gossypina	Asteraceae	Hemicryptophyte	Partial Rosette	Forb	0.09	0.44	Hairy silkgrass[a]	L
Heterotheca mariana	Composite	Hemicryptophyte	Partial Rosette	Forb	0.20	0.60	Erect silkgrass[a]	RL
Hieracium gronovii	Asteraceae	Cryptophyte	Geophyte	Forb	0.03	0.17	Queendevil	L
Hypericum gentianoides	Hypericaceae	Therophyte		Forb	0.66	1.06	Pineweed	LMHD
Hypericum hypericoides	Hypericaceae	Phanerophyte	Deciduous	Forb	0.34	0.88	St. Andrew's cross	LMD
Ilex glabra	Aquifoliaceae	Phanerophyte	Evergreen	Shrub	0.17	1.06	Inkberry	L
Ipomoea pandurata	Convolvulaceae	Chamaephytes	Active	Vine	0.07	0.31	Man of the Earth	M
Ipomoea purpurea	Convolvulaceae	Therophyte		Forb	0.01	0.12	Common morning glory	D
Lechea minor	Cistaceae	Hemicryptophyte	Proto	Forb	0.17	0.48	Thyme leaf pinweed	RLMD
Lechea villosa	Cistaceae	Hemicryptophyte	Proto	Forb	0.17	0.54	Hairy pinweed	MD
Lespedeza cuneata	Leguminosae	Hemicryptophyte	Proto	Forb	0.24	0.77	Chinese lespodeza	MD
Lespedeza hirta	Leguminosae	Hemicryptophyte	Proto	Forb	0.37	0.76	Hairy lespodeza	RLMD
Lespedeza repens	Leguminosae	Hemicryptophyte	Proto	Forb	0.19	0.57	Creeping lespodeza	MD
Lespedeza stuevei	Leguminosae	Hemicryptophyte	Proto	Forb	0.23	0.57	Tall lespodeza	RLMD
Liatris elegans	Asteraceae	Cryptophyte	Geophyte	Forb	0.21	0.59	Pinkscale gayfeather	RL
Liatris graminifolia	Asteraceae	Cryptophyte	Geophyte	Forb	0.17	0.45	Blazing star	RL
Liatris tenuafolia	Asteraceae	Cryptophyte	Geophyte	Forb	0.11	0.36	Blazing star	RM
Lichens				Lichens	0.61	1.69	Lichen	MD
Liquidambar stryraciflua	Hamamelidaceae	Phanerophyte	Deciduous	Tree	0.61	1.76	Sweet gum	RL
Lithospermum caroliniense	Boraginaceae	Hemicryptophyte	Proto	Forb	0.01	0.12	Puccoon	M
Lobelia puberula	Campanulaceae	Hemicryptophyte	Proto	Forb	0.01	0.12	Downy lobelia	L
Mollugo verticillata	Aizoceae	Therophyte		Forb	0.01	0.12	Indian chickweed	M
moss				Mosses	0.66	1.73	Moss	LMD
Muhlenbergia expansa	Graminae	Cryptophyte	Geophyte	Forb	0.11	0.55	Muhly	RD
Myrica cerifera	Myricaceae	Phanerophyte	Deciduous	Shrub	0.19	0.77	Southern bayberry	L
Opuntia compressa	Cactaceae	Hemnicryptophye	Rosette	Forb	0.03	0.17	Prickly pear	M
Paronychia herniarioides	Caryophyllaceae	Therophyte		Forb	0.03	0.17	Coastal Plain nailwort	M
Paspalum notatum	Graminae	Cryptophyte	Geophyte	Forb	1.33	2.50	Bahiagrass	M
Passifloria incarnata	Passifloraceae	Hemicryptophyte	Proto	Vine	0.01	0.12	Maypops	M
Petalostemum pinnatum	Leguminosae	Hemicryptophyte	Proto	Forb	0.10	0.39	Summer-farewell	RL
Pinus echinata	Pinaceae	Phanerophyte	Evergreen	Tree	0.23	0.85	Shortleaf pine	LH
Pinus palustris	Pinaceae	Phanerophyte	Evergreen	Tree	0.71	1.31	Longleaf pine	RLMD
Pinus taeda	Pinaceae	Phanerophyte	Evergreen	Tree	0.14	0.62	Loblolly pine	RLD
Polypremum procumbens	Loganiaceae	Cryptophyte	Geophyte	Forb	0.24	0.62	Juniper leaf	LMHD
Prunus sp. 1	Rosaceae	Phanerophyte	Deciduous	Tree	0.14	0.62	Plum	MD
Prunus serotina	Rosaceae	Phanerophyte	Deciduous	Tree	0.03	0.17	Black cherry	LD
Prunus sp. 2	Rosaceae	Phanerophyte	Deciduous	Tree	0.01	0.12	Plum	M
Pteridium aquilinum	Polypodiaceae	Cryptophyte	Geophyte	Forb	0.64	1.73	Western brackenfern	R
Quercus incana	Fagaceae	Phanerophyte	Evergreen	Tree	0.14	0.62	Blue jack oak	RLD
Quercus laevis	Fagaceae	Phanerophyte	Deciduous	Tree	0.10	0.51	Turkey oak	RL
Quercus laurifolia	Fagaceae	Phanerophyte	Deciduous	Tree	0.10	0.42	Laurel oak	RLM

Appendix A. (*Continued*)

Botanical name	Family	Raunkiaer life-form (as discussed by Kershaw and Looney, 1985)		Growth-form	Cover		Common name	Location by impact (R = reference, L = light, M = moderate, H = heavy, D = remediated)
					Mean	S.D.		
Quercus margaretta	Fagaceae	Phanerophyte	Deciduous	Tree	0.13	0.80	Shrubby post oak	RM
Quercus marilandica	Fagaceae	Phanerophyte	Deciduous	Tree	0.81	1.34	Blackjack oak	RL
Quercus nigra	Fagaceae	Phanerophyte	Deciduous	Tree	0.24	0.73	Water oak	RLMD
Quercus shumardii	Fagaceae	Phanerophyte	Deciduous	Tree	0.03	0.17	Swamp red oak	RM
Quercus stellata	Fagaceae	Phanerophyte	Deciduous	Tree	0.10	0.46	Post oak	L
Rhus aromatica	Anacardiaceae	Phanerophyte	Deciduous	Shrub	0.16	0.53	Fragrant sumac	MD
Rhus copallina	Anacardiaceae	Phanerophyte	Deciduous	Shrub	1.00	1.39	Flameleaf sumac	RLM
Rhynchosia reniformis	Leguminosae	Hemicryptophyte	Proto	Forb	0.50	0.76	Dollar leaf	RL
Rubus cuneifolius	Rosaceae	Phanerophyte	Deciduous	Shrub	1.24	1.58	Sand blackberry	RLMD
Rubus trivialis	Rosaceae	Chamaephytes	Active	Shrub	0.87	1.50	Dewberry	RLMD
Ruellia caroliniensis	Acanthaceae	Hemicryptophyte	Partial rosette	Forb	0.03	0.17	Carolina wild petunia	R
Sassafras albidum	Lauraceae	Phanerophyte	Deciduous	Tree	0.34	0.92	Sassafras	RLD
Schrankia microphylla	Leguminosae	Phanerophyte	Deciduous	Tree	0.06	0.23	Sensitive plant	RL
Seymeria pectinata	Scrophulariaceae	Therophyte		Forb	0.10	0.49	Piedmont blacksenna	L
Smilax bona-nox	Liliaceae	Chamaephytes	Active	Forb	0.20	0.91	Saw greenbriar	RLM
Smilax glauca	Liliaceae	Chamaephytes	Active	Forb	0.26	0.53	Cat greenbriar	RLMD
Smilax laurifolia	Liliaceae	Chamaephytes	Active	Forb	0.14	0.49	Laurel greenbriar	LMD
Smilax rotundifolia	Liliaceae	Chamaephytes	Active	Forb	0.14	0.49	Roundleaf greenbriar	LM
Solanum carolinense	Solanaceae	Hemicryptophyte	Proto	Forb	0.21	0.45	Carolina horsenettle	RLMD
Solidago leavenworthii	Asteraceae	Cryptophyte	Geophyte	Forb	0.01	0.12	Leavenworth goldenrod[a]	M
Solidago odora	Asteraceae	Cryptophyte	Geophyte	Forb	0.91	1.38	Anise-scented goldenrod	RLD
Solidago stricta	Asteraceae	Cryptophyte	Geophyte	Forb	0.33	0.77	Slender goldenrod[a]	RLD
Solidago tenuifolia	Asteraceae	Cryptophyte	Geophyte	Forb	0.16	0.58	Narrow goldenrod[a]	RL
Stipulicida setacea	Caryophyllaceae	Hemicryptophyte	Rosette	Forb	0.03	0.17	Stipulicida[a]	M
Strophostyles umbellata	Leguminosae	Chamaephytes	Active	Vine	0.20	0.77	Trailing strophostyles[a]	R
Stylosanthes biflora	Leguminosae	Hemicryptophyte	Proto	Forb	0.16	0.50	Pencil flower	RL
Tephrosia virginiana	Leguminosae	Chamaephytes	Suffruticose	Forb	0.59	1.34	goat's rue	RMD
Toxicodendron quercifolia	Anacardiacea	Chamaephytes	Suffruticose	Vine	0.50	1.06	poison ivy	RL
Trichostema dichotomum	Lamiaceae	Therophyte		Forb	0.01	0.12	Blue curls	L
Triplasis americana	Graminae	Cryptophyte	Geophyte	Grass	0.17	0.64	Sand grass	RLM
Triplasis purpurea	Graminae	Cryptophyte	Geophyte	Grass	0.46	1.14	Purple sand grass	LMHD
Vaccinium arboreum	Ericaceae	Phanerophyte	Deciduous	Shrub	0.74	1.68	Farkleberry	RLD
Vaccinium eliottii	Ericaceae	Phanerophyte	Deciduous	Shrub	0.60	1.42	Elliots blueberry	RL
Vaccinium myrsinites	Ericaceae	Phanerophyte	Evergreen	Shrub	0.64	1.50	Shinny blueberry	RLD
Vaccinium stamineum	Ericaceae	Phanerophyte	Deciduous	Shrub	1.06	1.80	Deerberry	RLD
Vernonia angustifolia	Asteraceae	Hemicryptophyte	Proto	Forb	0.26	0.61	Tall ironweed	RL
Viola palmata	Violaceae	Hemicryptophyte	Proto	Forb	0.06	0.29	Palmed violet	R
Vitis rotundifolia	Vitaceae	Chamaephytes	Passive	Vine	0.04	0.20	Muscadine	L
Wahlenbergia marginata	Campanulaceae	Hemicryptophyte	Proto	Forb	0.01	0.12	Southern rockbell	D
Yucca filamentosa	Liliaceae	Hemicryptophyte		Shrub	0.19	0.43	Adams needle	LMD

[a] No common name was provided by taxonomy books; so, these common names were derived from the Latin name or description.

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