Fire, Herbicide, and Chainsaw Felling Effects on Arthropods in Fire-Suppressed Longleaf Pine Sandhills at Eglin Air Force Base, Florida

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Abstract.—Experimentally evaluating the success of hardwood reduction techniques against a "model" reference condition of longleaf pine sandhill communities is not directly possible because reference sites are not randomized or replicated. We addressed this issue by measuring the similarity of arthropods in treatment (fire, herbicide, felling/girdling, and control) and reference sites using three indices. Arthropod assemblages from plots that burned were significantly more similar to those in the reference condition than were those that did not receive fire. Our findings suggest that increasing arthropod prey using fire will be beneficial both to management and to biodiversity.

Introduction

Southern longleaf pine (*Pinus palustris* P. Mill.) forest restoration is, in many ways, essentially synonymous with red-cockaded woodpecker (*Picoides borealis* Vieillot) habitat management, where mechanical removal and short burn rotations (1–3 years) are used to reduce and control midstory hardwood encroachment that is detrimental to the woodpeckers (Conner and Rudolph 1989; Hooper et al. 1991). Because many public lands in the southern U.S. are now managed for red-cockaded woodpeckers (Brennan et al. 1995; U.S. Forest Service 1995), management effects on non-target species, especially birds, have become a concern in recent years (Brennan et al. 1995; Burger et al. 1998; Hunter et al. 1994; Plentovich et al. 1998; White et al. 1999).

Red-cockaded woodpecker habitat management (i.e., fire) likely affects arthropods directly or indirectly by stimulating population growth through increased resource availability and quality (James et al. 1997; Reed 1997). It is well documented that fire causes plants to resprout and to be more palatable to herbivores (smaller C:N ratio for plant tissues) (Dunwiddie 1991; Nagel 1973; Owensby et al. 1970; Smith and Young 1959; Stein et al. 1992). Increased flowering after fire (Platt et al. 1988) should attract insect pollinators. In turn, increases in herbivores and pollinators may attract predatory arthropods and parasites. Some predatory ground beetles, for example, increase following fire (Harris and Whitcomb 1974). Increases in arthropods are important because they represent a fundamental prey base for red-cockaded woodpeckers and associated vertebrates, many of which exclusively feed arthropods to their offspring and depend on arthropods for food outside of the breeding season. Conversely, these species of concern may suffer if fire suppression results in decreases in arthropod abundance. Remarkably, there is a dearth of quantitative data published on the relationship between fire and the arthropods that red-cockaded woodpeckers consume (but see Hanula and Franzreb 1998; James et al. 1997) or on arthropods in longleaf pine forests (reviewed in Folkerts et al. 1993), especially describing old-growth communities.

We experimentally compared the effects of three hardwood reduction techniques (growing season burn, herbicide application, and midstory mechanical felling/girdling) and a no-treatment control on herb-layer arthropod densities in fire-suppressed longleaf pine sandhills at Eglin Air Force Base (EAFB), Florida. Hardwood reduction is necessary to meet EAFB's goals for restoring functional, diverse sandhill systems across the Base and for habitat restoration for the endangered red-cockaded woodpecker and other target species having similar habitat requirements. Our main goal was to identify which management technique(s) caused arthropod species assemblages to converge toward values found in fire-maintained sandhills, which we termed the "reference condition" to emphasize forest composition and function in addition to structure. Based on our analysis, we also developed metrics that may be indicators of sandhill management success.

Methods

Site Description

Eglin Air Force Base (EAFB) occupies 187,555 ha in the southern portions of Santa Rosa, Okaloosa, and Walton counties in the western Florida Panhandle. The mean annual temperature is 18.3° C, with approximately 275 freeze-free days per year. Mean annual precipitation is 158 cm. Monthly precipitation levels peak slightly during late spring and early summer months and decrease during the winter months (Chen and Gerber 1990). Since 1886, 25 tropical storms and 27 hurricanes made landfall within 97 km (60 miles) of EAFB.

The terrain is level to gently rolling with occasional areas of steep slopes along creeks. Elevation ranges from 0–100 m above sea level, and the landscape generally slopes to the southwest toward the Gulf of Mexico. Lakeland series, the common soil, is a medium to fine sand with 5-10 percent silt and clay (Overing et al.

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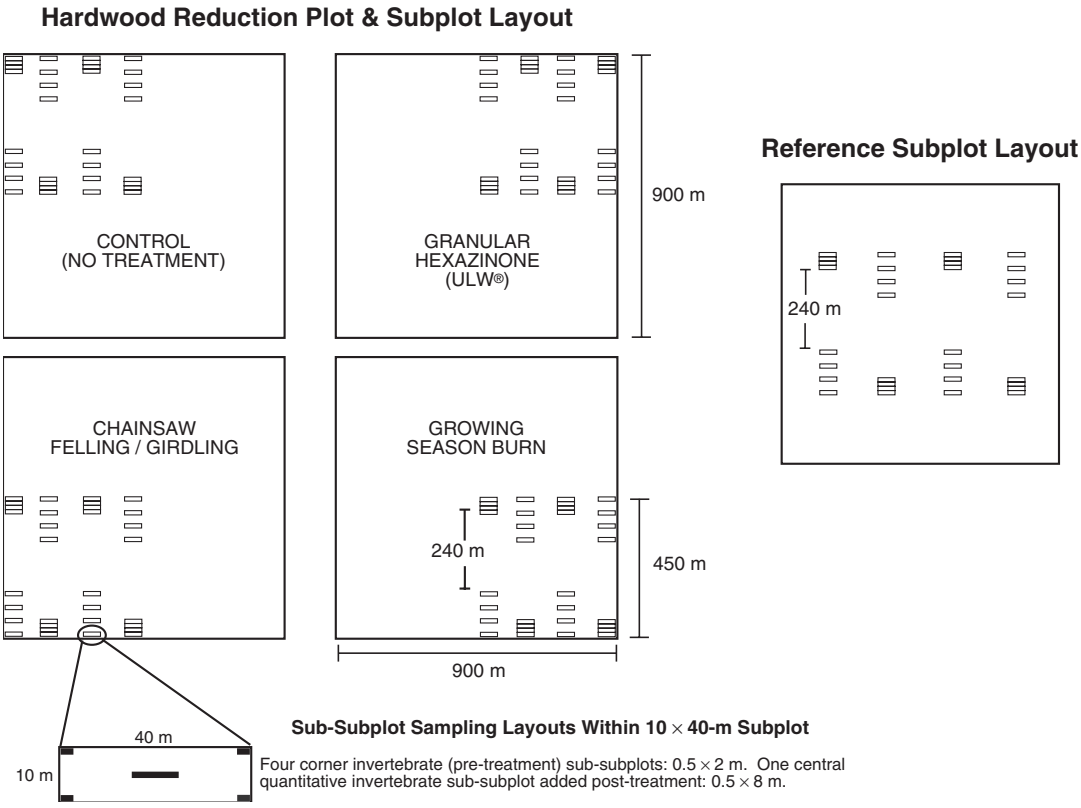

Figure 1.—Sample layout of one of six reference plots (81-ha) and of hardwood reduction plots and sampling areas in one of six blocks in a randomized complete block split-plot design consisting of four whole-plot treatments. Spatial randomization of treatments varies per block.

1995), is rapidly permeable and strongly acidic, with nearly level to steep slopes. The vegetation of EAFB's sandhills is described in Rodgers and Provencher (1999).

Restoration Experiment: Experimental Hardwood Removal Plots

A total of 24, 81-ha plots were established in six blocks of four fire-suppressed hardwood-longleaf pine sandhill plots across EAFB (see map in Rodgers and Provencher 1999). This study utilized a randomized complete block design (Steel and Torrie 1980), where each plot within an experimental block was randomly assigned to either control designation (no treatment), or to one of three restoration treatments applied during the spring and early summer of 1995: growing season burn in May or June, herbicide application (ULW®, the granular form of hexazinone with 75 percent active ingredient applied at 2.24 kg/ha), and oaks and sand pine felling/girdling by chainsaw (slash not removed). Fuel reduction burns were conducted in the herbicide and felling/girdling plots in early 1997. In each restoration plot, 32, 10 ´ 40-m subplots were located in the 20-ha corner farthest from the neighboring plots of the block to reduce the potential for recording organisms that can travel across adjacent plot boundaries (Figure 1).

Reference Plots

Three pairs of 81-ha frequently burned, longleaf pine-dominated reference sandhill plots were established (Fig. 1). These plots were not part of the experiment described above but were used to measure restoration success. In each reference plot, 32, 10 ´ 40-m subplots were located in the center of the plot to reduce edge effects (Figure 1). These plots are more fully described in Rodgers and Provencher (1999) and Provencher et al. (2000; 2001a; 2001b). For the duration of the restoration study, reference plots were under a "let burn" management policy (all reference plots burned once and four plots burned at least twice during the study period).

Data Collection

Densities of selected herb-layer arthropod species were estimated. To successfully collect arthropods of various sizes and mobility, individuals were first collected using a sweep net, followed immediately by a modified D-Vac insect vacuum. In 1994, individuals were collected from

herb-strata vegetation (<1.4 m) within four 0.5 ´ 2-m sub-subplots (Figure 1). Because we suspected that the noise and motion of our vacuum device and sweep net were flushing some arthropods from adjacent sub-subplots, we changed the location and shape of arthropod sampling sub-subplots to a single 0.5 ´ 8-m rectangle in the center of the subplot beginning in fall 1995 (Figure 1). Moreover, the second method minimized escapes by arthropods because we opened the sweep net once instead of four times. Specimens from sweep net/D-Vac samples were manually sorted and preserved in 70 percent ethanol. We enlisted the assistance of taxonomic specialists, where possible, to perform initial species identifications and established a reference collection of more than 300 species of authoritatively identified adult arthropods.

Statistical Analyses

Similarity measures allowed us to directly determine which treatment plots most resembled the reference plots. Treatment differences were tested using two-way analysis of covariance (ANCOVA). The advantages of this method over discriminant function analysis were that (1) we could include both common variables and those with patchy distributions and (2) the calculated similarity values, rather than the raw data, were required to meet any statistical assumptions of the tests. Although there are a wide variety of available similarity indices, we calculated similarity of selected variables between each treatment plot and each reference site using three formulas (Brower et al. 1989; Underwood and Chapman 1998). The purpose of using three indices was to achieve a consensus among them, especially for the identification of indicator variables (see below). The strength of an indicator increased with the number of indices identifying it as a significant contributor to the pattern of similarity.

Proportional similarity (PS) was selected because it is widely used and it accounts for the relative abundance of variables. This last feature was especially important to us because site conditions (e.g., soil productivity) may greatly change the values of certain variables but not their relative abundance on a particular sampling site. The PS between each treatment plot i (= 1,…, 24) and each reference plot j (= 1,…,6) was averaged over all reference plots per restoration plot i with a sum weighted by sample sizes;

$$PS_{ij} = \sum_{j=1}^{6} n_j \, (1-0.5\sum_{k=1}^{K} |p_{ik}-p_{jk}|)/N$$

where p_{ik} is the proportion of the logarithm of variable k in treatment plot i, p_{jk} is the proportion of the logarithm of variable k in reference plot j, n_j is the number of subplots in reference plot j, and N is the total number of subplots in all reference plots (Brower et al. 1989). We took the logarithm of variables to prevent large values from dominating PS and, thus, to increase the representation of uncommon species. Plots that share all the same variables in the same proportions will have a PS = 1, whereas plots that share no variables will have a PS = 0.

Following Underwood and Chapman's (1998) description of its superior properties, we calculated the weighted average of the 1 – Bray-Curtis index of dissimilarity,

$$BC_i = \sum_{j=1}^{6} n_j(1-\sum_{k=1}^{K} |Z_{ik}-Z_{jk}|/(\sum_{k=1}^{N} Z_{ik} + \sum_{k=1}^{N} Z_{jk}))/N$$

where Z_{ik} is the mean abundance of species k in plot i. This index does not require proportional abundance or any transformation and is, therefore, more intuitive than proportional similarity, but it is interpreted in the same way as proportional similarity.

We created a third similarity index, endpoint difference (ED), bounded by 0 and 1 to incorporate within-plot variation,

$$ED_i = \sum_{j=1}^{6} n_j \sum_{k=1}^{K} \exp[-|Z_{ik}-Z_{jk}|/\sigma_{eij}]/K/N$$

where the value within the exponential function is the absolute value of the *t* statistic (Steel and Torrie 1980), s_{eij} is the joint standard error of Z_{ik} and Z_{jk} assuming unequal sample sizes, K is the number of variables, and Z_{ik} is either the average of a single variable (no logarithmic transformation) k from plot i (similarly for plot j) or the average proportional value of variable p_{ik}. of variable k. Plots that share the same variables in the same proportions (all $|Z_{ik}-Z_{jk}| = 0$) or that have large variability (standard errors are large) preventing these plots from being differentiated will have an ED equal or close to 1. Plots that share no variables (all $|Z_{ik}-Z_{jk}|$ are large) or that can be easily distinguished due to low variability (standard errors approach 0) will have an ED close to 0.

To determine which variables contributed most to the similarity pattern among treatments, we correlated the 24 similarity values with the contribution of each species. A positive correlation would indicate that the variable supported the similarity pattern, whereas a negative correlation would mean that the variable weakened the similarity pattern. We retained only variables with significant correlations (≥ 0.481 or ≤ -0.482, df = 23, $P < 0.05$) (Steel and Torrie 1980). For proportional similarity, the contribution of each variable per plot *i* was arbitrarily measured by:

$$\sum_{j=1}^{6} (1-0.5|p_{ik}-p_{jk}|)/6$$

where we averaged contributions over the six reference sites per variable. Similar averaging and calculations were performed for the 1 - Bray-Curtis and endpoint difference contributions:

$$\sum_{j=1}^{6} (1-|Z_{ik}-Z_{jk}|/(\sum_{k=1}^{N} Z_{ik} + \sum_{k=1}^{N} Z_{jk}))/6, \text{ and}$$

$$\sum_{j=1}^{6} \exp[-|Z_{ik}-Z_{jk}|/\sigma_{eij}]/6, \text{ respectively.}$$

We tested restoration treatment effectiveness by comparing the similarity indices using two-way ANCOVA for a randomized complete block design (Steel and Torrie 1980). Pre-treatment similarity was used as the covariate to account for differences among plots that existed prior to treatment application. Keeping within the maximum number of allowable independent contrasts for three degrees of freedom (Sokal and Rohlf 1981), we contrasted the following treatments: control versus spring burn (C vs. B), burn versus the herbicide ULW® (B vs. H), and herbicide versus felling/girdling (H vs. F) (see Provencher et al. 2000b for more information). Similarity values were transformed with $\sqrt{x}$, x^2, or $\log(x)$ to stabilize variances when necessary.

Results and Discussion

Similarity to the Reference Condition

Significant increases in similarity for herb-layer arthropods between spring burn and reference plots were not observed until fall 1996, although endpoint difference, while congruent with the other indices, was not significantly affected by treatments (Fig. 2A). The fact that arthropod similarity was only responding to fire was instructive. The arthropods that we sampled appeared to be closely tied to the plants as resources, but not to the percentage of hardwood reduction. In 1996, one year after initial treatment, felling/girdling topkilled the most oaks (93 percent), followed by herbicide (69 percent), and fire (18 percent), compared to fire-suppressed control plots, where the highest oak densities were found (1330 stems/ha ± 60) (Provencher et al. 2001b). On the other hand, fire causes groundcover plants to resprout, providing tender, nutritious forage promoting the growth of plant-eating populations (e.g., grasshoppers, leafhoppers, planthoppers) or groups that feed on live and dead vegetation (e.g., springtails) (Dunwiddie 1991; Nagel 1973; Owensby et al. 1970; Smith and Young 1959; Stein et al. 1992). Herbivorous arthropods and springtails are among the numerically dominant species we sampled, therefore strongly affecting similarity. In turn, a greater availability of arthropods lower in the food web should attract predators and parasites such as spiders, wasps, and some flies and beetles. Indeed, the parasitic (braconid) wasps *Chelonus* sp. and *Heterospilus* spp. and the spiders *Tmarus rubromaculatus* (Keyserling), *Misumenops* spp., *Mimetus* sp., and *Hentzia palmarum* (Hentz) were among the 20 more common species in burn and reference plots during the fall 1996.

Fuel reduction burns applied to herbicide and felling/girdling plots during the winter and spring of 1997 presented several opportunities to test if the response of herb-layer arthropods in herbicide and felling/girdling plots would follow the same pattern observed in the spring burn plots. We suspected that the effect would be stronger as plant resprouting was expected to be more complete (due to the continuous fuel matrix created by oak leaf drop and felled oaks). Burning should result in approximately 50 percent topkill and abundant resprouting (Glitzenstein et al. 1995), while herbicide application should practically eliminate oaks and significantly reduce resprouting.

Spring 1997 was a rather unusual field season as it immediately followed fuel reduction burns. As a result, similarity analyses were potentially influenced by half of the plots being charred. This does not offer a compelling test of the hypothesis. Not surprisingly, the spring burn plots were closest to the reference condition for all indices, but only significantly so for proportional similarity and 1 – Bray-Curtis (Figure 2B).

Arthropod data collected in Fall 1997 showed the strongest convergence to that in the reference condition. Despite the hot fires in felling/girdling-fire plots, the herb-layer arthropod assemblage was more similar to the reference assemblages in the fire only and felling/girdling-fire than in the herbicide-fire plots for all indices (Figure 2B). We attribute the difference between the herbicide and felling/girdling treatments to the greater herbaceous (mostly grasses) cover in the former treatment, a resource that herbivores are expected to exploit. The fire-suppressed control plots were still the least similar to the reference plots. The hypothesis that arthropods would rapidly benefit from the more thorough coverage of the hotter fires was confirmed: arthropods responded within 6 months after the 1997 fires, whereas a response came 1 full year after the spring burns of 1995. Seasonality of fire should not explain this effect because most fuel reduction burns were completed in the early spring. As in 1996, the reduction of hardwoods was not a factor that explained similarity results, the greatest total cumulative topkill of oaks occurred in the herbicide-fire plots (94 percent), with lower mortality in the felling/girdling-fire plots (62 percent) and the prescribed fire only plots (41 percent, a delayed mortality relative to 1996) (Provencher et al. 2001).

Although we hypothesized that the growth of arthropod populations benefited from newly resprouting palatable vegetation, by 1997 this explanation no longer applied to the plots burned two years earlier. This implies that once established, arthropod populations persist beyond when plant palatability is a key factor and/or the continued resprouting of hardwoods (Provencher et al. 2001a) is utilized as a source of palatable vegetation. Our data do not allow evaluation of the duration of fire suppression necessary before insect populations again become depressed.

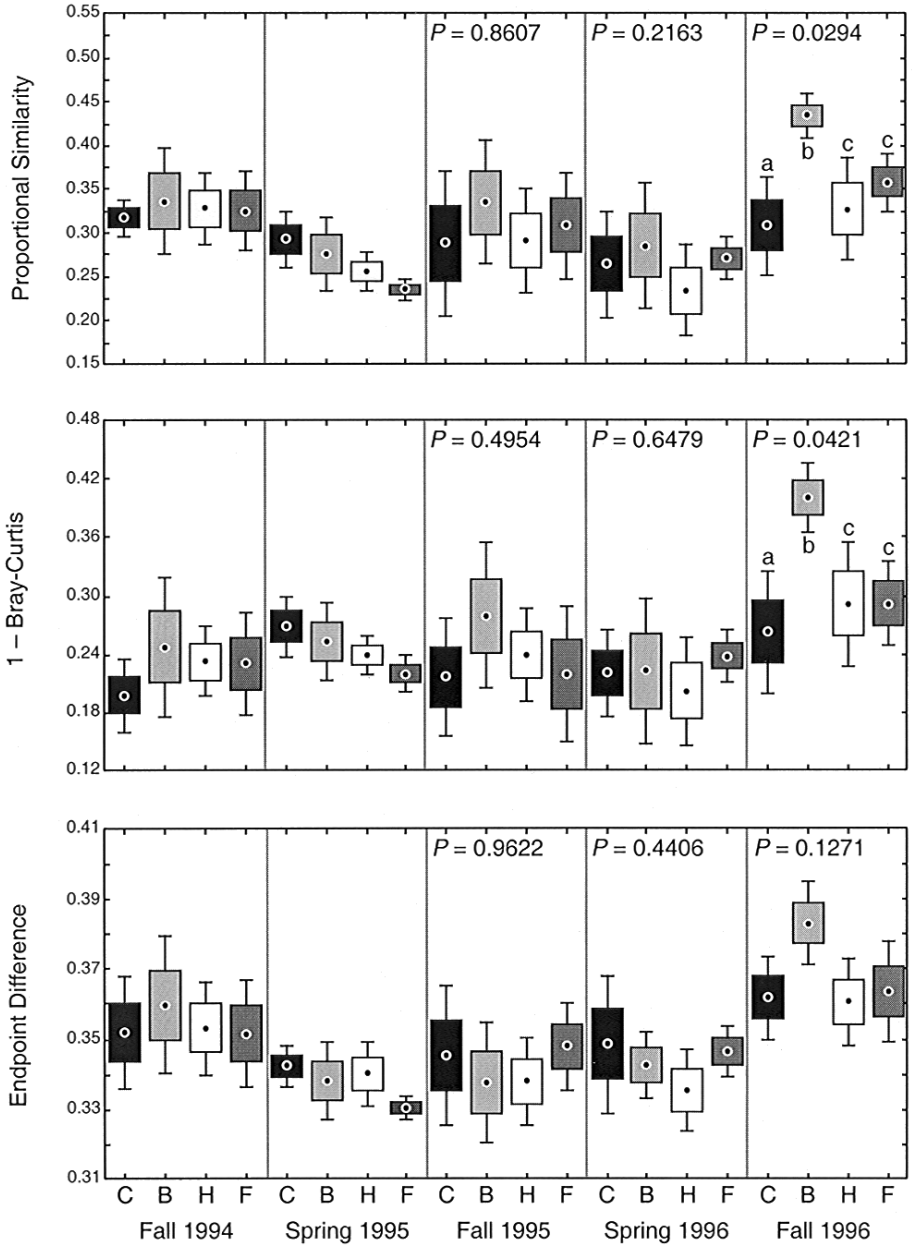

Figure 2A.—Time series of three indices (proportional similarity, 1 – Bray-Curtis index, and endpoint difference) measuring the similarity of herb-layer arthropods between each of four hardwood reduction treatments (spring burn, herbicide, felling/girdling, and no-treatment control) and reference plots from fall 1994-1996 at Eglin Air Force Base, Florida. Tests of treatment effects were calculated with two-way ANCOVA. The experimental design is a randomized complete block (6 blocks), split-plot design, but only the block design at the whole plot level is presented here. The covariate was the pre-treatment data from the fall 1994 or spring 1995. The error term is the mean square of the interaction of the block and restoration treatment effects. Similarity values received various transformations when it was necessary to stabilize variances. The center of the box is the mean, the edges of the box correspond to one standard error, and the error bars are a 95 percent confidence interval.

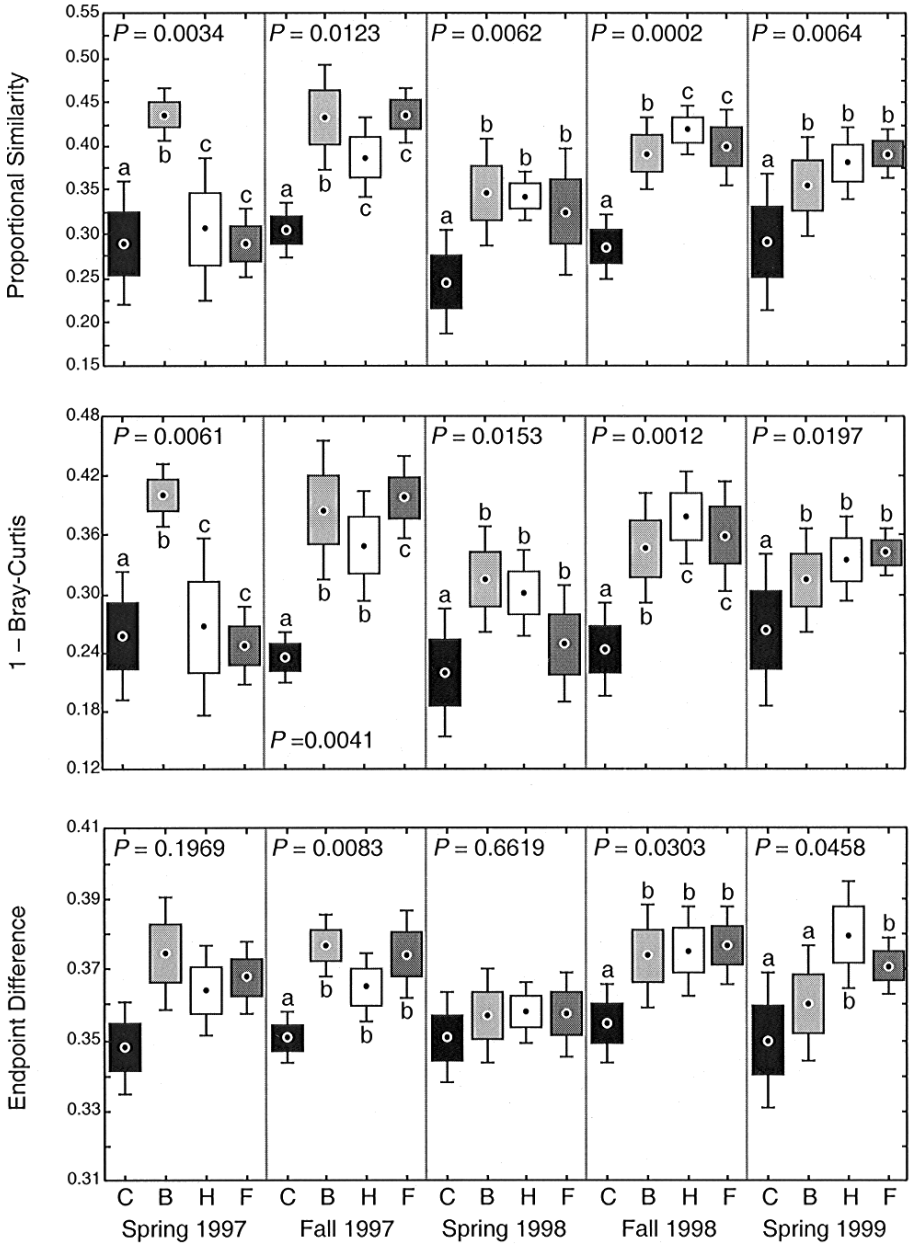

Figure 2B.—Time series of three indices (proportional similarity, 1 – Bray-Curtis index, and endpoint difference) measuring the similarity of herb-layer arthropods between each of four hardwood reduction treatments (spring burn, herbicide, felling/girdling, and no-treatment control) and reference plots from spring 1997-1999 at Eglin Air Force Base, Florida. Tests of treatment effects were calculated with two-way ANCOVA. The experimental design is a randomized complete block (6 blocks), split-plot design, but only the block design at the whole plot level is presented here. The covariate was the pre-treatment data from the fall 1994 or spring 1995. The error term is the mean square of the interaction of the block and restoration treatment effects. Similarity values received various transformations when it was necessary to stabilize variances. The center of the box is the mean, the edges of the box correspond to one standard error, and the error bars are a 95 percent confidence interval.

The similarity patterns seen in 1997 were repeated in spring and fall 1998 and spring 1999, with increased convergence toward the reference condition to some limited extent for herb-layer arthropods in herbicide plots (Figure 2B). Felling/girdling plots showed the same response to a lesser extent (Figure 2B). Fire appears to be the cause of these changes.

Indicators of restoration success

Two valuable outcomes of identifying the species or groups that contributed most to the similarly evaluation (indicator) are to reveal ecological relationships and to identify candidate variables that may be included in a monitoring program. We include as candidate indicators those variables that significantly contributed to the similarity of at least two of the three similarity indices.

Selection of arthropod indicators was difficult because of the great difference among similarity indices. For example, we never identified more than three species with the Bray-Curtis-based index, whereas >10 species were identified by the other indices. The springtail *Sminthurus* sp. 1, the leafhoppers *Erythroneura* spp., the planthopper *Metcalfa pruinosa* (Say), the leafhopper *Jikradia olitoria* (Say), and the jumping spider *H. palmarum* were the strongest indicators and the dominant species to increase after spring burning or immediately after the fuel reduction burns (Fig. 3). Except for the spider, these arthropods are herbivores or detritivores (the diet of *Sminthurus* sp. 1 is unknown but herbivory is suspected). Earlier we explained the relationship between fire, palatable plant resprouts, and arthropod population growth. These indicators illustrate this scenario well. These spiders are generalist predators and may themselves be tracking arthropod prey densities. (Although not evident in Figure 3 for fall 1996, average *H. palmarum* densities were higher in the burn plots than other treatments only after logarithmic transformation.)

During fall 1997, the first time the three similarity measures showed significant treatment differences, *Sminthurus* sp. 1 and the leafhoppers *Empoasca* spp., another common herbivore, were the strongest contributors to all the indices. The jumping spiders *Habronattus* spp. were also positively and significantly correlated to the similarity pattern, but they were uncommon in our samples. Endpoint difference was the only index that did not differentiate among the treatments in spring 1998, therefore suggesting that high variance in species density affected the treatment comparisons. The common leafhopper *J. olitoria* was the sole indicator shared by proportional similarity and the Bray-Curtis-based index, thus replacing *Sminthurus* sp. 1, which was not a strong contributor to any of the indices.

All three indices showed significant treatment differences in the following two seasons. In fall 1998, the leafhoppers (*Empoasca* spp.) were the group to contribute significantly to more than one index (proportional similarity and endpoint difference). These species' response to all hardwood reduction methods, especially fire, was pronounced as virtually no individuals were ever recorded from control plots (Figure 3). As in the previous season, no species significantly influenced all three indices during spring 1999. *Sminthurus* sp. 1, the jumping spider #25 (unidentified), the planthopper *Oecleus* sp., and the ant *Crematogaster ashmeadi* Mayr were the only indicators identified by at least two indices. Because the restoration effect for endpoint difference was barely significant (P = 0.046), jumping spider #25, *Oecleus* sp., and *C. ashmeadi* may not be the most reliable indicators of restoration success. This left *Sminthurus* sp. 1 as the strongest potential indicator, achieving its highest densities in felling/girdling plots, somewhat lower in herbicide and burn plots, and the lowest densities in control plots (Figure 3).

Overall, very few species dominated the list that we would suggest as indicators of restoration success over time: *Sminthurus* sp. 1, *J. olitoria*, *Empoasca* spp., *Erythroneura* spp., and *M. pruinosa*. With the exception of *Empoasca* spp., these species were generally common and statistical analyses could be performed on their densities (see Figure 3). Clearly, there was a connection between fire and the increased densities of these arthropods: we hypothesize that the palatability of resprouting plants is the main cause of this interaction.

Management Implications

- Long-term management of sandhills and other communities on Eglin on a large scale requires economical methods that stimulate productivity in the understory. Only fire will satisfy these two constraints for herb-layer arthropods.

Prescribed burning is substantially cheaper to apply than herbicide and felling/girdling. In 2000, burns started with ground ignition cost approximately $21.90/ha, whereas aerial ignition can now be accomplished for $8.60/ha (J. Furman, EAFB, pers. comm.). Herbicide application operations amount to $140.80/ha for the herbicide and $76.57/ha for labor (total $217.40/ha). Chainsaw felling/girdling is $158.10/ha, involving only labor. These estimates do not include the cost of a fuel reduction burn that would normally follow herbicide and felling/girdling operations.

- The relationship between fire, understory arthropods, and the diet of red-cockaded woodpeckers requires further research as this connection affects their management and that of other species in longleaf pine forests.

The diet of red-cockaded woodpeckers during the breeding season depends exclusively on arthropods. Hanula and Franzreb (1998) have shown that 70

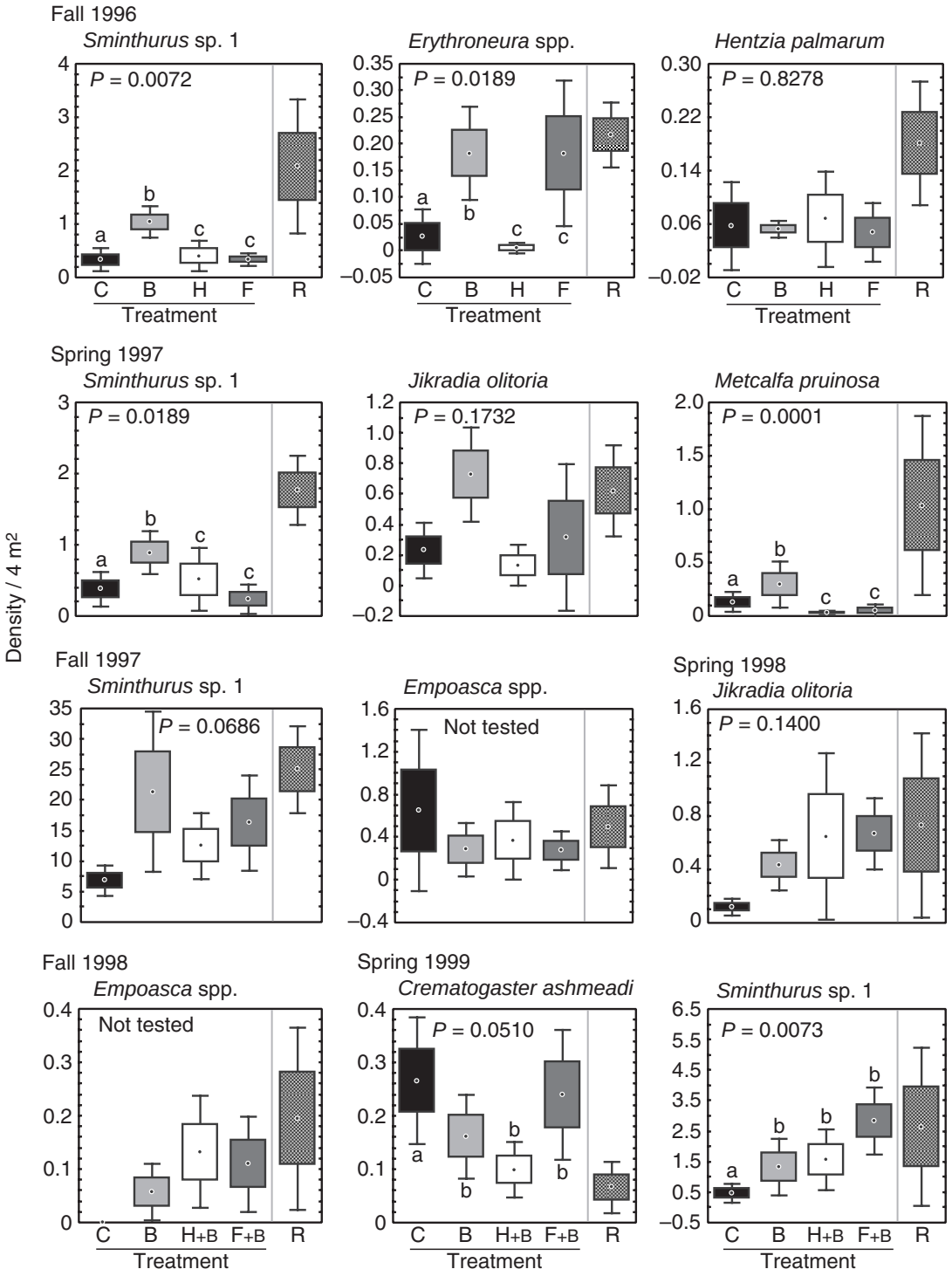

Figure 3.—The densities of herb-layer arthropods identified as the strongest indicators of restoration success by similarity analyses in hardwood reduction and reference plots at Eglin Air Force Base, Florida, from fall 1996 to spring 1999. Indicators were only selected when similarity values were significantly different among hardwood reduction treatments. Tests of treatment effects were calculated with two-way ANCOVA. The experimental design is a randomized complete block (6 blocks), split-plot design, but only the block design at the whole plot level is presented here. The covariate was the pre-treatment data from the fall 1994 or spring 1995. The error term is the mean square of the interaction of the block and restoration treatment effects. Density values received various transformations when it was necessary to stabilize variances. The center of the box is the mean, the edges of the box correspond to one standard error, and the error bars are a 95 percent confidence interval.

percent of the arthropod prey consumed by red-cockaded woodpeckers below the crown of longleaf pines disperse from the understory (mostly ground/soil arthropods). Therefore, there appears to be a strong dietary link between fire, understory arthropod population growth, and the woodpeckers' reproductive success (see also James et al. 1997).

- Little is known about arthropods in second- and old-growth longleaf pine forests. Quantitative and taxonomic research on this subject would greatly help both ecologists studying other aspects of longleaf pine forest ecology and managers needing to conserve arthropod communities and recover the populations of threatened and endangered species.

We identified potential indicators to monitor that may inform managers on longleaf pine sandhill quality and fire intervals. It is worthwhile to determine if decreasing similarity of herb-layer arthropods between managed and reference sites may roughly correspond with the end of a fire-free interval.

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