

MONARCH (*DANAUS PLEXIPPUS* L. NYMPHALIDAE) MIGRATION, NECTAR RESOURCES AND FIRE REGIMES IN THE OUACHITA MOUNTAINS OF ARKANSAS

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ABSTRACT. Monarchs (*Danaus plexippus*) pass through the Ouachita Mountains in large numbers in September and October on their annual migration to overwintering sites in the Transvolcanic Belt of central Mexico. Monarchs are dependent on nectar resources to fuel their migratory movements. In the Ouachita Mountains of west-central Arkansas migrating monarchs obtain nectar from a variety of plant species, especially *Bidens aristosa* and other composites. Fire suppression has greatly altered the structure of forest communities with major implications for ecological relationships. Sites that are undergoing restoration to a shortleaf pine-bluestem grass community following thinning and frequent prescribed fire, and thought to closely resemble pre-European conditions, support increased abundances of nectar resources and migrating monarchs compared to untreated controls. These results suggest that widespread fire-suppression since the early 1900s has substantially reduced nectar production for migrating monarchs in the Ouachita Mountains Physiographic Region.

Additional key words: Interior Highlands, surveys, restoration

The eastern North American population of the monarch butterfly, *Danaus plexippus* L., undertakes one of the most remarkable migrations of any lepidopteran (Urquhart 1976, Brower & Malcolm 1991). During the fall most individuals of this population migrate to extremely restricted sites in the Transvolcanic Belt of central Mexico (Urquhart 1976, Calvert & Brower 1986). Concern has been expressed about the continued health of this population and the persistence of the massive migration phenomenon (Wells *et al.* 1983, Brower & Malcolm 1991). Changes in abundance and quality of larval hosts (Zalucki & Brower 1992), loss of critical overwintering sites due to logging and fire (Brower 1996, Brower *et al.* 2002), vehicle mortality (McKenna *et al.* 2001), pesticides (Oberhauser 2004), introduced species (Calvert 2004), and transgenic Bt modified crops (Losey *et al.* 1999, Jesse and Obrycki 2004) have been identified as actual or potential threats. Less attention has been directed to landscape-level changes in nectar availability which ultimately fuels the extended fall migration to central Mexico (Garcia & Equihau-Zamora 1997, Brower & Pyle 2004).

Land use changes and management protocols in more natural habitats have drastically altered essentially all the land base that constitutes the breeding range and migration corridors of *D. plexippus* in eastern North America. The Ouachita Mountains Physiographic Region of west-central Arkansas and southeastern Oklahoma, encompassing 3,237,600 ha, remains primarily forested (Bukenhofer and Hedrick 1997). However, logging, fire suppression, and silvicultural management have altered vegetation structure and composition throughout the region (Foti and Glenn 1991, Masters *et al.* 1995). Fire-maintained shortleaf pine (*Pinus echinata*) forests were widespread in the

Ouachita Mountains until the early 20th century (Foti & Glenn 1991). Since the original harvest of these pine forests, most forested sites have been altered using intensive short-rotation pine production or remain as more natural forests, but have been subjected to fire suppression for several decades (Bukenhofer and Hedrick 1997). In either case, the abundance and quality of nectar resources available to Lepidoptera has been drastically altered (Thill *et al.* 2004).

The managers of the Ouachita National Forest have initiated a landscape scale restoration of the fire-maintained shortleaf pine-bluestem (*Schizachrium* spp., *Andropogon* spp.) ecosystem on 48,706 ha (U. S. Forest Service 1996). Restoration involves thinning the overstory, reduction of midstory vegetation, and prescribed burning on a three-year return interval. This restoration was undertaken to restore habitat for the endangered red-cockaded woodpecker (*Picoides borealis*) and to restore what is thought to be the pre-European structure and composition of the vegetation (Foti and Glenn 1991, Bukenhofer and Hedrick 1997). A number of authors have examined the effect of these restoration efforts on a diversity of taxa (see Thill *et al.* 2004).

As part of ongoing studies of the effects of restoration of fire-maintained shortleaf pine-bluestem habitat on lepidopteran communities, butterfly and nectar resource surveys were conducted in restored and untreated control plots. This paper reports results for *D. plexippus* in relation to the fire regime and suggests implications for fall migration and over-winter survival.

MATERIALS AND METHODS

This study was conducted on the Poteau Ranger District (34°45'N, 94°15'W) of the Ouachita National

Forest in west-central Arkansas. Topography in this region consists of east-west trending ridges and valleys with an elevational range of 150–820 m. Mixed hardwood forests dominate north-facing slopes and pine and mixed pine-hardwood forests dominate south-facing slopes. Prior to the initiation of fire-suppression activities, much of the landscape, especially the more xeric pine communities on south- and west-facing slopes, burned on a regular basis (Foti and Glenn 1991, Masters *et al.* 1995). These were primarily low intensity ground fires ignited by lightning, Native Americans, and more recently by European colonists. The resulting forest structure was characterized by pine-dominated overstories, sparse midstories, and diverse herbaceous understories (du Pratz 1975, Featherstonhaugh 1844, Nuttall 1980, Foti and Glenn 1991).

The Ouachita Mountains are still predominately forested; however, logging and fire-suppression have dramatically altered vegetation structure (Bukenhofer and Hedrick 1997). Compared to pre-European conditions, existing forests are typically characterized by a younger and denser canopy, a dense woody midstory, and a very suppressed herbaceous understory (Fenwood *et al.* 1984, Masters 1991, Sparks 1996). These changes have profoundly altered the original biodiversity of the Ouachita Mountains (Neal and Montague 1991, Smith and Neal 1991, Wilson *et al.* 1995, Sparks *et al.* 1998, Thill *et al.* 2004).

Landscape scale restoration was initiated in 1979, formally incorporated into the Ouachita National Forest Plan in 1996, and currently projects the restoration of 48,706 ha (7.3% of the Forest) to a shortleaf pine-bluestem condition (U. S. Forest Service 1996, Bukenhofer and Hedrick 1997).

Restoration consists of thinning of the overstory, removal of most midstory vegetation, and prescribed burning on approximately a 3-year rotation (U. S. Forest Service 1996). Ultimately, regeneration of canopy trees will be accomplished primarily through the implementation of irregular shelterwood and seed-tree harvests with a portion of the overstory retained indefinitely (U. S. Forest Service 1996). In addition, rotation age will be lengthened, primarily to provide sufficient older trees to support red-cockaded woodpecker recovery (Rudolph and Conner 1991). At the initiation of our studies, approximately 9,071 ha had been restored in a 42,148 ha landscape on the Poteau Ranger District (W. G. Montague pers. com.). We use "restored" in a relative sense and recognize that stands are on a trajectory toward an ecological state that resembles pre-European conditions.

MATERIALS AND METHODS

We censused butterflies and nectar resources annually in nine restored (treatment) sites and three un-restored (control) sites. Sites varied from 10.5 to 42.1 ha. All treated sites had received a minimum of four prescribed burns prior to the initiation of the study. Restored sites were included as portions of larger areas (range 65 to 2226 ha) burned on the same day. A total of three restored sites were prescribe-burned each spring. Consequently, in any given year, first, second, and third growing seasons post-fire were each represented by three sites. Additional details concerning treatment and control sites can be found in Thill *et al.* (2004).

Adult butterflies (only *D. plexippus* data reported here) were censused using a time-constrained walking census along 500-m triangular transects centrally located within each site (Pollard 1977, Pollard and Yates 1993). Individual transects were censused by slowly walking the length of transects for approximately 20 min. Time involved in counting butterfly aggregations, netting individuals for identification, or waiting for sun or wind conditions to conform to set variables was not included in the 20-min period. During 2000–2003, census counts were conducted four times each year (first week of April, June, August, October). Only October data for *D. plexippus* are reported here. Census counts were replicated three times each month, each replicate conducted by a different observer on different days during the survey week. Individual censuses were conducted between 0900 and 1330 hrs CST when temperatures were between 18–36° C and wind velocity beneath the canopy was not too high to suppress butterfly flight (Beaufort Scale <4). Censusing was further restricted to periods when sunlight was sufficient to cast discernable shadows. The response of butterflies to light, wind, temperature and cloud cover varies seasonally and daily in complex ways. Consequently, observer judgement further constrained censusing to those periods when butterfly activity appeared to be substantial. Additional details concerning treatment and control sites can be found in Thill *et al.* (2004).

In addition to census counts of butterflies, we recorded all observations of nectaring and other feeding activities by butterflies observed during this and other studies in the Ouachita Mountains between 1999 and 2004. Voucher specimens were deposited in the herbarium of Stephen F. Austin State University. Plant nomenclature uses the nomenclature found in Smith (1994).

Nectar resources were quantified by counting flowers

in three 1×100-m plots at each study site. Plots were located parallel to each side of the triangular 500-m butterfly census transect. Within these plots all potential nectar resources were counted each week that butterfly censuses were conducted. For most plant species, individual flowers or composite heads (capitula) were enumerated. Inflorescences, or portions thereof, were counted for a few species with small and/or dense aggregations of flowers (e.g. *Ceanothus americanus*, *Allium* spp., *Solidago* spp., Apiaceae). These enumeration decisions were based on estimating the structure that most closely approximated a separate landing site for a typical butterfly.

TABLE 1. List of nectar plants, inclusive nectaring dates by plant species, and number of nectaring observations for monarchs (*Danaus plexippus*) in the Ouachita Mountains, Arkansas during 1999–2005.

Plant Species	Dates	# Observations
<i>Bidens aristosa</i>	9/7–10/5	1890
<i>Eupatorium serotinum</i>	8/20–10/5	164
<i>Solidago</i> spp.	8/1–10/5	101
<i>Vernonia baldwinii</i>	6/30–10/2	93
<i>Cunila origanoides</i>	9/9–10/2	69
<i>Solidago petiolaris</i>	9/27–10/2	60
<i>Liatris elegans</i>	7/2–10/4	44
<i>Helenium amarum</i>	7/2–10/2	40
<i>Aster</i> spp.	9/8–10/5	39
<i>Aster ericoides</i>	9/27–10/4	28
<i>Aster anomalus</i>	9/27–10/2	22
<i>Senecio obovatus</i>	4/5–4/23	21
<i>Solidago rugosa</i>	10/1–10/5	19
<i>Asclepias tuberosa</i>	5/17–8/2	14
<i>Polygonum pennsylvanicum</i>	10/2–10/5	13
<i>Eupatorium</i> spp.	8/20–10/5	10
35 other species		74

RESULTS

In the Ouachita Mountains *D. plexippus* adults were rarely observed in spring and summer. However, during the fall migration in September and October, *D. plexippus* were common to abundant. We obtained a total of 2701 *D. plexippus* nectaring observations from 1999 to 2004. All but 101 of these observations were made during September and October (Table 1). *Danaus plexippus* nectared most frequently on *Bidens aristosa* (1890, 70.0%), *Solidago* spp. (180, 7.0%), *Eupatorium serotinum* (164, 6.1%), *Aster* spp. (98,

3.6%), *Vernonia baldwinii* (93, 3.4%), *Cunila origanoides* (69, 2.6%), *Liatris* spp. (59, 2.2%), and occasionally on an additional 31 species. The 1890 nectaring observations on *Bidens aristosa* were during the fall migration, and were concentrated primarily on the verges of the extensive road system within the region.

Due to low regional abundance we counted only 15 *D. plexippus* during April, June, and August censuses. During October, generally the peak of migration, a total of 1019 *D. plexippus* were detected during transect surveys. These observations occurred most often on restored treatments, especially during the first growing season post-fire, rather than on controls (Table 2). Significant differences were detected across treatments ($\chi^2 = 1637.6$, $df = 3$, $P < 0.001$).

Nectar resources were also more abundant on restored treatments than on controls (Table 3). Within restored treatments, nectar resources were more abundant on first year post-burn treatments and least abundant in third year post-burn treatments during the October surveys. Significant differences were frequently detected across these four treatments (Table 3).

TABLE 2. Number of *Danaus plexippus*, summed across plots and observers, detected during October surveys on restored sites and control sites on the Ouachita National Forest during 2000–2002.

Year	B-1 ^a	B-2	B-3	Control
2000	55	29	53	9
2001	746	101	13	0
2002	8	3	1	1
Total	809	133	67	10

^a B-1, B-2, and B-3 correspond to 1st, 2nd, and 3rd growing seasons post-burn.

DISCUSSION

Restored sites in the Ouachita Mountains consisting of a fire-maintained shortleaf pine-bluestem community supported a higher abundance of *D. plexippus* during migration than un-restored, fire-suppressed controls. This pattern was most noticeable during the first October post-fire. Both aspects of this pattern were similar to the abundance of nectar sources. Numbers of *D. plexippus* detected varied considerably across years. This may have been due to timing of the migration relative to our survey times, or changes in *D. plexippus* numbers in the eastern North American

TABLE 3. Response of nectar resources to pine-bluestem restoration on the Ouachita National Forest during October 2000–2002. Mean number of nectar resources per 300 m² plots in restored and control stands. Means in the same row sharing the same letter were not significantly different in a 1-way ANOVA with REGWQ at $P < 0.1$ (SAS Inst. Inc. 1988:598). Because abundance values varied greatly within treatments, data were rank transformed prior to analysis.

Year	B-1 ^a		B-2		B-3		Control		P
	x	SE	x	SE	x	SE	x	SE	
2000	746.3A	66.4	84.3B	45.9	59.3B	21.9	7.3C	5.0	0.0010
2001	2745.0A	604.9	3219.0A	1605.5	515.3B	106.2	183.7B	130.4	0.0047
2002	4587.3A	2987.2	1746.7A	689.1	719.3AB	355.0	35.0B	8.3	0.0181

^a B-1, B-2, and B-3 correspond to 1st, 2nd, and 3rd growing seasons post-burn

population. The very low numbers in 2002 followed catastrophic winter storm mortality at the Mexican overwintering sites the previous January (Brower *et al.* 2004).

In the absence of frequent fire, nectar resources in the forested portions of the Ouachita Mountains Physiographic Region are generally low. Improved pastures and intensively managed pine plantations 2–3 years after planting, the only other significant land uses in the region, also typically support a low abundance of nectar resources. Limited areas of increased nectar abundance occur in disturbed sites, i.e. road verges, utility rights-of-way, fence rows, and areas of recent timber harvest. Thus, at the regional level, in this primarily forested area, nectar resources may be limiting for lepidopteran species that require them (Thill *et al.* 2004, Rudolph *et al.* In prep.). Similar results were found for fire-maintained pine communities in eastern Texas (Rudolph and Ely 2000).

Due to the very patchy distribution of nectar sources in relation to roads, rights-of-way, and forest management we were unable to assess the relative abundance of nectar sources across the entire landscape. The relative numbers of nectaring observations in Table 1 are probably biased toward those occurring along road verges. However, butterflies, including *D. plexippus*, were frequently observed nectaring along the transect surveys, especially in the restored treatments.

Data presented here indicate that fire suppression has resulted in a landscape that is currently depauperate in nectar availability. We suggest that reduced nectar availability, compared to probable pre-European conditions, limits use of the widespread fire-suppressed habitats by monarchs and other lepidopteran species (Thill *et al.* 2004). The large numbers of monarchs passing through the Ouachita Mountains each fall obtain nectar resources primarily from concentrations

of flowers located in disturbed sites, mainly the abundant *Bidens aristosa* growing on road verges. How this current availability of nectar resources compares with the pattern of nectar resources dispersed across the forest landscape in the pre-European fire-maintained shortleaf pine forests is unknown, but this pattern suggests that fire suppression has greatly limited the availability of nectar resources across most of the forested landscape.

Lipid-loading by *D. plexippus* during the fall migration, both to fuel the migration and sustain winter survival, is crucial (Brower 1985, Alonso-Mejia *et al.* 1997). Brower and Pyle (2004) suggest that lack of nectar resources might be a limiting factor for migrating *D. plexippus*. In addition, a significant proportion of the monarchs inhabiting the wintering sites in the Transvolcanic Belt lack sufficient lipids to survive until spring (Brower & Pyle 2004). A detailed understanding of the current quality and availability of nectar resources along the migration corridor, and effects of historical changes, would allow an improved understanding of the remarkable migration of *D. plexippus*. Our results suggest that historical changes have been substantial, even in a landscape still dominated by “natural” plant communities. These changes may have potential consequences for migrating monarchs. Habitat and critical ecological processes, fire in this instance, may both be important in maintaining a major biological phenomenon on a continental scale.

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