The Suitability of Butterflies as Indicators of Ecosystem Condition: A Comparison of Butterfly Diversity Across Stand Treatments in Northern Arizona

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Abstract. Past human activities have resulted in a broad spectrum of ponderosa pine (*Pinus ponderosa*) stand conditions on the Colorado Plateau. A team of researchers at Northern Arizona University's School of Forestry is using common experimental plots to evaluate how highly-variable forest conditions influence potential ecological indicator species and guilds. Butterflies are one of several insect guilds that we are evaluating. During 1997 and 1998, we monitored populations of adult butterflies within replicated unmanaged, thinned, thinned and prescribed-burned, and wildfire-affected ponderosa pine sites. We did not detect a significant effect of stand treatment on butterfly abundance or similarity at the family level after two years, despite our large plot size (20-80 ha). Important treatment effects may be masked by butterfly movement between plots, heterogeneous forest stand structure, time since treatment, number of stands sampled, climate, and our sampling of adult butterflies. We suggest that sampling effort should be increased and data analyzed at the species level to quantify butterfly response to stand treatment.

Key words: Lepidoptera, *Pinus ponderosa*, indicator species, forest treatments, thinning, prescribed fire, wildfire

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INTRODUCTION

Past human activities (e.g, logging, grazing, fire suppression) have impacted stand conditions in ponderosa pine forests across the Colorado Plateau (Weaver 1951, Covington et al. 1997). The combination of past human activities has lead to structural and functional forest changes, often resulting in dense stands with low understory plant diversity (Harrington and Sackett 1992, White 1985, Covington and Moore 1994, Fulé et al. 1997). A team of researchers (STIFH, Stand Treatment Impacts on Forest Health) at Northern Arizona University's School of Forestry is evaluating the effects of past stand treatments on insects, fungi, understory plants, forest structure, and eventually ecosystem function. Butterflies (Lepidoptera) are one of several guilds that we are evaluating as a potential ecological indicator of forest condition in northern Arizona. Our goal is to find a group of species that is easy to evaluate, in addition to exhibiting changes in abundance and richness in response to differences in stand treatments.

Indicator species are thought to either signal the presence/abundance of other species, or to signal chemical/physical changes in the environment through changes in their own presence or abundance (Landres et al. 1988, Simberloff 1998). The second of these types of indicators is referred to as an ecological indicator (McGeoch 1998). One of the key goals in using an indicator is to simplify measurements of a complex system without losing important information (Ferris and Humphrey 1999). A number of authors have proposed criteria for selecting indicator species (e.g., Landres et al. 1988, Rodriguez et al. 1998, Ferris and Humphrey 1999). Recently, Hilty and Merenlender (2000) organized and compiled these criteria into a comprehensive list. They suggest that no indicator can meet all the suggested criteria, but should meet a majority of the standards.

In many regions of the world, Lepidoptera are widely accepted as ecological indicators of ecosystem health (Rosenberg et al. 1986, New et al. 1995, Beccaloni and Gaston 1995, Oostermeijer and van Swaay 1998), and meet a number of the criteria set forth by Hilty and Merenlender (2000). Butterflies have a fairly clear taxonomy, and their life history and biology are well defined (Nelson and Anderson 1994, Wood and Gillman 1998). Many of their physiological tolerances, such as light, temperature, and habitat requirements, have been quantified (Warren 1985, Thomas and Harrison 1992, Greatorex-Davies et al. 1993, Sparks et al. 1996, Oostermeijer and Swaay 1998, Pollard et al. 1998), and correlations with changes in ecosystem conditions have been demonstrated (Bowman et al. 1990, Thomas and Harrison 1992, Hill et al. 1995, Pullin 1996, Sparks et al. 1996, Spitzer et al. 1997, Pollard et al. 1998, Schultz 1998, Swengel 1998). In addition, butterflies are small, have high reproductive rates, and are at a low trophic level that allow them to quickly respond to environmental stress. Many butterflies specialize on a specific plant species for oviposition or feeding (Ehrlich 1984, Oostermeijer and van Swaay 1998). Butterflies tend to be easy to find and measure. Also, they are charismatic, and the public tends to show interest in them.

There are drawbacks to using butterflies as ecological indicators: (1) they are fairly mobile and may be able to tolerate some levels of disturbance because of their ability to move and find resources; (2) their ability to respond to change can be a hindrance in areas with high climatic variability, as changes detected in their abundance may be in response to a climatic condition instead of ecosystem structure (Pollard and Yates 1993).

We evaluated how the abundance and diversity of butterflies varied among four replicated forest treatments in northern Arizona. We hypothesized that butterfly abundance and diversity should be lower in unmanaged areas than in treated stands, and that high intensity fire (represented by stand-replacing wildfire) should correlate with high butterfly abundance and diversity. Another study, using our same stands and other stands from the STIFH project, found the abundance of nectar-bearing plants highest in stands that experienced wildfire, and lowest in stands that did not have applied silvicultural treatments (Griffis et al. 2001). We attempt, by showing correlations between butterfly abundance and diversity, to assess the suitability of using butterflies as environmental indicators in northern Arizona ponderosa pine forests.

METHODS

Study Site

The study area, located on the Coconino Plateau in northern Arizona (Fig. 1), is approximately 2,000 to 2,450 m elevation in a ponderosa pine/Arizona fescue (*Pinus ponderosa* Dougl. ex Laws /*Festuca arizonica* Vasey) association (USDA Forest Service 1997). The dominant overstory species was *Pinus ponderosa* (ponderosa pine) with a small component of *Quercus gambelii* (gambel oak). The understory is characterized by the most common native species; *Festuca arizonica*, *Elymus elymoides* (Raf.) Swezey,

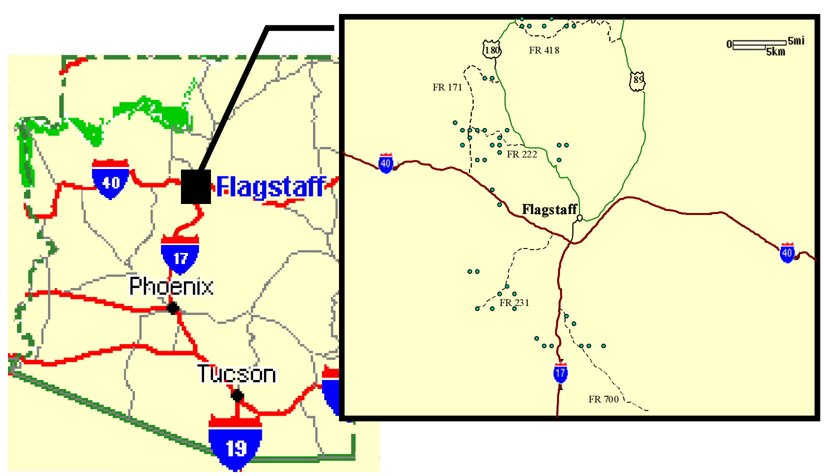

Figure 1. Location of STIFH research plots in ponderosa pine forests near Flagstaff, Arizona. Circles on inset illustrate individual plots. From Bailey et al. (this volume).

Cirsium wheeleri (Gray) Petrak., *Carex* spp., *Muhlenbergia montana* (Nutt.) A.S. Hitchc., *Lupinus argenteus* Pursh, and *Achillea millefolium* L.; and the most common exotic species; *Salsola kali* var. *tenuifolia* Tausch., *Verbascum thapsus* L., *Poa pratensis* L., *Chenopodium graveolens* Willd., *Bromus tectorum* L., and *Descurainia obtusa* (Greene) O.E. Schulz (Griffis et al. 2001). During the first year of the study (1997), three stand treatments were examined: unmanaged, thinned and burned, and wildfire. In the second year, 1998, thinned stands were sampled in addition to the 1997 treatments. Three stands per treatment were sampled in 1997; four stands per treatment were sampled in 1998. Stands ranged in size from 20-80 ha (50-200 acres).

Stands were selected randomly from a larger pool of stands used in the STIFH project (Fig. 1). Our stands were composed of mature, even-aged blackjack (younger than approximately 125 years) ponderosa pine, with larger, yellow pine (older than approximately 125 years and larger than 64 cm dbh) not exceeding 10 trees/ha. Thinned stands had greater than 30% of their basal area removed between 1987 and 1993, with at least 50% of this coming from diameter classes greater than 30 cm (pulpwood size). Thinned and prescribed burned stands additionally received a broadcast burn treatment within 3 to 4 years of thinning. Three of these stands were burned in 1991 and one in 1995. Overstory survival following the broadcast burn was greater than 90%. Unmanaged stands have not received a density altering treatment within the last 30 years, such that the stands have greater than 60% of maximum stand density index (and thus are actively self-thinning). Wildfire areas are stands in which greater than 90% of the basal area was killed and/or consumed by wildfire since 1994 (Bailey et al. 2001).

Butterfly Sampling in 1997

All butterfly specimens captured in 1997 were included in the establishment of a permanent reference collection used for identification in later studies. Two person hours of sampling were conducted at each site every three weeks for five visits from May to August 1997. Butterflies were collected using a time-constrained area search during peak flight periods (0900 to 1500 hours), using standard 18" insect collecting nets. The same people collected data throughout the year to minimize variation in collection methods. We searched the pre-delineated stand, collecting as many butterflies as possible. All specimens were handled and mounted using conventional procedures, with butterflies identified using Pyle (1981) and Tilden and Smith (1986). When further taxonomic identification was necessary, wing venation was examined, as described by Borror et al. (1976). External experts confirmed most species identification.

Butterfly Sampling in 1998

We conducted a time-constrained area search and counted all Lepidoptera observed and captured, using the same techniques and time constraints for capture as in the previous year (1997). All stands were visited once during the summer during peak butterfly activity (based on information from 1997 surveys). We only used one sampling visit based on when the largest numbers of lepidopterans were active during 1997. Butterfly populations fluctuate throughout the year based on species life history. Our goal was to assess using butterflies as a very rapid and simple indicator of the amount of disturbance in a stand; therefore, we made our sampling as simple as possible. At the end of the sampling period, we recorded the number and family of all butterflies observed and caught, and released all insects. Data were summarized at the family level because of identification ease in the field, and because others have shown responses of insects to changes in the environment at higher taxonomic and guild levels (Greenburg and McGrane 1996, Kevan 1999).

Data Analysis

We used data from 1997 to calculate Jaccard's similarity index to compare the similarity of butterfly species across treatments. Data from 1997 and 1998 were analyzed separately due to differences in sampling procedures. The butterfly numbers in 1997, by family, were averaged across repeated sampling over time to calculate one number per family per plot. We used Kruskal-Wallis rank tests to assess variation in number of individuals per family, by treatment type for both years.

RESULTS

The numbers of individuals caught in each treatment for each butterfly family in the analyses are listed in Table 1. A list of butterfly species caught during 1997 and verified to species is listed in Table 2. The total number of butterflies did not vary among treatment types for either 1997 ($\chi^2 = 0.622$, df = 2, p = 0.733) or 1998 ($\chi^2 = 0.969$, df = 3, p = 0.809). Neither species similarity nor abundance of butterflies by families was significantly different across the four experimental treatments. Butterfly similarity from Jaccard's similarity index, were statistically equal in 1997 across the experimental treatments (Table 3). These analyses were not repeated in 1998. Likewise, total abundance of butterflies distributed by treatment type was not statistically significant in either 1997 or 1998 (Table 4).

Table 1. The numbers of individuals within families of Lepidoptera captured (1997) and captured and observed (1998) in ponderosa pine cover type under four experimental stand conditions (unmanaged, thinned, thinned and burned, and wildfire) on the Coconino National Forest.

Family	Unmanaged		Thinned		Thinned and Burned		Wildfire	
	97'	98'	97'	98'	97'	98'	97'	98'
Lycanidae	6	81	-	59	3	79	1	43
Peridae	26	9	-	4	26	20	12	27
Nymphalidae	1	18	-	16	1	2	13	26
Hesperidae	0	3	-	3	0	2	1	5
Papilionidae	0	0	-	0	0	0	0	1

Table 2. Species of butterflies collected and verified in 1997 and 1998 in ponderosa pine cover type under four experimental stand conditions (unmanaged, thinned, thinned and burned, and wildfire) on the Coconino National Forest.

Family	Scientific Name	Common Name
PIERIDAE:	*Neophasia menapia*	Pine White
	Pontia protodice	Checkered White
	Colias eurytheme	Orange Sulphur
	Nathalis iole	Dainty Sulphur
LYCAENIDAE:	*Callophrys eryphou*	Western Pine Elfin
	Strymon melinus	Gray Hairstreak
	Hemiargus isola	Reakirt's Hairstreak
	Celastrina ladon	Spring Azure
	Lycaeides melissa	Melissa Blue
	Icaricia icariodes	Boisduval's Blue
	Icaricia lupini	Lupine Blue
NYMPHALIDAE:	*Euptoieta claudia*	Variegated Fritillary
	Poladryas minuta	Dotted Checkerspot
	Vanessa cardui	Painted Lady
	Vanessa virginiensis	American Lady
	Phyciodes pratensis	Field Crescent
HESPERIDAE:	*Pyrgus communis*	Common Checkered-Skipper

The butterfly community in this ponderosa pine system is dominated by three families: Lycaenidae, Pieridae, and Nymphalidae. The abundance of individuals within these families varied between years (Fig. 2). There appeared to be a trend of decreased abundance of lycanid butterflies across the treatment gradient in both years. There was an increase in perid butterflies across the same gradient in 1998, but a decrease in 1997. There may also be an increase in nymphalid species for both years across the disturbance gradient (Fig. 2).

DISCUSSION

We did not detect differences in butterfly abundance or diversity among forest treatments, but a similar study focused on forest restoration, including thinning and

Table 3. Jaccard's similarity index calculated based on butterfly species similarity for 1997 sampling on the Coconino National Forest.

Comparison	Jaccard's Similarity Index
Thinned and Prescribed Burned vs. Control	0.575
Thinned and Burned vs. Wildfire	0.650
Wildfire vs Control	0.575

Table 4. Results from Kruskal-Wallis rank tests on the distribution of butterfly families among treatments (unmanaged, thinned, thinned and prescribed burned, stand replacing wildfire) for 1997 and 1998 on the Coconino National Forest, northern Arizona.

Family		χ^2	df	P-value
1997	Lycaenidae	2.249	2	0.325
	Pieridae	1.689	2	0.430
	Nymphalidae	3.684	2	0.159
	Hesperidae	2.889	2	0.236
1998	Lycaenidae	1.994	3	0.574
	Pieridae	2.051	3	0.562
	Nymphalidae	6.357	3	0.095
	Hesperidae	0.489	3	0.921
	Papilionidae	3.000	3	0.392

burning treatments in northern Arizona, demonstrated increased species richness and abundance in treated areas of the ponderosa pine forest (Waltz and Covington 1999). Their study concluded that there was an increase in butterfly abundance, correlated with an increase in flowering plants, in response to restoration treatments. However, their study compared a single transect in a thinned and burned stand with a single control-stand transect. Their lack of replication can decrease variance and artificially increase the chances of detecting significant relationships between treatments and butterflies.

Other studies have detected changes in abundances of various insect taxa, including butterflies, in response to silvicultural treatments (Greenburg and McGrane 1996, Swengel 1998, Wood and Gillman 1998). Furthermore, some have suggested that sampling at the genus or family level of insects may give enough detailed information to permit evaluation of the health or sustainability of the system in question (Paoletti 1999). However, when the butterflies are lumped by family, it is likely that individual species effects are masked (Weaver 1995). Species within a family vary in their life histories and, hence, may vary in their responses to environmental perturbation. It is often at the individual or population level that organisms respond to changes in the environment (Maltby 1999). Future work should include a focus on individual species, as well as the family, and in particular species and families that are relatively abundant but specific in their ecological requirements (Thomas and Mallorie 1985).

We also want to point out that butterfly numbers varied greatly between years. This variation could be an artifact of our small sample size. In addition, at high elevations climatic conditions (e.g., temperature, precipitation, wind) can vary erratically and cyclically between years (Gass and Lertzman 1980, Griffis 1999). Butterflies

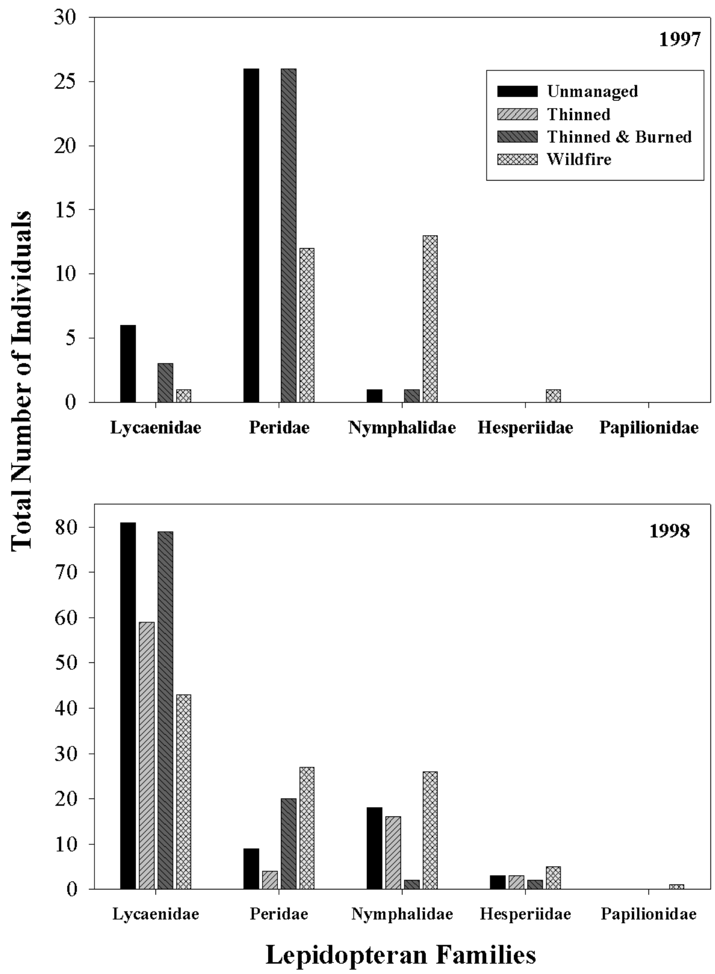

Figure 2. Total numbers of butterflies observed and captured; grouped by family during 1997 and 1998 in relation to forest stand treatments on the Coconino National Forest. Notice the difference in scales between graphs.

may respond more directly to climatic conditions than to stand conditions (Pollard and Yates 1993). This alone would make them very difficult to utilize as an indicator of stand condition. In addition, when surveying, we recorded adult butterfly diurnal behavior and did not measure butterfly fitness (i.e., survival or reproductive success) in relation to habitat patch. If butterflies disperse from a source population into marginal habitat, we may just be measuring density dependent population responses or dispersal events, and not responses to stand condition.

Finally, the methods that we used in this study may be better used for assessing presence or absence of a species/family (e.g., Thomas and Harrison 1992). We suggest using transect counts, which can give quantitative estimates of abundance based on area, and may be better used to quantify butterfly abundance in heterogeneous forest stands (Pollard et al. 1975, Thomas 1983).

We suggest that at the family level, butterflies may not be an indicator of ecosystem health that is both simply and rapidly measured. It is possible, with a sampling design based on achieving quantitative estimates of abundance and species identification, butterflies could be used as ecosystem indicators. However, in an arid environment such as northern Arizona, achieving a sample size large enough to account for climatic variation may be difficult. Also, the length of response time from treatment may influence butterfly presence.

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