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Land Management and Climate Impacts on Missouri Forest Insects

by Robert J. Marquis

Insect declines

Over the last 50 years, entomologists, ecologists, naturalists, and conservation biologists have been shining a light on the problem of declining insect populations. Of the estimated 10 million or so insects on Earth today, about 1.1 million species have been described. Of those species, population trends in butterflies and bees are the most well-known. Unlike the more diverse moths, which are mostly active at night, butterflies and bees are active during the day, when humans are most often out observing in nature. In North America, there is a manageable number of species of both butterflies and bees at any one location. With the help of guidebooks, one can learn to identify most if not all the species in a given location with a little effort, and thus contribute to our understanding of population trends through participation in citizen science studies. Forty to 80 species of butterflies might be found commonly in a given location in Missouri, while bumble bees in Missouri number about 10 species total.

Aquatic insects, especially caddisflies, mayflies, midges, and stoneflies, are also particularly well known. Because these insects are prey of fish, they are of great interest to fishermen. Tie flying, the creation of artificial lures that mimic insects, is an art form and an entire cottage industry unto itself. These aquatic insects are of great import to stream ecologists and water quality managers because the particular composition of the aquatic insect community at any one location is an excellent indicator of water quality.

Dragon- and damselflies span the terrestrial and aquatic habitats. Juvenile forms are aquatic while adults are terrestrial. Adults are often brightly colored, live a relatively long time, hold territories, and are fierce predators of other insects. Naturalists and insect behavioral ecologists often spend much time observing them, and there are also field guides dedicated to the identification of dragon- and damselflies of many regions.

These various insects are all under threat. The main cause of population decline and ultimately extinction is the alteration of the natural habitat of these animals, mostly by conversion to agriculture, grazing, logging, draining of wetlands, and urbanization. Also implicated are pesticides, climate change, disease, imported parasites, and nutrient and light pollution. As so aptly put in a recent review article on the causes of insect declines, it is a 'death by a thousand cuts' (Wagner et al. 2021).

Two relatively local studies provide evidence that the effects of habitat destruction have been going on for some time. A survey conducted in 1908 of butterflies in Winneshiek County, Iowa, documented 73 species. Ninety years later, only 55 species could be found (Larsen and Bovee 2001). Similarly, 50% of the bee species documented in the late 1880's in the Carlinville, Illinois, area, could not be found 120 years later (Burkle et al. 2013). In both cases, loss of natural habitat was implicated, while in the Illinois study, there was a shift in the timing of bee activity and flowering phenology of the plants on which the bees depend, suggesting an additional impact of climate change.

A recent study in Germany brought to the forefront the issue of declining insect populations. These researchers sampled flying insects over the years 1989–2016 in various locations in Germany. They found more than a 75% decline in flying insect biomass over these 27 years (Hallman et al. 2017). Increased temperatures and reduced rainfall were implicated as the probable causes for change (Welti et al. 2022). This Hallman study led to the first use of the term 'Insect Apocalypse' in the popular press (Jarvis 2018), which in turn led to a special session on insect decline at the annual meeting of the Entomological Society of America, held in St. Louis, in November, 2019. Since that conference, numerous data papers, reviews, and meta-analyses have been published, only supporting the earlier reported trends.

Habitat alteration in Missouri: Logging in the Ozarks

The history of logging in Missouri and in most forests of the United States is one of over exploitation and habitat alteration. In Missouri, almost all forested land had been logged by the early 1900's with just a few stands of virgin timber left uncut (Flader 2004). Most timber harvested was oak, while pine was prized to such a degree that only one-tenth of the original pine forest acreage exists today (Guyette et al. 2007). Erosion following logging and farming in river bottoms of the Ozarks filled many channels with excessive sands and gravels (Jacobsen and Primm 1997). Both deer (Budd et al. 2018) and turkey (Clawson et al. 2015) were imported from surrounding states to make up for the loss following complete alteration of the landscape. Historical and first-hand accounts and photos attest to the devastation (e.g., Jacobsen and Primm 1997). Given that today there is much continuous forest, broken up by openings of natural glades, towns, and scattered farmlands, it is difficult to imagine the extreme loss of forest cover that occurred. Today, 34% of Missouri is covered in forest, while in the 1880's it is estimated that 70% of the state was in some form of wooded cover including forest, woodland and savanna (Goff 2018).

The Missouri Department of Conservation (MDC), founded in 1937, realized that by the late 1980's the second growth forests were maturing, and at some point in the near future, trees would be old enough to harvest once again. The question was, 'How was logging to be conducted in a more sustainable way?': that is, in a way that will ensure forest productivity long into future? One measure of sustainability is an economic one: can current extraction of resources be continued into the distant future without decreased productivity? One parameter to consider is the economic benefit to humans through timber production, recreation, and protection of water quality of the streams and rivers that drain the forest watersheds. It is likely that complete clear-cutting of the state once again would not be sustainable by this definition as the ecosystem would unable to provide sufficient resources to maintain forest productivity. But of course, we value forests more than just for their wood volume. We value the insects, birds, reptiles and amphibians, the mussels and fish of the streams and rivers, and all plants that are not trees. We have little data that might tell us what the impact of this original devastation might have had on the biodiversity of region, but this is where the Missouri Forest Ecosystem Project becomes relevant.

Missouri Ozark Forest Ecosystem Project

The MDC initiated a 100–200 year experiment, the Missouri Forest Ecosystem Project or MOFEP, in 1989, in the Current River Watershed in southeastern Missouri (Shifley and Brookshire 2000). The MOFEP is one of the best well-kept secrets among experimental forest ecosystem studies in North America. The goal of this experiment was to quantify the relative sustainability of two contrasting tree extraction regimes on 1) timber production, and 2) maintenance of non-tree components (i.e., birds, insects, aquatic biota, etc.). Two treatments or management regimes were applied: clear-cutting in small patches or thinning of forests in the same size patches. Measures for the two experimental types would then be compared to non-harvested (control) forests. The designers of the project wanted to know both the local impacts of cutting (comparing logged forests vs. nearby unlogged forest), but more importantly how clear-cutting vs. thinning affects processes at the landscape level, across multiple units of the same treatment or management type. Harvest would take place every 10–15 years, depending on how fast trees were growing. A full cycle of cutting would be completed after 100–150 years. Data collection would be by teams of researchers focusing on particular components of the ecosystem: trees, birds, amphibians, soil invertebrates, forest insects, acorn and berry production, and many others.

Our group focused on insects feeding on white and black oak trees, two of the dominant tree species in southern Missouri. Most of these are caterpillars, the immature stages of butterflies and moths. These insects consume much leaf tissue of Missouri trees, in certain years reaching high enough numbers that large tracts of forest are completely defoliated. One concern was that forest management regime might influence the abundance of these insects, perhaps increasing them, and in so doing, cause widespread defoliation and a resultant decrease in tree growth. These insects, however, also serve as food for the vertebrate animals that consume them, mostly birds, bats, and rodents. Finally, as adults many are pollinators of the flowers of understory shrubs and the ground flora. The Missouri Ozark forests probably house a large percentage of the total 2,280+ species of moths and butterflies known for Missouri (P. E. Koenig, pers. comm.). Thus they represent a major portion of the state's biodiversity in terms of sheer numbers, but also are a component that is key to important ecological processes, predation and pollination, and parasitism, which promote the maintenance of other diverse components of the Ozark ecosystem.

When we first began this project, we had little idea which species of caterpillars we would encounter and how many of each, let alone what the effects of timber harvest might be on caterpillar abundance. In fact, we were being extremely optimistic that we could identify the insects we encountered. There was only a single guidebook to caterpillars of any location in North America, and many of the descriptions and photographs were scattered throughout the primary scientific literature and "gray" publications of the U.S. Forest Service and state forestry agencies. A further obstacle was that available descriptions were of economically important species (outbreak species) and usually of last instars, the last caterpillar stage. But we were sampling many species that caused little damage by themselves, so they had not been studied in any depth, and we were encountering them in early as well as late instars. It was not unusual to find that caterpillars change morphology and color pattern as they go from one instar stage to the next. Prior to starting, we conferred with a number of caterpillar experts, many of whom had sampled in various parts of the country, on oaks, focusing on their particular specialty group of caterpillars. When we described the project, the general reaction was a sarcastic "Good luck!" We also had to deal with the fact that most of the foliage of oak trees is located in the canopy, to which there was no easy access. Finally, even prior to our starting, oaks were thought to harbor an inordinate amount of caterpillar diversity, something that we took to be an exciting challenge rather than an excuse not to be involved or to study tree species with less diverse faunas.

Photo by R.J. Marquis

Figure 1. Using a boom truck with attached bucket to census insects in the oak canopy of the Current River Watershed, Missouri Ozark Forest Ecosystem Project.

Photo by J. Fabara-Rojas

Figure 2. Censusing insects on understory white oak in the Missouri Ozark Forest Ecosystem Project

Many of these problems that we encountered have been resolved. There are now a number of guidebooks that allow identification of forest caterpillars, including the one that we published with the goal of alleviating this problem for future researchers (Marquis et al. 2019b). In addition there are now a number of dependable websites that can aid identification and provide geographic information based on museum specimens. Finally, most butterfly and moth species of North America have been genetically bar-coded, so it is possible to send extracted DNA from unidentified individuals to a Canadian lab for identification based on matching genes of the unidentified individuals to the lab's identified specimens. To solve the issue of tree canopy access, we rented a bucket truck with a 35-foot boom to get us in the canopy in a few selected locations where the terrain was flat. It became a real art to maneuver this huge truck amongst trees without damaging them, and getting the boom in position to sample branches with sufficient numbers of leaves.

Missouri Ozark Oak Caterpillar Fauna

We sampled caterpillars for twenty years within the MOFEP experimental study (Marquis et al. 2019a). We recorded leaf-chewing insects encountered on marked branches of marked trees. All insects were left on trees, unless we could not identify them, in which case we took them to the lab for rearing to adults. Adult moth and butterflies are easier to identify than their larval counterparts. We sampled four times during the growing season, up until the last two years when we only sampled during the spring. Four of our findings are relevant to the question of the past and future effects of land use on current and future insect diversity and abundance in a rapidly changing world.

First, we found a very high diversity of caterpillars, and other insect herbivores, on these two tree species. Our current list includes approximately 228 species of moths, 5 species of butterflies, 12 species of beetles, 2 species of walking sticks, 4 species of grasshoppers and katydids, and 14 species of sawflies (related to bees and wasps). This is not all of the diversity of oak-feeding moths known to occur in Missouri. We did not encounter caterpillars of 193 species of moths whose caterpillars are known to feed on oak trees in locations outside of Missouri but have been collected only as adults in Missouri. We know they occur or occurred in Missouri because J. Richard Heitzman kept records of moths and butterflies collected in Missouri until his death in 2013, with Phillip E. Koenig continuing this effort today. It is a mystery why we have not seen these species after sampling tens of thousands of caterpillars (220,000+ in the first 10 years). Perhaps some of them occurred in the state prior to the logging of the late 1800s but now are extinct in Missouri as a result of the logging.

Photos by R.J. Marquis

Figure 3. Common caterpillar species encountered in the Missouri Ozark Forest Ecosystem Project on white and black oak trees. *(top to bottom)* **Green Oak Caterpillar** (*Nadata gibbosa,* Notodontidae). Note the sub-dorsal yellow lines running the length of the body. Mandibles are yellow with black tips. **Banded Tussock Moth Caterpillar** (*Halysidota tesselaris,* Erebidae). Found on a wide variety of tree species, often on tops of leaves, the mature larvae come in either a yellow or gray form. **Variable Oakleaf Caterpillar** (*Lochmaeus manteo,* Notodontidae). This species has a dorsal gland that emits acetic acid when disturbed. **Spiny Oak Slug** (*Euclea delphinii,* Limacodidae). This is the green form of this caterpillar. Also seen in Missouri are orange and white forms. All have urticating spines. **Common Lytrosis Caterpillar** (*Lytrosis unitaria,* Geometridae). A spectacular twig mimic.

Second, we found a very strong effect of forest age on the insects associated with them in the nine MOFEP study sites prior to the first forest harvest in 1996. We first found that older forests, that is, forests that had been longer in the possession of the Missouri Department of Conservation, had more insects on white and black oak trees. There was about a 27-year difference in age from the youngest forest (1953, Peck Ranch Conservation Area) to the oldest (1926, Deer Run State Forest, which was 57 years old at the time of sampling) (Marquis and Le Corff 1997). When we expanded this sampling to white oaks outside of the MOFEP study sites to include forests 2 years to 300 years of age, we found that species numbers and insect density were higher in the oldest forests, and insect composition in older stands of white oak differed from that on younger stands (Jeffries et al. 2006).

To explain the above result, we suggest that older forests contain unique habitats and resources that some insects may require that are not otherwise found in younger forests. For example, there may be particular micro-niches necessary for pupation and overwintering of caterpillars, such as large logs; crevices in bark in which caterpillars can hide during the day to escape predators; and sites for background matching of adults to avoid predation, true for many underwing moths (genus *Catocala*) that hide against bark on trunks of large trees. Additionally there may be more floral resources in older forests needed by adults that are not found in younger forests. Similar effects of forest age have been found for beetles in Australian (Grove 2002) and Japanese forests (Maeto et al. 2002), and in Douglas fir forests in the Pacific Northwest (Schowalter 1995). Salamander diversity also increased with forest age in MOFEP sites (Herbeck and Larsen 1999).

These results suggest that current distribution of diversity of both invertebrates and vertebrates in Missouri Ozark forests is a function of previous logging history as it affects forest age at a given location. Thus, the legacy of clear-cutting the state in the 1880s is apparent even after more than 100 years. In setting up the MOFEP experiment, the designers had the wisdom to demarcate a core of uncut forest that would be maintained uncut in perpetuity regardless of the surrounding experimental treatment.

Third, we see little evidence at this time that insect populations on oak trees are declining (or increasing) in Missouri as a consequence of current land use practices (Forkner et al. 2006). We see a very strong effect of local cutting on insect abundance and diversity if we compare a clear-cut slope to a nearby, uncut one. However, at the landscape level after the first round of cutting we saw few effects of harvest, all subtle and relatively weak. This is a tentative conclusion because we have only sampled after a single round of timber extraction, after approximately 10% of the MOFEP forests had been harvested. Future sampling following additional rounds of cutting will be needed to determine the magnitude of the impact of continued harvest, and which management regime will produce the least harm, if any.

Finally, our data address the question of the role of climate change on Missouri forest insects (Marquis et al. 2019a). Reports by MDC forest entomologists during the 1950s–1970s reveal a pattern of peaks and valleys in forest insect abundance across the state from year to year. Our results confirm this pattern but allow us to attribute these changes to changes in local weather. Part of this year-to-year variation is driven in part by late spring frosts, which reduce abundances of insects by killing young, developing leaves, and in part driven by summer droughts that have negative impacts on summer-feeding insects. Because we have many years of sampling, we can say that recovery from these weather events takes three to five years or even more. Predictions by climate scientists suggest that climate patterns will only become more variable, increasing the likelihood of late spring frosts. Summer droughts are also expected to increase in the Midwest states. Both would have negative consequences for Missouri forest insects.

We predict that an increasingly more variable and extreme climate will have negative consequences for multiple species of forest insects in the Missouri Ozarks. These climate change impacts may only be exacerbated as more tree biomass is removed from MOFEP plots. Continued removal of trees may make forests more susceptible to early spring frosts and their attendant negative effects on the insects (Langvall and Löfvenius 2002). Lower tree density should also increase temperatures and decrease water content of foliage in the summer, both of which would have negative effects on the summer-feeding insects (Scriber 1977). Thus tree health might be improved due to lower stocking but insect population decline might be exacerbated.

Return to the issue of insect decline

Many years of continuous data collection are necessary to establish trajectories of insect populations to determine whether they are declining. Establishing the causes of changes can be challenging but experiments like the MOFEP help us determine whether current management practices affect the biodiversity that we seek to preserve. We have found evidence that large-scale deforestation can have significant, long-lasting negative effects on forest insect abundance and diversity. Rapidly changing climate however is likely to have major negative effects on Missouri insects, and may be made worse by the effects of future timber harvest.

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Web resources:

Missouri Ozark Forest Ecosystem Project[1]

Caterpillars on Missouri Oaks, an Illustrated Guide[2]

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1 https://research.mdc.mo.gov/project/mofep

2 https://www.fs.usda.gov/foresthealth/technology/pdfs/FHAAST-2018-05_Immature_Lepidoptera_Oaks.pdf

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2025 Event Calendar

February 11, 2025 • 11am CST

Natural Areas Association Webinar

Presented by Bethany Bradley, Co-Director, Northeast Climate Adaptation Science Center

naturalareas.org/webinars.php

February 19–21, 2025

Missouri Natural Resources Conference

Margaritaville Resort, Osage Beach, MO

mnrc.org

February 24–27, 2025

National Native Seed Conference

Tucson, AZ

appliedeco.org/nnsc25

February 28, 2025 • 4:30pm

Short-Eared Owl Hike

Shawnee Trail Conservation Area,
160 SW 160th Lane, Mindenmines, MO

moprairie.org/events

March 7–9, 2025

89th Conservation Federation of Missouri Conference

Lodge of the Four Seasons, Lake Ozark, MO

confedmo.org

August 21–22, 2025

Missouri Bird Conservation Initiative Conference

Columbia Country Club, Columbia, MO

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