INSECT POLLINATORS OF THREE RARE PLANTS IN A FLORIDA LONGLEAF PINE FOREST

INSECT POLLINATORS OF THREE RARE PLANTS IN A FLORIDA LONGLEAF PINE FOREST

THERESA L. PITTS-SINGER[1], JAMES L. HANULA[1] AND JOAN L. WALKER[2]
[1]U.S.D.A. Forest Service, Forestry Sciences Laboratory, 320 Green St., Athens, GA 30602

[2]U.S.D.A. Forest Service, Department of Forest Resources, Clemson University, Clemson, SC 29634

ABSTRACT

As a result of human activity, longleaf pine (*Pinus palustris* Miller) forests in the southern United States have been lost or drastically altered. Many of the plant species that historically occupied those forests now persist only as remnants and are classified as threatened or endangered. In order to safeguard such species, a better understanding of their pollination ecology is needed. We identified insect visitors and potential pollinators of *Harperocallis flava* (McDaniel) (Amaryllidaceae), *Macbridea alba* Chapman (Lamiaceae) and *Scutellaria floridana* Chapman (Lamiaceae) that occur in longleaf pine habitat on the Apalachicola National Forest in Florida. We observed that potential pollinators of *H. flava* were Halictidae, of *M. alba* were bumble bees (Apidae: *Bombus*), and of *S. floridana* were Megachilidae and Halictidae. However, the rates at which these insects visited the flowers were very low. Our results raise important concerns about how forest management practices affect the survival of rare plants, as well as their pollinators.

Key Words: *Harperocallis flava* (McDaniel), *Macbridea alba* Chapman, *Scutellaria floridana* Chapman, *Pinus palustris* Miller, threatened species, endangered species

RESUMEN

Como resultado de la actividad humana, los bosques de pino de hoja larga (*Pinus palustris* Miller) del sureste de los Estados Unidos han desaparecido o han sido drasticamente alterados. Muchas de las especies de plantas que historicamente ocupaban estos bosques persisten en la actualidad como restos y estan clasificadas como amenazadas o en peligro de extincíon. Para salvaguardar estas especies es necesitario entender la ecologia de su polinizacíon. Para ello, identificamos los insectos visitadores y polinizadores potenciales de *Harperocallis flava* (McDaniel) (Amaryllidaceae), *Macbridea alba* Chapman (Lamiaceae) y *Scutellaria floridiana* Chapman (Lamiaceae) que existen en el habitat del pino de hoja larga del Bosque Nacional de Apalachicola en Florida. Observamos que los polinizadores potenciales de *H. flava* eran Halictidae, de *M. alba* eran abejorros (Apidae*:* *Bombus*), y de *S. floridiana* eran Megachilidae y Halictidae. Sin embargo, los niveles de visitacion de estos insectos a las flores era muy bajo. Nuestros resultados crean dudas importantes acerca de como practicas de mantenimiento de los bosques afectan a la supervivencia de plantas amenazadas, asi como a sus polinizadores.

The longleaf pine ecosystem is a conservation priority area within the U.S. Department of Agriculture Conservation Reserve Program (Food Security Act of 1985, Title XII). Longleaf pine (*Pinus palustris* Miller) forests once occupied >24 million ha in the southern United States. Today, <1.3 million ha remain as small isolated parcels (Outcalt & Sheffield 1996). The diversity of groundcover plants per unit area (e.g., 140 vascular plant species/1000 m^2 in mesic longleaf woodlands) illustrates the remarkable species richness of longleaf pine ecosystems (Peet & Allard 1993). At least 30 endangered or threatened plant species now reside in the few remnant understory communities of longleaf pine forest, and populations of at least 191 taxa of vascular plants have been reduced to low levels (Hardin & White 1989; Walker 1993). Thus, it is important to understand the physiological and ecological requirements of these plants in order to develop appropriate recovery plans.

Studies of potential management effects on rare plants in some fire-disturbed habitats have considered the response of plants to management practices e.g., Hessl & Spackman 1995; Brewer 1999; Lesica 1999), but not the effects on their pollinator systems. One reason for this lack of information is simply that the effective pollinators are unknown. Pollinators are critical to the long-term survival of many flowering plants because they provide a mechanism for ensuring seed set and development, and often facilitate gene flow between plants and plant populations. In return for pollination services, the flowers provide vital floral resources for the foraging insects (Proctor et al. 1996).

A worldwide pollination crisis is at hand, and environmental degradation from habitat destruction, modification, or fragmentation can disrupt plant-pollinator interactions and jeopardize their existence (Rathcke & Jules 1993; Kearns et al. 1998). Tepedino et al. (1997) express a need for "extended care" in conservation. When rare plants are imperiled, their extended families of pollinators also must be considered. It is important to "maintain the integrity of ecosystems by preserving interactions between plants and their pollinators" (Tepedino et al. 1997).

Our study investigates the pollinator-plant relationships of Harper's beauty, *Harperocallis flava* (McDaniel) (Amaryllidaceae), white birds-in-a-nest, *Macbridea alba* Chapman (Lamiaceae), and Florida skullcap, *Scutellaria floridana* Chapman (Lamiaceae). All of these plants are federally listed species and are endemic to the longleaf pine ecosystem in the Apalachicola lowlands of the Florida panhandle (Kral 1983; Walker 1993). They are fire-dependent species (Kral 1983; Walker 1993), and the local USDA Forest Service uses prescribed fires to help maintain their habitats.

For *H. flava* pollination, insects may not be as important as for the other species in this study, if they are important at all. Allozyme studies have indicated that *H. flava* individuals and populations are genetically uniform (Godt et al. 1997). Further, a preliminary study by Wagner & Spira (1996) indicated that *H. flava* flowers are self-compatible and capable of selfing. Mature fruits were produced from flowers that were open-pollinated, cross-pollinated, and self-pollinated.

Harperocallis flava was first listed as an endangered species in 1979 (U.S. Fish & Wildlife Service 1992). It occurs in Franklin and Liberty Counties, Florida, in open pineland bogs and along moist roadside ditches. This perennial species has a single yellow flower with 6 tepals (each being 9-15 mm in length) produced atop a stalk that emerges from stiff, grasslike leaves. Flowering occurs from mid-April through May and fruits mature in July. Kral (1983) reported that the density of *H. flava* has declined since its discovery in 1965 primarily because of lack of fire in the area. Presently, the USDA Forest Service manages a Franklin County location and carries out periodic controlled burns to help maintain the open habitat required by this species (U.S. Fish & Wildlife Service 1992).

Macbridea alba was first listed as a federally threatened species in 1992 (U.S. Fish & Wildlife Service 1992). It occurs in open savannahs as well as in drainage areas in pine stands in Bay, Gulf, Franklin, and Liberty Counties, Florida (Kral 1983; U.S. Fish & Wildlife Service 1992). This perennial herb usually has only one stem, which may be branched. Brilliant white flowers are clustered in terminal compressed thyrses on erect stems. Each flower has a green calyx (1 cm in length) and a white, 2-lipped corolla (3 cm in length). Flowering of *M. alba* is stimulated by fire during the growing season and usually occurs from May to July (U.S. Fish & Wildlife Service 1992, Madsen 1999). Some information available concerning this flower species relies on insect pollinators. Madsen (1999) found that when insects were excluded from *M. alba* flowers, almost no seeds were produced.

Scutellaria floridana was also placed on the federal threatened species list in 1992 (U.S. Fish & Wildlife Service 1992). It is found in Franklin, Liberty, and Gulf Counties, Florida. The stem is simple or sparingly branched, and its solitary purple flowers are well separated in the axils of short, leafy bracts. The corolla (2.5 cm in length) has 2 lips, the lower one being white in the middle. The preferred habitat of *S. floridana* is similar to that of *M. alba*, although it is more restricted (Kral 1983; U.S. Fish & Wildlife Service 1992). This perennial herb is reported to flower in May or June (Kral 1983).

We monitored arthropod visitors to flowers of these plants, identified them, and evaluated their importance as pollinators. The results of our study are an important first step towards understanding the interactions between these rare plants and their pollinators in this Florida longleaf pine ecosystem.

Materials and Method

All study sites were located on the Apalachicola National Forest near Sumatra and Wilma, Florida. Field observations were made to determine which insects frequently visited flowers and how they behaved. In the summers of 1999 and 2000, we selected and tagged 10-25 flowers (or inflorescences) at each site, and then monitored the flowers for 3- or 5-min periods throughout the day for 2-5 days. Arthropod activity and the time they were present on the flowers were recorded during the observation period. The visits of arthropods to flowers were counted only when they occurred during the observation period for that flower, although visits to other tagged flowers in the vicinity could be seen during this same time. Observations were not made at the same time each day. Because the 1999 sites did not produce enough flowers for study in 2000, sites chosen in 2000 were not the same as those used in 1999. In summer 2000, we also used a video camcorder to record insect activity on focal flowers.

The video equipment consisted of a tripod-mounted Sony CCD-VX3 Video Recorder that was auto-controlled via a Dell Latitude Xpi Laptop computer with custom-developed "VideoSpy" software (Mark Evans, John Deere Commercial Products, Inc., unpublished). The custom software allowed us to set a filming schedule for each day using "record" times (3 or 5 min) and "wait" times (10-15 min) so that up to 2 h of video could be recorded throughout the day. The system was powered by a 12-volt marine deep cycle battery. Video-imaging allows pollinator visits to be reviewed repeatedly or in slow-motion. Furthermore, this technique eliminates any effect of human presence (e.g., scent and motion) on the behavior of the visitors. From both researcher and video monitoring, we recorded the identity of a visitor, the duration of its visit, and its behavior on a flower.

From field observations, we identified insects that were potentially pollinators, herbivores, nectar robbers, or incidental visitors. We also determined the time of day potential pollinators were present. Visitation rates were calculated from data recorded by the field observer while watching focal flowers and also from data recorded on individual flowers by the camcorder. Rate of visitation (visits per flower per min) was calculated as number of arthropod visits to flowers per number of flowers observed per total observation time. When flowers were observed over more than one day, a visitation rate was calculated for each day, and then an average rate for those days was determined.

On two separate occasions in 1999, a halictid bee was collected after it had visited an *H. flava* flower. Each bee was washed in a vial containing deionized water to remove pollen from its body, and then it was released unharmed. The pollen was cleaned and slide-mounted according to a potassium hydroxide-acetolysis procedure provided by Jean Porter at the University of Georgia Paleoecology Laboratory, Athens, Georgia (see also Erdtman 1969). Jean Porter also prepared a reference slide of *H. flava* pollen from pollen extracted from a specimen in the University of Georgia Herbarium. We used the reference slide for determining if *H. flava* pollen was present on the slides we made from field collections.

Results

Harperocallis flava

In 1999, 25 *H. flava* flowers at one roadside study site and 20 flowers at a nearby site (1 km north of other site, approximately 20-40 m off the road) were tagged and then monitored at 3-min periods for a total of 20 h of observation over 3 days (May 18-20; range 0830-1555 h EDT). Although many bees, wasps, and beetles were seen on nearby *Ilex glabra* L. (Aquifoliaceae), *Hypericum* sp. (Clusiaceae), and *Iris* sp. (Iridaceae), only 5 different insect species visited *H. flava* (Table 1), resulting in 8 floral visits. Of all the insect visitors, halictid bees (n = 3) were the only ones that spent time on the flowers gathering pollen (Fig. 1). One of the halictids was collected, and later identified by T. L. Pitts-Singer as *Dialictus* sp. (using key in Mitchell 1960). The specimen was retained for reference at the U.S. Department of Agriculture Forest Service, Forestry Sciences Laboratory, Athens, Georgia. While on a flower, each bee focused its attention on one or two anthers for pollen collection, occasionally crawling across the centrally located stigma. Duration of visits by the halictids ranged from 30 s to 7 min on a single flower.

In summer 2000 at a different site located approximately 5.1 km from the 1999 site, an observer monitored 12 *H. flava* flowers on May 16, and 13 flowers on May 17, for a total of 6 h 15 min (range 0830-1656 h EDT). Observations were made for 5-min periods (instead of 3-min). The video camcorder recorded 3 h 56 min of videotape over the same 2 days noted above. Four visits (2 by halictids, 1 by a mordellid, and 1 by a syrphid) were recorded on one flower using the video camcorder. Arthropods that were recorded visiting *H. flava* by both the human observer and by video camcorder are shown in Table 1. Again, halictid bees were the only insects that gathered pollen from the flowers (Fig. 1), and their visits lasted from 1 s to 10 min (i.e., some visits exceeded the 5-min period). Halictid visits occurred throughout the day (0945-1345 h EDT), but not in the early morning or late afternoon (Fig. 1). Another small yellow flower, *Xyris baldwiniana* Roemer & Schultes (Xyridaceae), was also present at this *H. flava* site and was visited by halictid bees. *Xyris baldwiniana* flowers were only open during the morning, and their presence could have affected the rate at which bees visited *H. flava*. No halictids were collected in 2000 for identification to the generic level.

In both 1999 and 2000, average insect visitation rates to *H. flava* were very low (Table 2). Based on human observations, the rate was higher in 2000 than in 1999. Rates from the video camcorder used in 2000 on a focal flower were higher than that recorded by the human observer.

Macbridea alba

Twenty inflorescences of *M. alba* at each of two sites (distance between sites = approx. 4.4 km) were observed for 34 h over 5 days (June 24-25, June 29-July 1; range 0724-1805 h EDT). Nine insect and spider species made 70 visits (Table 1), but only bumblebees (*Bombus*) were large enough to contact the reproductive structures of the flower. No bumblebees were collected in order to determine their specific scientific identity during this study. Bumblebee visits to each flower were very short (1-9 s), but they usually visited more than one flower per inflorescence (Fig. 2) and visited throughout the day (0800-1645 h EDT). The bees landed on the lower lip (petal) of the flower and immediately pushed their heads down into the corolla, presumably to obtain nectar. With its head in the flower corolla, the bee's thorax contacted anthers and stigma. Occasionally, just before leaving the flower, the bee appeared to probe the anthers with its proboscis for ~1 s. The purpose of the latter behavior is not clear. Overall, visita-

TABLE 1. LIST OF VISITORS TO MARKED FLOWERS OF *H. FLAVA*, *M. ALBA* AND *S. FLORIDANA* IN SUMMER 1999 AND 2000 AT THE APALACHICOLA NATIONAL FOREST, FLORIDA, AND TOTAL OBSERVATION TIME AND NUMBER OF VISITS.

Plant species; observation time and no. visits	Visitor scientific name	Common name
H. flava		
1999	1999	1999
obs. time = 20 h	Halictidae: *Dialictus**	sweat bee
visits = 8	Apidae: *Bombus*	bumble bee
	Mordellidae	tumbling flower beetle
	Tettigoniidae	katydid nymph
	Diptera	fly
2000	2000	2000
human obs. = 8 h 25 min	Halictidae: sp. #1*	sweat bee
video = 3 h 56 min	Halictidae: sp. #2*	sweat bee
visits = 8	Mordellidae	tumbling flower beetle
	Syrphidae	bee fly
M. alba		
1999	1999	1999
obs. time = 34 h	Apidae: *Bombus**	bumble bee
visits = 70	Formicidae: Paratrechina	ant
	Curculionidae	weevil
	Melandryidae	false darkling beetle
	Lycaenidae	gossamer-winged butterfly
	Acrididae	grasshopper
	Tettigoniidae	katydid
	Oxyopidae	lynx spider
	Thomisidae	crab spider
S. floridana		
1999	1999	1999
obs. time = 6 h	Apidae: *Bombus**	bumblebee
visits = 9	Megachilidae*	leafcutter bee
	Halictidae: *Dialictus*	sweat bee
	Halictidae?: sp. #2	bee
	Syrphidae?	syrphid fly
	Acrididae	grasshopper
	Thomisidae	crab spider
S. floridana		
2000	2000	2000
human obs. = 6 h	Megachilidae*	leafcutter bee
video = 2 h 43 min	Halictidae*	sweat bee
visits = 10	Tettigoniidae	small katydid
	Thomisidae	crab spider

*Indicates insects that were seen to collect pollen and are probably important pollinators.
?Researcher is not positive of family-level identification.

tion rates were higher for *M. alba* than for *H. flava* (Table 2). Bumble bees also visited *Rhexia alifanus* Walter (Melastomaceae) and *Hibiscus aculeatus* Walter (Malvaceae) that occurred at the same sites. The bees spent more time collecting pollen on these common flowers than they did on *M. alba* collecting nectar.

In 2000, very few *M. alba* flowers were produced, presumably because of drought and other unfavorable environmental conditions. Thus, we were unable to make further observations of visitors to this flower species.

Scutellaria floridana

In 1999, 10 inflorescences of *S. floridana* at one site were monitored over 2 days (September 14-15; range 0825-1632 h EDT) for 6 h of observation, during which 7 insect and spider species made 9 visits (Table 1). Visitations occurred between 1000 and 1530 h (Fig. 3). Of the visitors recorded during observation periods, megachilid bees and possibly halictid bees displayed behavior that may have resulted in pollination of *S. floridana* flowers (Fig. 3). Megachilids landed on

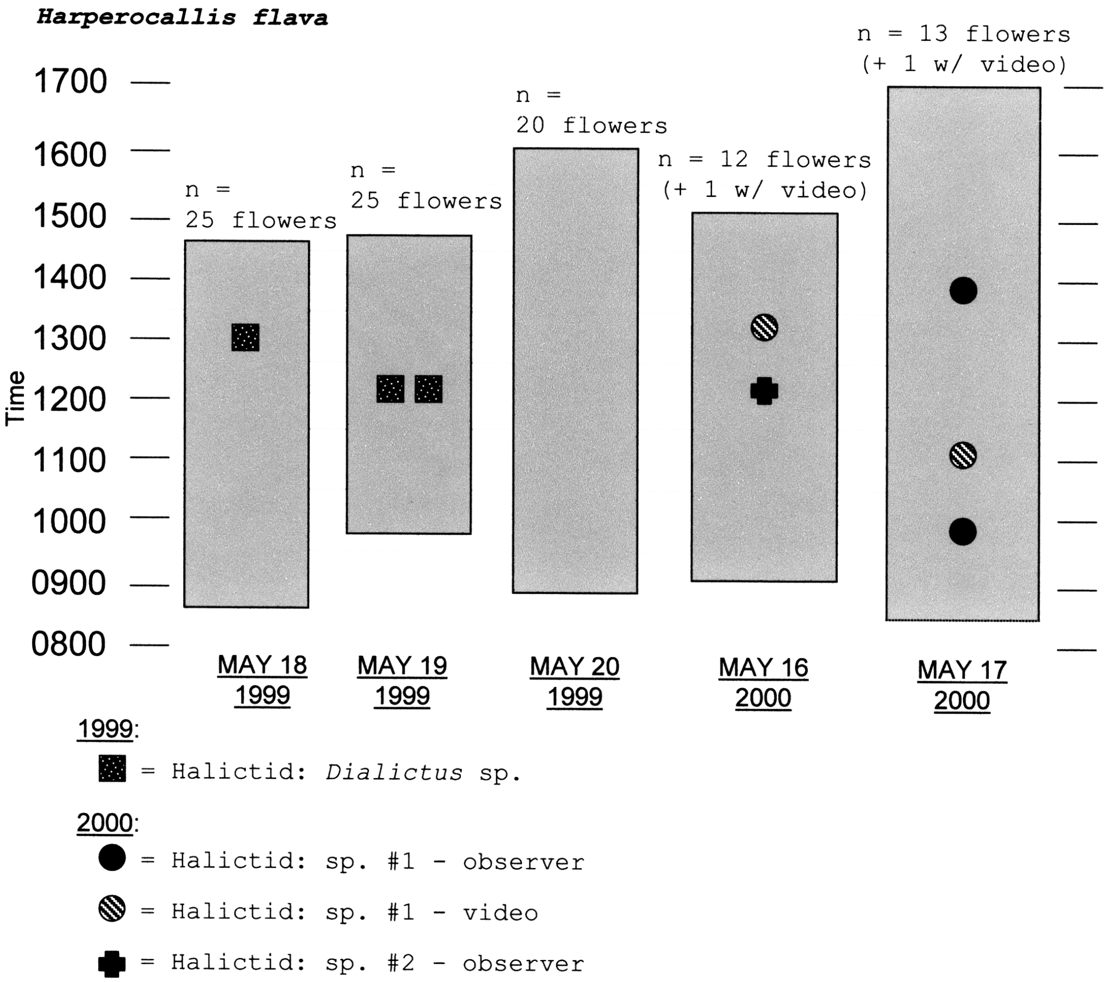

Fig. 1. Visitation by halictids on *H. flava* flowers recorded by human observer and by video camcorder in May 1999 and 2000 at the Apalachicola National Forest, Florida. Bars represent time frame in which 3- or 5-min observation periods occurred. Symbols represent pollinator visits.

the flower, clung to the flower hood in an upside-down position, and then kicked into the hood through the seam so that pollen fell onto the scopa on the venter of the gaster. Durations of megachilid visitations were 21-23 s. Although halictids (*Dialictus* sp.) also visited these flowers (Fig. 3), they did not appear to come into contact with the stigma and, therefore, may have been pollen "robbers." The small halictids entered into the hood of the flower, out of the observer's view. The halictids presumably collected pollen before exiting the flower. Their visits lasted from 2 s to 1 min. In addition to the megachilid and halictid bees, the observer noted that one bumblebee visited a flower before the study began (Fig. 3). This bee spent a few seconds on a flower and used floral sonication to dislodge pollen from the anthers. A few lepidoptera (not on marked flowers) and a fly also were observed on the flowers, although they appeared to collect only nectar and did not contact the anthers. Compared to the other 2 plants in this study, the overall visitation rate was high (Table 2).

In 2000 at a site located approximately 16.25 km from the 1999 site, 10 flowers of *S. floridana* were monitored by a human observer for 6 h on April 20-21 (range 0850-1754 h EDT) in 2000. The video camcorder captured 2 h 43 min of tape, revealing visits by 4 megachilids and 1 halictid. Altogether, 4 insect species made 10 visits to flowers (Table 1). Megachilids (visit duration = 10-15 s) and halictids (visit duration = 5-31 s) were the most frequent visitors to *S. floridana* (Fig. 3). Behavioral observations of megachilids and halictids, which were larger halictids than those seen in 1999, indicated that these bees probably are effective pollinators of *S. floridana*. These bees clung to the outside of the flower hood, sometimes

TABLE 2. AVERAGE VISITATION RATES (ARTHROPOD VISITS PER FLOWER PER MIN) AND NUMBER OF VISITS (N) OVER 1-5 DAYS OF OBSERVATIONS OF MARKED FLOWERS AT THE APALACHICOLA NATIONAL FOREST, FLORIDA IN SUMMERS OF 1999 AND 2000.

Flower species: visitors—method	Visitation rate ($\times 10^{-2}$) 1999	2000
H. flava: halictids—observer	0.01 (n = 3)	0.06 (n = 3)
H. flava: all visitors—observer	0.03 (n = 8)	0.06 (n = 3)
H. flava: halictids—video	n.a.	0.85 (n = 2)
H. flava: all visitors—video	n.a.	2.1 (n = 5)
M. alba: bumblebees—observer	0.07 (n = 21)	n.a.
M. alba: all visitors—observer	0.18 (n = 70)	n.a.
S. floridana: bees*—observer	0.14 (n = 5)	0.06 (n = 3)
S. floridana: all visitors—observer	0.25 (n = 9)	0.15 (n = 5)
S. floridana: bees*—video	n.a.	3.72 (n = 5)
S. floridana: all visitors—video	n.a.	3.72 (n = 5)

*"Bees" includes megachilids and halictids.

touching the stigma, as they forced their heads and thoraces into the hood. Pollinator visitations occurred from morning until late afternoon (Fig. 3). Visitation rates were lower in 2000 than they were in 1999. Carpenter bees (*Xylocopa* sp.) were seen to rob nectar by piercing the base of the corolla. Other flowers such as *Aletris lutea* Small (Liliaceae), *Balduina uniflora* Nuttall (Asteraceae), and *Pityopsis graminifollia* (Michaux) (Asteraceae) were also at this site, attracting bumblebees and butterflies.

Pollen from Halictid Bees

We found pollen on only 1 of the 2 slides prepared from washes of the 2 halictid bees captured on *H. flava* flowers. There were 7 pollen grains of *H. flava*, 1 grain of 3 other types, and 3 grains of a fourth type. The absence of pollen on the second slide does not preclude that pollen was not present on the bee. The pollen may have been lost in the insect net during collection, the water wash may have not removed pollen from the bee, or maybe the pollen was lost in the process of extracting pollen out of water in the vial.

DISCUSSION

We found that native bees were the likely pollinators of all 3 of the threatened or endangered flowers we studied in the Apalachicola longleaf pine forest. Bumblebees are probably important pollinators of *M. alba* and possibly of *S. floridana*, but megachilids and halictids may be the primary pollinators of *S. floridana*. Halictids may play a significant role in the pollination system of *H. flava*. Although honeybee (*Apis mellifera* L.) hives are present near the forest (Louise Kirn, U.S.D.A. Forest Service, Bristol, FL, pers. comm.), we observed no honeybees on these flowers.

Arthropod visits to the rare flowers were quite infrequent (Table 2) (Figs. 1-3). Unfortunately, we found no other pollinator visitation data in the literature for flowers in the Apalachicola National Forest or vicinity for making comparisons. However, pollinator studies performed on flowers from other habitats may offer an idea of potential bee visitation rates. For example, a study on *Hibiscus moscheutos* in Maryland revealed average visitations by bumblebees and anthophorid bees of 27-13 visits per flower per min $\times 10^{-2}$ (Spira et al. 1992). Another study in Michigan on catnip, *Nepeta cataria* L., found average visitations by bumblebees to be 8.6 visits per flower per min $\times 10^{-2}$ and by Halictidae to be 7.4 visits per flower per min $\times 10^{-2}$ (Sih & Baltus 1987). Compared to these studies, bee visitation rates to the flowers we studied are indeed quite low (range = 0.01×10^{-2} to 3.72×10^{-2} per min) (Table 2). However, we saw these same insects visiting other flowers in the area.

Regardless of whether or not these rare flowers are imperiled because of low pollinator frequency, our studies showed that certain insects collect pollen and nectar from them and may be important in their pollination ecology. Bumblebees were the only insects observed whose size and behavior was efficient for pollinating *M. alba*. Observations of *M. alba* flowers in the South Carolina Botanical Garden suggest that bumblebees are very frequent visitors and efficient pollinators (J. L. Walker, pers. obs.). Continued studies of pollinators of this flower species should determine how many individual bumble bees are visiting the rare flowers or other flowers in the area and if these bees are important for out-crossing in this species.

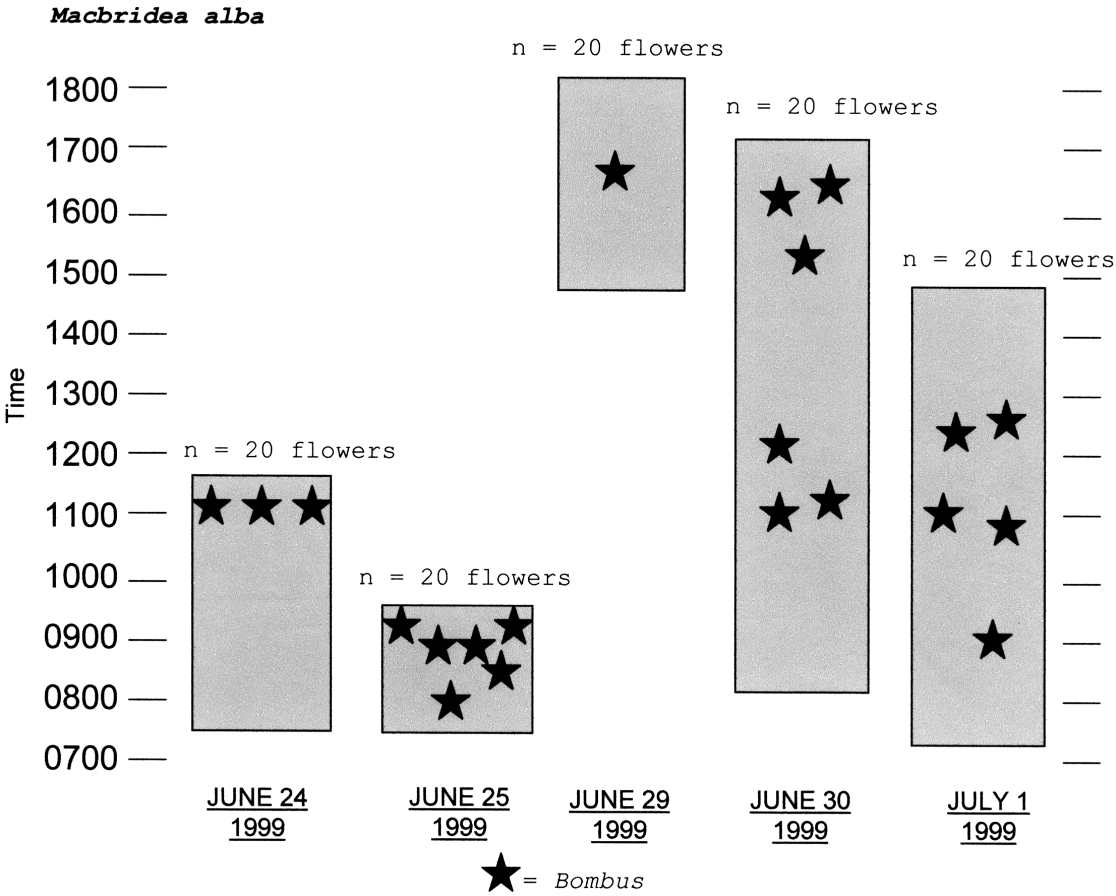

Fig. 2. Visitation by bumblebees on *M. alba* inflorescences recorded by human observer in June-July 1999 at the Apalachicola National Forest, Florida. Bars represent time frame in which 3-min observation periods occurred. Symbols represent pollinator visits.

Although some evidence has indicated that *H. flava* flowers are self-compatible and undergo selfing, we observed several halictid bees collecting pollen from *H. flava* flowers, especially in 2000 (Tables 1 and 2) (Fig. 1). The pollen-collecting behavior of halictids on *H. flava* flowers could have facilitated pollination. For a hermaphroditic species like *H. flava*, visitation by bees may improve out-crossing; or the activity of bees on anthers may dislodge pollen for better wind dispersal (Cane et al. 1992). Nonetheless, if out-crossing were evolutionarily important for this species in the past, it may now be ineffectual as a result of the low genetic variability in *H. flava*. Though pollinator services may not benefit *H. flava*, the availability of this pollen may be a useful resource for the solitary bees that harvest it.

Our study provides the first documentation of the pollination ecology of *S. floridana*. The behaviors of megachilids and halictid bees on the flowers were appropriate for pollination. We also noted that the newly opened flowers were more readily approached and subsequently visited than 2-day-old flowers. In 2000, the flowers bloomed at the beginning of the summer (May) and not at the end of the summer (September) as in 1999. These different flowering dates may have had an effect on the diversity and abundance of insects that visited the flowers. Further investigation of pollinators of this species should include insect exclusion experiments on *S. floridana* and comparative studies with another common skullcap, *S. integrifolia* L., which occurs in the area.

Another useful outcome from this study is in the methodology. Using the video camcorder to collect visitation data may have had an advantage over human observation (Table 2). By focusing on only 1 flower throughout the day, up to 2 hours of observable data could be gathered without human intervention. A higher visitation rate was recorded for both *H. flava* and *S. floridana* when this method was used.

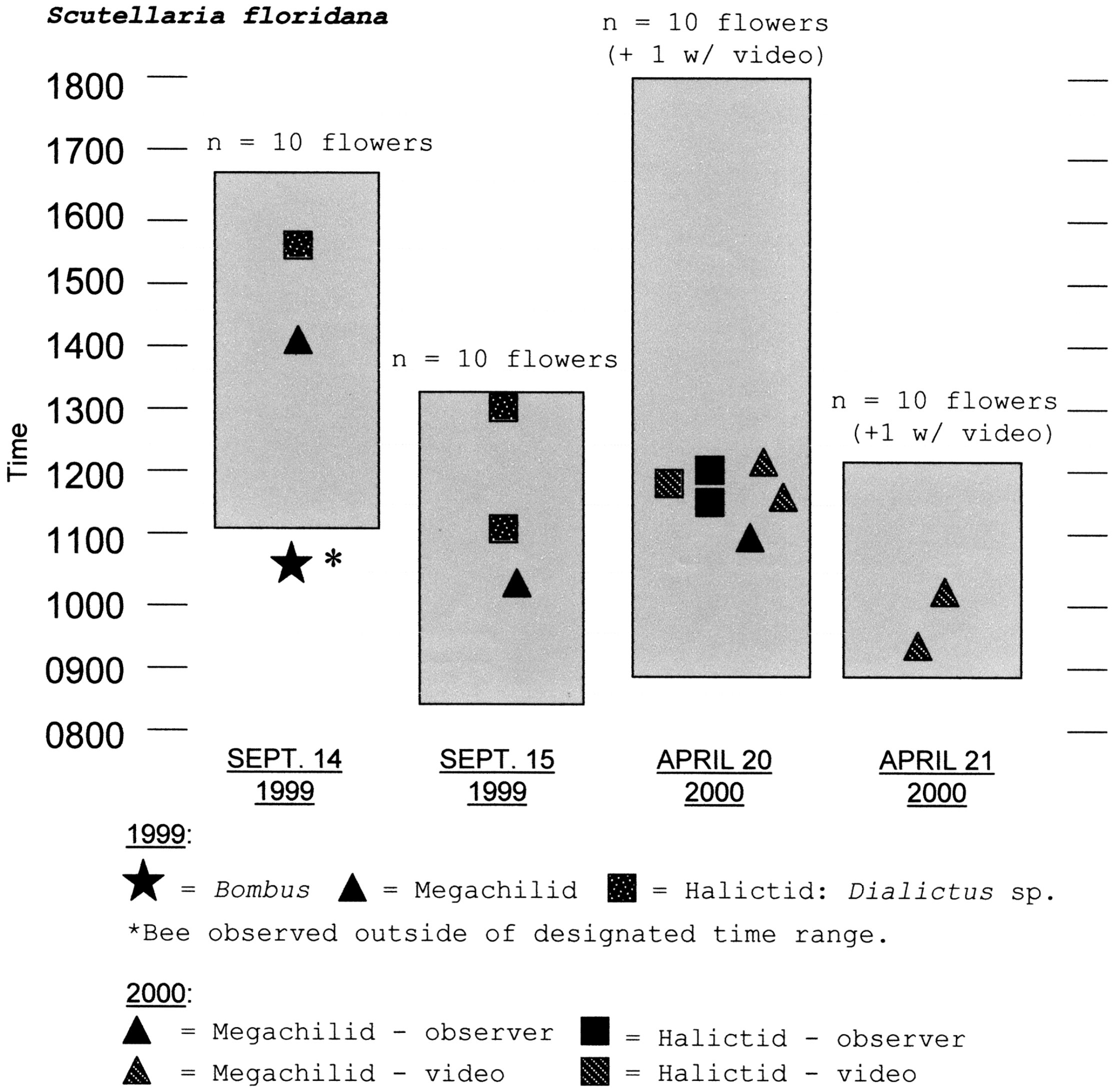

Fig. 3. Visitation by bumblebees, megachilids, and halictids on S. floridana flowers recorded by human observer and video camcorder in September 1999 and April 2000 at the Apalachicola National Forest, Florida. Bars represent time frame in which 3-min observation periods occurred. Symbols represent pollinator visits.

Early in the study, we planned to collect insects that visited the rare flowers in order to create a reference collection and to identify pollen samples from the insects. However, because visitation rates were low, we decided that removal of potential pollinators might have been detrimental to the reproductive success of the plants, and we abandoned this effort.

Each of the plants we studied responds to fire by increased growth and flowering (Madsen 1999; Louise Kirn, USDA Forest Service, Apalachicola Ranger Station, Bristol, FL, pers. comm.). This response suggests that fire timing is important to ensure that flowering occurs when pollinators are available. Thus, we must also understand the life cycle of important pollinators, and, further, whether fire has an effect on the availability of food and nesting materials.

At least three requirements must be met for effective conservation of pollinators in any ecosystem and of bee pollinators in the Apalachicola ecosystem. They require proper nesting sites, nest-building material, and a sufficient amount of food at appropriate times both for adults (who need nectar) and for larvae (who need pollen) (Westrich 1996). Thus, it is imperative to identify the specialized needs of each pollinator. Such information will help in determining which, if any, forest management practices affect availability of these resources; or if improvements can be made in certain areas to maintain suitable habitat.

The pollination ecology of some communities has been neglected, and more information concerning the plant-pollinator interactions of rare and endangered plants is needed (Kevan 1975; Kevan et al. 1993; Buchmann & Nabhan 1996; Kearns et al. 1998). Researchers must first have basic knowledge of a system before making hypotheses at an ecosystem level and designing experiments to test them. Researchers must perform the necessary studies to determine the importance of insect (and other animal) visitors in pollination (Kwak et al. 1996). Conservation plans need to be backed by solid, scientific evidence. Our results are a starting point for understanding insect pollinators of three rare plants in a longleaf pine ecosystem and provide a basis for future examination and conservation of these plants and their pollinators.

Acknowledgments

We thank personnel of the Apalachicola National Forest Ranger Station for their support of this project, especially Louise Kirn (USDA Forest Service) who kept us informed of when flowers were in bloom, guided us to field sites, and helped us identify various flowers at field sites. David Jenkins (University of Georgia) was a valuable field and laboratory assistant in summer 1999, and his observations and suggestions are much appreciated. We thank Robert W. Matthews, Christopher J. Fettig, and James P. Pitts (Department of Entomology, University of Georgia, Athens, Georgia), Kerry O. Britton (USDA Forest Service, Athens, Georgia), and Paul Smith (USDA Forest Service, Asheville, North Carolina) and 3 anonymous reviewers for their critical assessments of this manuscript.

References Cited

Brewer, J. S. 1999. Effects of competition, litter, and disturbance on an annual carnivorous plant (*Utricularia juncea*). Plant Ecol. 140: 159-165.

Buchmann, S. L., and G. P. Nabhan. 1996. The Forgotten Pollinators. Island Press/Shearwater Books: Washington, D.C.

Cane, J. H., S. L. Buchmann, and W. E. LaBerge. 1992. The solitary bee *Melissodes thelypodii thelypodii* Cockerell (Hymenoptera: Anthophoridae) collects pollen from wind-pollinated *Amaranthus palmeri* Watson. Pan-Pacific Entomol. 68: 97-99.

Erdtman, G. 1969. Handbook of Palynology. Hafner Publishing Co., New York, NY.

Godt, M. J. W., J. Walker, and J. L. Hamrick. 1997. Genetic diversity in the endangered lily *Haperocallis flava* and a close relative, *Tofieldia racemosa*. Conserv. Biol. 11: 361-366.

Hardin, E. D., and D. L. White. 1989. Rare vascular plant taxa associated with wiregrass (*Aristida stricta*) in the southeastern United States. Nat. Areas J. 9: 234-245.

Hessl, A. and S. Spackman. 1995. Effects of fire on threatened and endangered plants: an annotated bibliography. Information and Technology Report 2. U.S. Department of the Interior, Washington, DC. 55 pp.

Kearns, C. A., D. W. Inouye, and N. M. Waser. 1998. Endangered mutualisms: the conservation of plant-pollinator interactions. Ann. Rev. Ecol. Syst. 29: 83-112.

Kevan, P. G. 1975. Pollination and environmental conservation. Environ. Conserv. 2: 293-298.

Kevan, P. G., E. A. Tikhmenev, and M. Usui. 1993. Insects and plants in the pollination ecology of the boreal zone. Ecol. Res. 8: 247-267.

Kral, R. 1983. A report on some rare, threatened, or endangered forest-related vasular plants of the south. U.S.D.A. Forest Service Tech. Pub. R8-TP, Vols. 1&2.

Kwak, M. M., O. Velterop, and E. J. M. Boerrigter. 1996. Insect diversity and the pollination of rare plant species, pp. 116-124. *In* A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich, and I. Williams [eds.], The Conservation of Bees. Academic Press, London.

Lesica, P. 1999. Effects of fire on the demography of the endangered, geophytic herb *Silene spaldingii* (Caryophyllaceae). Amer. J. Bot. 86(7): 996-1002.

Madsen, D. L. 1999. Seed production and germination studies of *Macbridea alba*. Master's Thesis, Clemson University.

Mitchell, T. B. 1960. Bees of the Eastern United States, Vol. I. North Carolina Agricultural Experiment Station, Tech. Bul. No. 141.

Peet, R. K., and D. J. Allard. 1993. Longleaf pine-dominated vegetation of the southern Atlantic and eastern Gulf Coast region, USA. Proc. Tall Timbers Fire Ecol. Conf. #18, pp. 45-81.

Proctor, M., Yeo, P. and A. Lack. 1996. The Natural History of Pollination: Timber press, Portland, OR.

Outcalt, K. W. and R. M. Sheffield. 1996. The longleaf pine forest: trends and current conditions. U.S. Forest Service Resource Bulletin SRS-RB-9.

Rathcke, B. J. and E. S. Jules. 1993. Habitat fragmentation and plant-pollinator interactions. Current Science 65: 273-277.

Sih, A. and M.-S. Baltus. 1987. Patch size, pollinator behavior, and pollinator limitation in catnip. Ecology 68: 1679-1690.

Spira, T. P., A. A. Snow, D. F. Whigham, and J. Leak. 1992. Flower visitation, pollen deposition, and pollen-tube competition in *Hibiscus moscheutos* (Malvaceae). Am. J. Bot. 79: 428-433.

Tepedino, V. T., S. D. Sipes, J. L. Barnes, and L. L. Hickerson. 1997. The need for "extended care" in conservation: examples from studies of rare plants in the Western United States, pp. 245-248. *In* K.W. Richards [ed.], Seventh International Symposium on Pollination, Acta Hort 437, ISHS.

U.S. Fish and Wildlife Service. 1992. Endangered and Threatened Species of the Southeastern United States (The Red Book), Vol. 2., Fish & Wildlife Service, Atlanta, GA.

Wagner, L. K. and T. P. Spira. 1996. Germination behavior of *Harperocallis flava*, an endangered Florida endemic. Botanical Society of America Annual Meeting, University of Washington, Seattle.

Walker, J. 1993. Rare and vascular plant taxa associated with the longleaf pine ecosystems: patterns in taxonomy and ecology. Proc. Tall Timbers Fire Ecol. Conf. #18, pp. 105-125.

Westrich, P. 1996. Habitat requirements of central European bees and the problems of partial habitats, pp. 1-16. *In* A. Matheson, S. L. Buchmann, C. O'Toole, P. Westrich, and I. Williams [eds.], The Conservation of Bees. Academic Press, London.