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STATUS AND ECOLOGY OF *AGALINIS KINGSII* (SCROPHULARIACEAE), A RARE ENDEMIC TO THE CAYMAN ISLANDS (CARIBBEAN SEA)

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ABSTRACT. *Agalinis kingsii* (Scrophulariaceae) is a rare Grand Cayman species that is poorly known taxonomically and ecologically. Sampling in 1999 suggested that approximately 43,000 individuals occurred within a single 500,000 m^2 sedge wetland habitat in the Salina Reserve and that approximately 500 plants occurred in a 9 m^2 location in the Central Mangrove Wetland. For every tenth individual located during the population count in the Salina Reserve, vegetation community associations, environmental parameters, and individual morphology were noted. Based on the findings, we suggest that rarity is a consequence of habitat availability. Since both populations were found within a narrow geographic and ecological range, we conclude that this species may be sensitive to extinction via a stochastic event.

Key Words: *Agalinis kingsii*, Caribbean Sea, endemism, endangered species, Grand Cayman, Scrophulariaceae

Agalinis kingsii Proctor (Scrophulariaceae) is one of 21 endemic species of vascular plants reported from the Cayman Islands (Caribbean Sea; Proctor 1994). Proctor (1977) described *A. kingsii* based on a single collection by Kings in 1935, but the exact location of the type locality ("Forest Glen") is unknown. The species was compared with *A. albida* Britton & Pennell and *A. purpurea* (L.) Pennell, and included in the *Flora of the Cayman Islands* without further study (Proctor 1984). A small, but stable population of *A. kingsii* was later reported by Davies (1994) based on unpublished observations by Burton in 1988. Both accounts reported the species growing on drier ground in *Conocarpus erectus* L. swamps. These limited reports are the only known accounts of the species and bring to light the lack of taxonomic, biogeographic, and ecological information on *A. kingsii*.

The aforementioned *Agalinis kingsii* populations are small and found within a narrow geographic and ecological range. According to Gilfedder et al. (1997) and van Treuren et al. (1993), narrowly endemic species with small populations are vulnerable to extinction due to stochastic events. Translocation techniques are commonly used to ensure the survival of self-sustaining populations in the wild (Gilfedder et al. 1997; Watson et al. 1994), but this approach might not be suitable for *A. kingsii*. Although a botanical garden exists on Grand Cayman, habitat on this small island is rapidly disappearing (Davies 1994) and the management needs of the species are unknown. In order to effectively devise a management strategy, knowledge of the autecology of the species in its natural environment is essential (Gilfedder et al. 1997; Grigore and Tramer 1996; Lesica 1999; Watson et al. 1994).

The objectives of this study were to: 1) provide a more detailed morphological and ecological description of *Agalinis kingsii*; 2) evaluate the distribution and abundance of *A. kingsii* on Grand Cayman; 3) consider the long-term survival of *A. kingsii* in light of the impact of human activities and frequent disturbance in its primary habitat; and 4) suggest management strategies to enhance the long-term survival of *A. kingsii*.

MATERIALS AND METHODS

Study area. The Salina Reserve (hereafter referred to as the Salina) is located inland off the northeast coast of Grand Cayman, British West Indies (B.W.I.; 19°21′N, 81°07′E; Figure 1). The area was established as a nature reserve in 1988 through a Crown land grant to the National Trust for the Cayman Islands and is currently protected under strict legislation (National Trust for the Cayman Islands 1997). The relative remoteness of the location and rough terrain provide natural restrictions on public access, and fencing and dolostone karst outcrops prevent livestock grazing.

Agalinis kingsii grows in the sedge wetland on the southern side of the Salina. The wetland displays evidence of a former buttonwood (*Conocarpus erectus*) swamp, possibly brought to its present state because of fire or anthropogenic disturbance (National Trust for the Cayman Islands 1997). The wetland is a mosaic of communities, and has been likened to the Florida Everglades (Diochon, pers. obs.; National Trust for the Cayman Islands 1997).

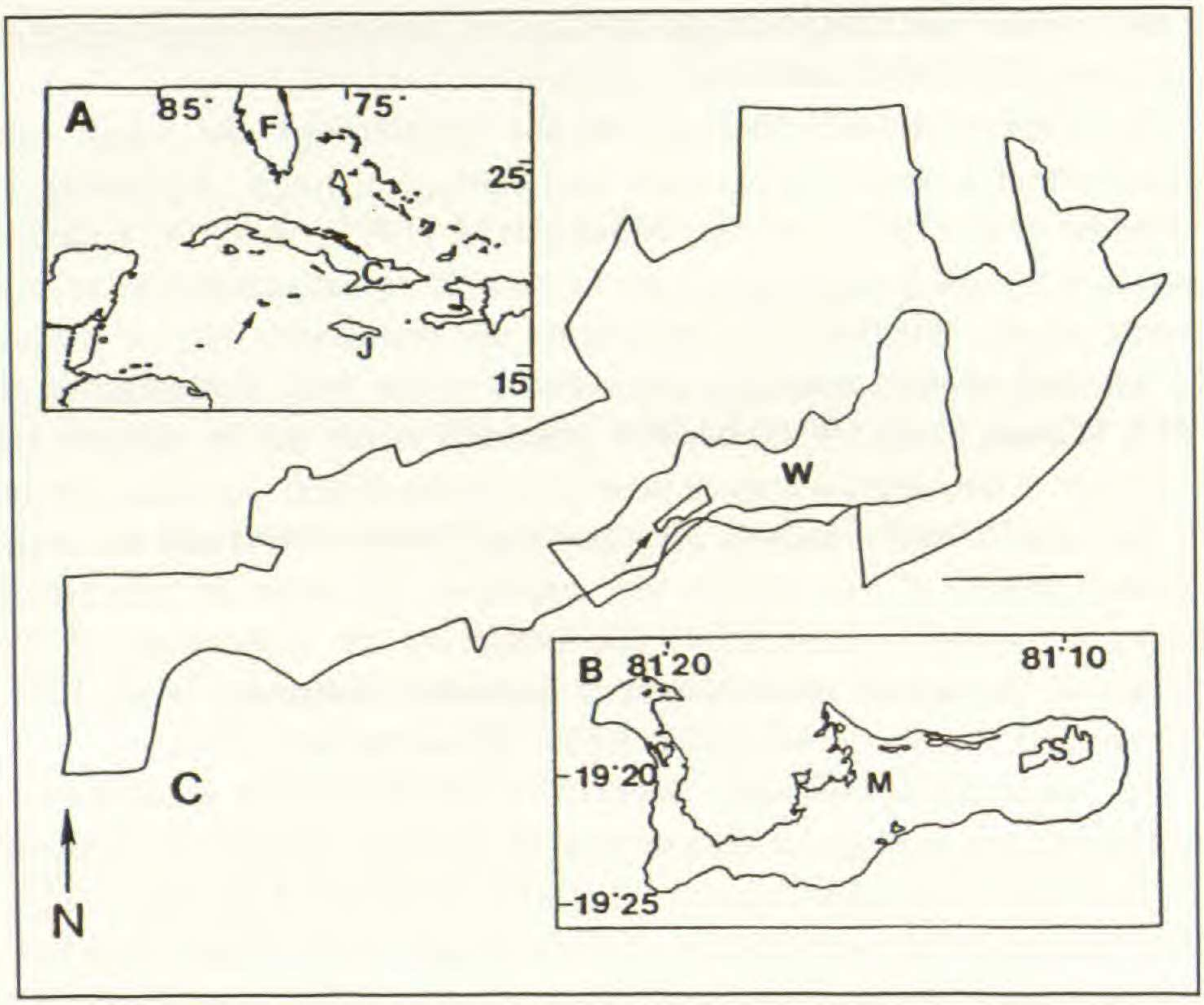


Figure 1. Location of study area. A. Map of Caribbean Sea showing location of Grand Cayman (arrow), and positions of Florida (F), Cuba (C) and Jamaica (J). B. Detail of Grand Cayman showing location of the Salina Reserve (S) and Central Mangrove Wetland (M) populations of *Agalinis kingsii*. C. Detail of Salina Reserve showing location of sedge wetland (W) and area examined for population count (arrow).

This study was conducted from May to August 1999. A population count was completed during July 1999 when the plants were most conspicuous. A portion of the sedge wetland was selected based on accessibility, and a grid was established in this area for a concurrent study on the community structure of the wetland. All plants of *Agalinis kingsii* in the grid were counted and the search was expanded into the surrounding area for *A. kingsii* individuals. Care was taken to mark the boundaries of the area examined to facilitate area calculation using a Trimble (Sunnyvale, CA) global positioning system and ArcView GIS software (ESRI, Redlands, CA).

Data collection. The relative position of every tenth *Agalinis kingsii* individual (N = 101) was noted in conjunction with the number of individuals in the immediate area (N = 1014). For every tenth individual, the following environmental and biological factors were recorded: 1) percent (%) shade at the soil surface, estimated by the percentage of biomass cover at the soil surface; 2) the distance from soil surface to the water table; 3) plant height, measured as the distance from the soil surface to tip of peduncle; 4) number of flowers on peduncle; 5) number of lateral branches; 6) average number of flowers on lateral branches; 7) associated species and % cover in a 1 m quadrat using the individual as the center; 8) community association; 9) evidence of previous generations; 10) evidence of defoliation (i.e., herbivory); and 11) the presence of ants in or on the corolla. If the tenth individual was a juvenile, no data were recorded.

Continuous monitoring for potential pollinators entering the corolla was undertaken for the duration of the study between the hours of 0730 and 1630, Monday to Saturday. A qualitative description of flower morphology was developed based on both field observations and measurements of flower structures using a dissecting microscope and a standard ruler on 20 flowers transported in alcohol. Flower structure measurements included: 1) length and position of stamens; 2) length, width, and morphology of ovary; and 3) length of style and stigma. In addition, the phenology of 20 marked individuals was monitored throughout the study. To determine if the species self-fertilized, one flower on each of 10 of these individuals was bagged with nylon mesh, and the bag was left until the flower wilted and/or detached.

Mature seeds were collected on an ongoing basis from the Salina (month/day: 06/09; 06/12; 06/16; 06/23; 07/02; 07/19; 07/16; 07/23; 07/29). Seeds were also collected from a second population in the Central Mangrove Wetland (07/22; 07/29; Figure 1). The length and width of mature seed capsules (N = 100), not yet dehisced, were measured using a dissecting microscope and a standard ruler. The number of seeds was counted from each capsule, and measurements of length and width were recorded for 50 randomly selected seeds using a dissecting microscope and ruler. Voucher specimens for seeds are deposited in the herbarium of the National Trust for the Cayman Islands (CAYM; Grand Cayman). Because of the concern over the status of *Agalinis kingsii*, whole plant specimens were not collected.

Seed morphology has been recognized for its value in the systematic analysis of *Agalinis* (Canne 1979, 1980; Musselman and Mann 1976; Pennell 1913, 1929, 1935). To provide a more detailed description of the species, surface morphology of mature seeds was examined using scanning electron microscopy (SEM). Seeds (unfixed and without critical point drying) were mounted on a sticky carbon stub, sputter-coated with gold (2–60 sec. cycles), and examined on a Joel JSM-5300 SEM.

Data were analyzed using the descriptive statistics package in SPSS 8.0 for Windows (SPSS Inc., Chicago, IL). Values given in text are ranges and means ± SE. The nomenclature used in this paper follows Proctor (1984).

RESULTS

Description of *Agalinis kingsii*. *Agalinis kingsii* individuals ranged in height from 28.0 cm to 75.0 cm. The stems were pale green, but sometimes violet, and blackened upon drying. The flowers and the leaves were decussate (Figure 2) and the pedicels were observed to ascend. All lobes of the corolla spread and were pubescent within at the base of the posterior lobes. There were between 5 and 13 flowers on the peduncle and 0–7 flowers on each lateral branch, with 0–7 lateral branches per plant.

The corolla was membranous and pink, with darker spots and two yellow lines within the anterior of the throat. The capsule was globose, and the calyx lobes were always less than the length of the tube. There were two shorter (4–5 mm) and two longer (8–9 mm) stamens that attached to the posterior of the corolla. The ovary was two-celled (1–2 mm). The style was 9–10 mm long and the stigma was 4–5 mm.

Mature seed capsules were 16.5–21 mm long and 11–13 mm wide and contained 196–205 seeds of unknown viability. Seeds were 0.6–0.9 mm long and 0.2–0.3 mm wide (Figure 2). The shape was angular and bluntly trapezoidal (Figure 3). The outer seed coat was black and reticulate, and the cells of the outer seed coat had conspicuous walls that were medium to deep relative to other species in the genus (Figure 4, 5). The wall suture between cells consisted of a trough, but this trough was shallow (Figure 5, 6). The radial walls were uniformly thickened and the surface was smooth (Figure 4). The thickenings were always smooth; however, the pattern of thickening was variable (Figure 4, 5).

Abundance and ecology. In the 17,764 m^2 area examined in the Salina, 1524 *Agalinis kingsii* individuals were located, equaling a density of 8.57 10^{-3} individuals m^{-2}. The area of the sedge wetland where *A. kingsii* occurred is 491,040 m^2 and an extrapolation of the data suggests the existence of approximately 42,000 individuals growing in the Salina during July, 1999. The second population of *A. kingsii* in the Central Mangrove Wetland (Figure 1) was much less extensive. A single dense population was observed on dry ground with < 1000 individuals in a 3 × 3 m open area with a few scattered individuals observed along a path to this site.

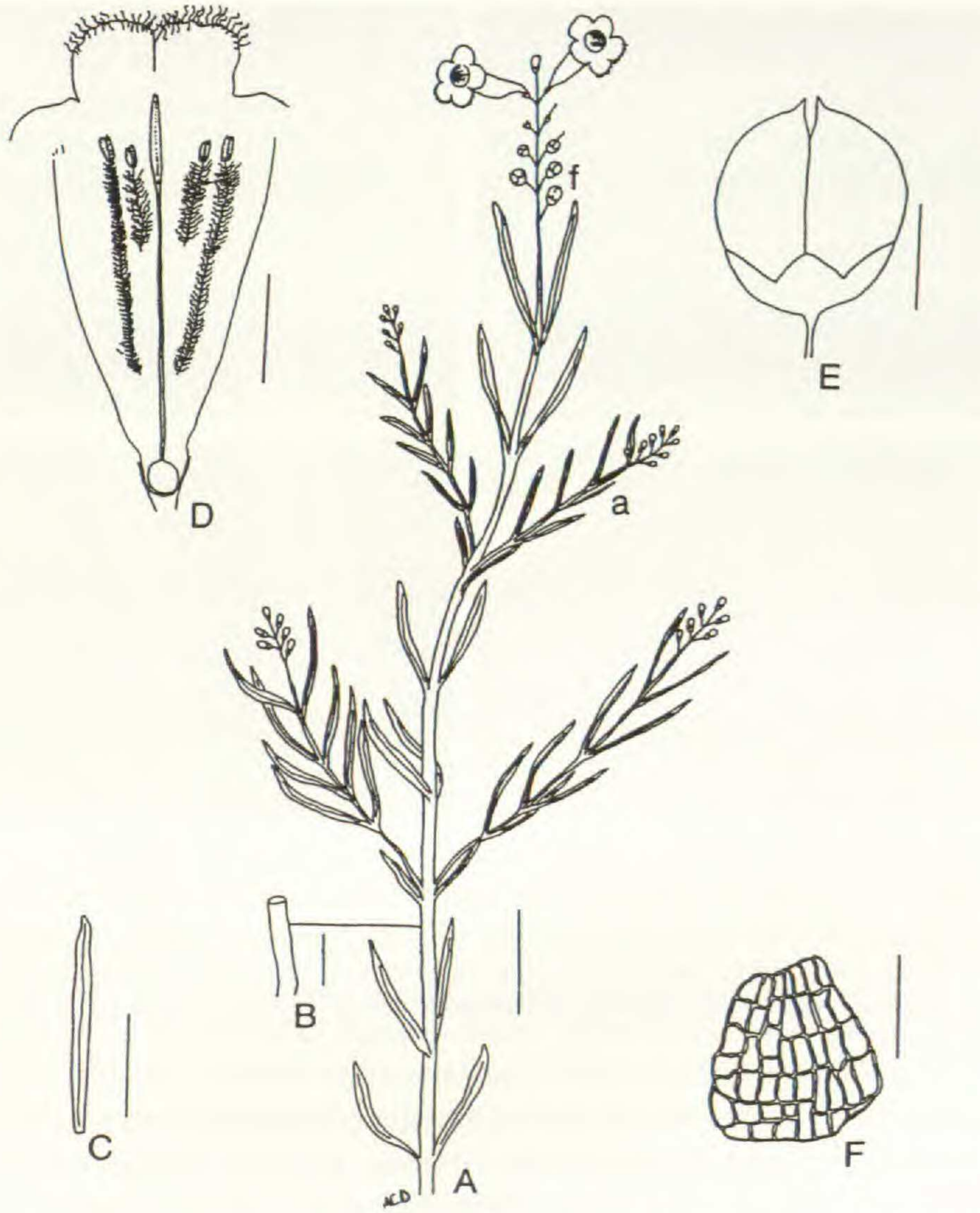
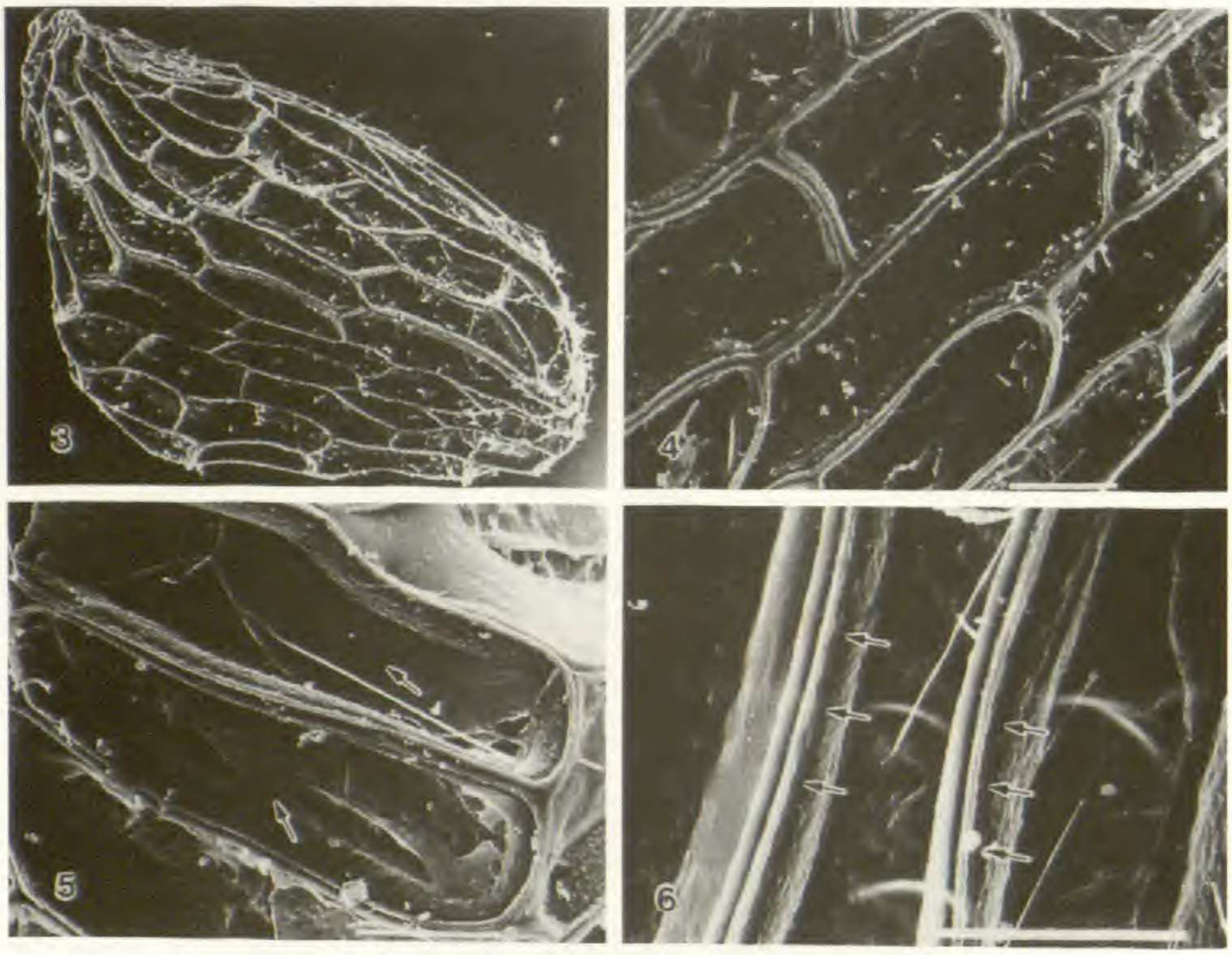


Figure 2. *Agalinis kingsii*. A. Habit of mature plant with flowers, fruits (f), and lateral branches (a). Scale = 4 cm. B. Stem section indicating terete transverse section. Scale = 0.5 cm. C. Leaf. Scale = 2 cm. D. Section of flower showing two large and two small stamens and single pistil. Note conspicuous hairs on stamens and dorsally on petal tips. Scale = 0.4 cm. E. Partially dehiscent fruit. Scale bar = 0.1 cm. F. Mature seed. Scale = 0.05 cm.

Agalinis kingsii had a clumped distribution and when located, there were 2–28 individuals in 1 m^2. In the Salina *A. kingsii* could be found with the base of the stem submerged in standing water, but was generally found 4.2 ± 0.9 cm above the water table. *Agalinis kingsii* was most commonly found growing on the sides of *Conocarpus erectus–Cladium jamaicense* Crantz tree islands and at drier, upland locations in the *C. jamaicense* community (Table 1). Individuals were located most



Figures 3–6. Scanning electron microscopy of seeds of *Agalinis kingsii*. 3. Whole seed. Scale bar = 100 μm. 4. Shape and relative depth of outer seed coat cells and pattern of wall thickening. Scale bar = 50 μm. 5. Surface features of radial walls (arrows), wall sutures, and relative depth of outer seed coat walls. Scale bar = 50 μm. 6. Detail of wall suture showing conspicuous trough (arrows). Scale bar = 50 μm.

frequently (74.3%) on the side of small (< 5 m diameter) *Conocarpus erectus–Cladium jamaicense* tree islands. *Agalinis kingsii* was found associated with *C. jamaicense* [frequency (f) = 100%], *Eleocharis cellulosa* Torr. (f = 54.5%), *Metastelma palustre* (Pursh) Schltr. (f = 18.8%), *Rhabdadenia biflora* (Jacq.) Muell.-Arg. (f = 3%), and *Acrostichum aureum* L. (f = 3%).

Growth time from emergence to flowering was 16–21 days. Flowering of each pair of buds was consecutive (1–2 days between pairs) and each pair was viable for 1 day. Accordingly, *Agalinis kingsii* probably began emerging in mid-April and continued until early September. Flowering began in early May and climaxed in July. Upon emergence, growth of the peduncle was rapid. A raceme formed and began to produce flower buds. Each pair of buds (or single for the terminal bud), flowered in the early morning, which is common in the genus (Dieringer 1991, 1992). Flowers wilted and detached in the afternoon on the day of emergence. Seed set began approximately 18

Table 1. Frequency table for presence of past year(s) individuals, ants on stem or in corolla, defoliation, and general habitat for *Agalinis kingsii*. N = 100.

Ecological Feature	Frequency (%)
Presence of past year(s) individuals	90
Presence of ants on stem or in corolla	99
Presence of defoliation	47
Presence on small tree islands (< 5 m diam.)	78
Presence on medium tree islands (5–10 m diam.)	15
Presence on large tree islands (> 10 m diam.)	6

days after pollination. The seeds were dispersed to the ground. Once all capsules had dehisced, the peduncle turned black and detached.

Individuals from the previous year(s), as evidenced by dead standing biomass, were present at 90.1% of the sites where *Agalinis kingsii* occurred (Table 1). There was evidence of defoliation on 46.5% of plants, presumably by larvae of *Junonia evarete* (Pule 1995; Smith et al. 1994; Stiling 1989). Pupae of the same species were observed on *A. kingsii* in the Central Mangrove Wetland. No winged insects were observed entering the corollas during the study. Flightless ants were the only insects observed entering the corolla and they were present in the corolla or on the stem of 99% of the individuals examined (Table 1). Ants, covered in pollen, were regularly seen exiting the corollas. Bagged flowers did not self-fertilize and the ovary detached after 1–2 days.

Several environmental factors were significantly correlated with growth, and the number of flowers per plant showed significant correlations with size. Percent shade at the soil surface correlated with individual height ($r = 0.753$, $p < 0.05$), and distance from the plant base to the water table correlated with plant height from base to tip of the peduncle ($r = 0.378$, $p < 0.05$). As well, the number of flowers on the peduncle correlated with height of the plant ($r = -0.301$, $p < 0.05$). These relationships may have significant implications for species persistence and their importance will be addressed in the forthcoming discussion.

DISCUSSION

This account of the biology and the life history of *Agalinis kingsii* will aid in designing more detailed ecological studies, as well as in developing long-term survival and management strategies for *A. kingsii* on Grand Cayman. The following discussion will focus on understanding species-environment interactions, in the context of species rarity, to further assist in the design of a management plan that will encourage persistence of the species.

The rarity of *Agalinis kingsii* on the island might be explained by the limited quantity of suitable habitat. This species was never located in an area that had 100% "forest" canopy cover. Thus habitat in the Central Mangrove Wetland that is suitable in terms of species composition may have inadequate light. *Agalinis kingsii* germinated in areas where there was 100% shade at the soil surface, but dead, overlying vegetation or dense stands of *Cladium jamaicense* typically imposed this shade. The data suggest that lower light at germination results in a taller individual at maturity. However, the taller the plant, the fewer flowers present on the peduncle. The relationship implies that, as competition for light increases, reproductive fitness of the individual decreases. If fitness is decreased, then there may be fewer individuals recruited into these small, rare populations.

Concomitantly, many rare species are known to benefit from disturbance (Grigore and Tramer 1996; Hartnett and Richardson 1989; Jacobson et al. 1991; Lesica 1999; Watson et al. 1994) and *Agalinis kingsii* does not appear to be an exception. *Agalinis kingsii* in the Salina was found in an area frequently (< 10 years) affected by fire. Fire constrains the growth of woody species in the Salina and removes dead aboveground biomass, creating an adequate light environment for successful growth. The recurring fires in the Salina may be a requirement for the long-term stability of *A. kingsii* populations on Grand Cayman. The long-term survival of the *A. kingsii* population in the Central Mangrove Wetland, without recurring fires, appears more tenuous. As previously mentioned, the *A. kingsii* plants in the Central Mangrove Wetland were found in a very limited area but this area has been cleared annually by the Mosquito Research and Control Unit (MRCU) of the Cayman Islands government. Should the MRCU halt their path maintenance in this area, *A. kingsii* may be in danger of disappearing. Disturbance, especially by fire and clearance, removes litter and thereby increases seedling emergence and opens habitat that was previously unsuitable. The autecology of *A. kingsii* suggests a positive relationship with disturbance and, as such, no attempt should be made to alter the disturbance regime.

In the Salina, *Agalinis kingsii* was most often found growing in the *Conocarpus erectus–Cladium jamaicense* community. This community differs from all other communities in the sedge wetland in its soil pH, water salinity, and distance from the water table (Diochon, unpubl. data). Any commercial developments undertaken in the northeast corner of Grand Cayman have the potential to influence hydrographic features in the Salina. Alterations to the water table may have a dramatic effect on community structure, possibly similar to the alarming modifications to the vegetation structure in the Florida Everglades subsequent to development in the surrounding area (Jordan et al. 1997; Loveless 1959). Although the populations of *A. kingsii* on Grand Cayman are small, but appear stable, they may be at risk due to their narrow geographic and environmental range.

Conservation measures should be taken to ensure species survival. Such measures could include: 1) continuous monitoring of the status of the populations; 2) a continuation of current disturbance regimes in the Salina and Central Mangrove Wetland; 3) establishment of a seed bank; and 4) introduction of the species to the Queen Elizabeth II Botanic Park, located on Grand Cayman Island. The authors are hopeful that this account might encourage further systematic analysis of *Agalinis kingsii* to confirm its endemic status.

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