HOLARCTIC LEPIDOPTERA, 10(1-2): 53-57 (2005)

BUTTERFLY CONSERVATION AND HOSTPLANT FLUCTUATIONS: THE RELATIONSHIP BETWEEN *STRYMON ACIS BARTRAMI* AND *ANAEA TROGLODYTA FLORIDALIS* ON *CROTON LINEARIS* IN FLORIDA (LEPIDOPTERA: LYCAENIDAE AND NYMPHALIDAE)

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ABSTRACT.– A year-long survey was conducted in the Florida pine rocklands of Everglades National Park and the National Key Deer Refuge to determine the status of two potentially threatened butterfly subspecies; the Florida Leafwing, *Anaea troglodyta floridalis* F. Johnson & Comstock, and Bartram's Hairstreak, *Strymon acis bartrami* (Comstock & Huntington). These butterfly species appear so specialized on their sole host, *Croton linearis* Jacq.(Euphorbiaceae), that fluctuations in this plant's density and life-cycle (i.e. in response to climatic conditions and fire influence) appear to dictate the population behavior and status of the butterflies. This study encountered stable populations of all three taxa in the remaining pinelands of Big Pine Key, Florida. *Strymon a. bartrami* was particularly common on Big Pine Key during periods of active *C. linearis* flower bloom in the open pineland survey areas. *Strymon a. bartrami* was not observed in the Everglades during this survey. The status of this butterfly on the mainland should be viewed with concern. *Anaea t. floridalis* was frequent in the transitional pineland/hardwood hammock ecosystems, during drier parts of the survey, both on Big Pine and on the mainland.

KEY WORDS: Big Pine Key, bionomics, ecology, forestry, Long Pine Key, Nearctic, Neotropical, West Indies.

The pineland of South Florida and the Lower Florida Keys is a subclimax community lying upon oolite limestone rock. This ecosystem consists of an overstory of slash pine *Pinus elliottii* Engelm. var. *densa* Little and Dorman and an understory of herbs, vines and shrubs, such as woolly croton *Croton linearis* Jacq. (Euphorbiaceae) (Myers and Ewel, 1990; Koptur, 1991). *Croton linearis* is a small dioecious shrub species possessing two distinct forms. One form is dominant historically in the Lower Keys (Monroe County), characterized by long narrow leaves (Fig. 1c,d). The other form possesses much shorter leaves and is located on the southern mainland extending as far north as Jupiter Island (Martin County, FL). The mainland form now occurs predominantly in fragmented populations, whereas the keys variety is extirpated from all islands except Big Pine Key. The plant serves as the sole host of two endemic butterflies, the Florida Leafwing (*Anaea troglodyta floridalis* F. Johnson & Comstock) (Nymphalidae) (Fig. 1a) and Bartram's Hairstreak (*Strymon acis bartrami* Comstock & Huntington) (Lycaenidae) (Fig. 1b). The demise of these butterflies has followed the rapid decline of *Croton*-containing pineland in South Florida.

The strong flight abilities of *A. t. floridalis* gives this species the opportunity to disperse over large areas when searching for extant host populations. Conversely adult *S. a. bartrami* are seldom found far from their host, maintaining flight patterns that take them no more than 5m from the *Croton*-pineland association (Schwartz, 1987; Worth et al, 1996). Less mobile over larger distances than *A. t. floridalis, S. a. bartrami* may be unable to readjust to the range fragmentation of *C. linearis* that has resulted from extensive urban development, thus causing this butterfly to become isolated into small populations. This would appear to be the case, especially in the pinelands of the Everglades, an area that contains the largest remaining population of *C. linearis* on the mainland. Here, stable *A. t. floridalis* populations have persisted throughout the park as those of *S. a. bartrami* have dwindled.

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The problem of habitat loss is further complicated by habitat mismanagement. The largest component of this is a lack of prescribed burns and suppression of natural fires. For a tropical pineland, as in South Florida, frequent fires in the dry season burn back the overgrowth of the herbaceous layer, allowing native shrubs to re-sprout from secondary roots under the slash pine canopy (Carlson *et al.*, 1993; Olson and Platt, 1995; Bergh and Wisby, 1996). Several studies have been conducted on the natural histories and status of *A. t. floridalis* and *S. a. bartrami* in South Florida (Hennessey and Habeck, 1991; Schwarz *et al.*, 1995; Worth *et al.*, 1996; Salvato, 1999). These studies suggested that the suppression of natural fires, combined with an inconsistent prescribed burn agenda, has allowed populations of *C. linearis* to become extremely localized, especially in the pine rocklands of the Everglades. The present study monitored the remaining populations of *A. t. floridalis* and *S. a. bartrami* and evaluated to what extent the decrease and fragmentation of *C. linearis* has affected the densities of these butterfly species. The study also looked at the nature of the relationship between these two very different butterflies and their ability to each make use of a shared and dwindling host.

MATERIALS AND METHODS

Line transects were established at Gate 4 of Long Pine Key (n = 1) (within Everglades National Park) and on Big Pine Key (n = 3) (within the National Key Deer Refuge). The survey employed a combination of several butterfly count methods (Pollard, 1977; Gall, 1995). Transects at Long Pine Key (LPK) and Watson's Hammock (Big Pine Key) were similar, each consisting of a variety of vegetation found in the transitional zones between pineland and hardwood hammock ecosystems. The two remaining transects on Big Pine Key consisted of grass-savanna surrounded by pineland habitat. Each transect was 400m in length x 5m in width (area 0.2 ha) (437 x 6 yards, or 0.5 acres); each had evenly distributed amounts of host for the butterflies to use. The locations chosen were the same as those used by Hennessey and Habeck (1991) and followed their survey parameters. Transects were monitored once or

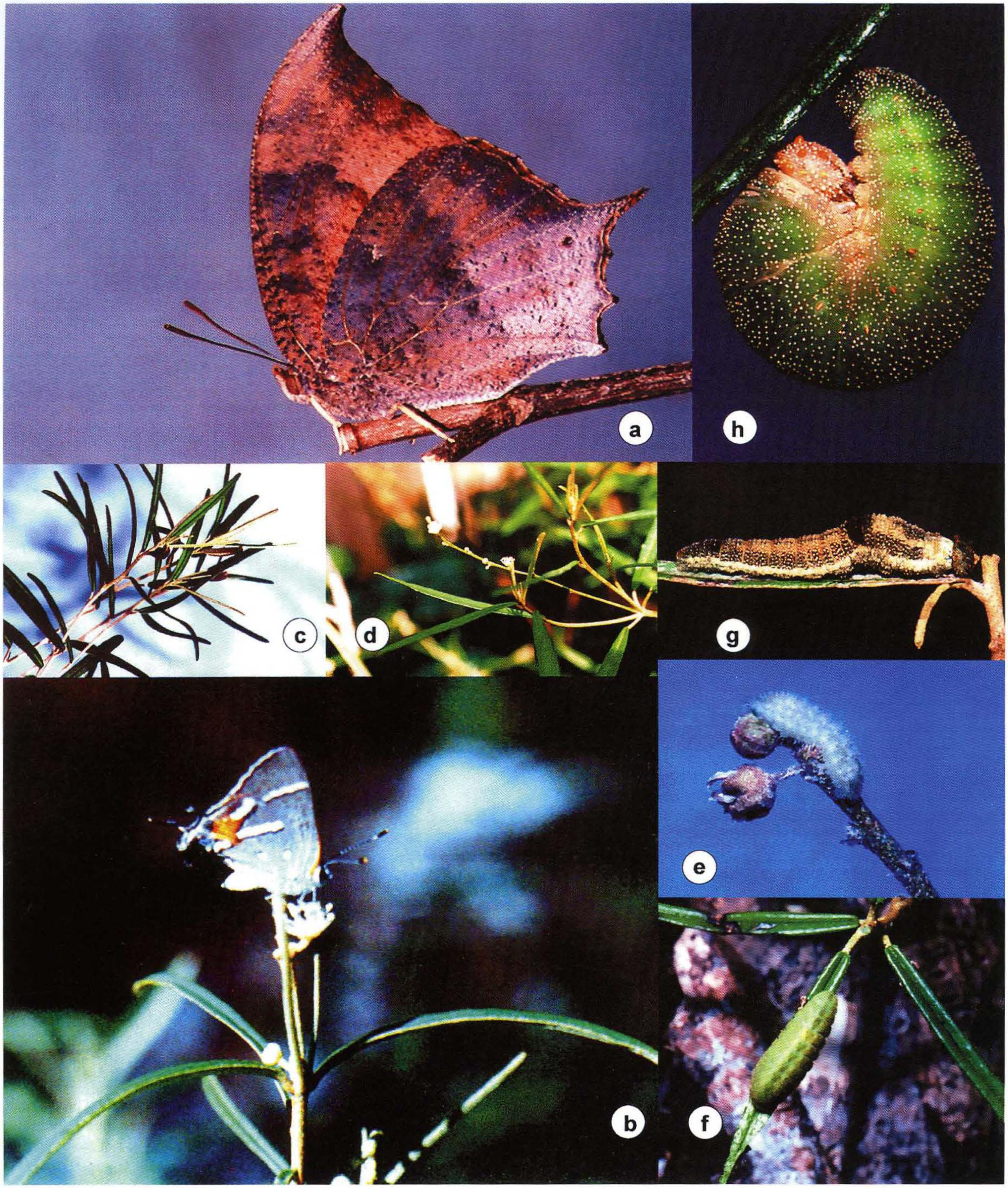

Fig 1. a, the Florida leafwing butterfly, *Anaea troglodyta floridalis* (Postmus photo); **b,** the Bartram's hairstreak butterfly, *Strymon acis bartrami*, shown feeding on the flower of *Croton linearis* (Salvato photo); **c,** *Croton linearis* (Postmus photo); **d,** a terminal of *C. linearis* showing fresh growth (Salvato photo); **e,** 1st instar *S. a. bartrami* (Schwarz photo); **f,** 5th instar *S. a. bartrami* (Schwarz photo); **g,** 4th instar *A. t. floridalis* (Ruffin photo); **h,** 5th instar *A. t. floridalis* (Postmus photo).

Table 1. Comparison of *Anaea t. floridalis* and *Strymon a. bartrami* adult densities per ha (acre) in the eleven year interval between 1988 and 1998. Based on 29, 13, 27 and 29 sampling dates for 1988, 1989, 1997 and 1998, respectively at Long Pine Key (Everglades) and Big Pine Key (1988-89 data are from Mike Hennessey and Dale Habeck).

Transect / Species	1988	1989	1997	1998
Long Pine Key				
Anaea t. floridalis	6.0 (2.4)	1.4 (0.6)	2.4 (1.0)	2.4 (1.0)
Strymon a. bartrami	0.5 (0.2)	0.5 (0.2)	0.0	0.0
Watson's Hammock				
Anaea t. floridalis	5.8 (2.3)	1.5 (0.6)	2.2 (0.9)	3.9 (1.6)
Strymon a. bartrami	2.7 (1.1)	1.6 (0.6)	1.7 (0.7)	2.0 (0.8)
North Key Deer Refuge				
Anaea t. floridalis	0.5 (0.2)	0.8 (0.3)	0.3 (0.1)	0.7 (0.3)
Strymon a. bartrami	1.0 (0.4)	2.1 (0.8)	5.0 (2.0)	5.4 (2.2)
Central Key Deer Refuge				
Anaea t. floridalis	2.2 (0.9)	0.8 (0.3)	0.0	1.7 (0.7)
Strymon a. bartrami	0.3 (0.1)	0.0	5.2 (2.1)	4.4 (1.8)

Table 2. Comparison of *Anaea t. floridalis* and *Strymon a. bartrami* larval densities per ha (acre) in the eleven year interval between 1988 and 1998. Based on 29, 13, 27 and 29 sampling dates for 1988, 1989, 1997 and 1998, respectively at Long Pine Key (Everglades) and Big Pine Key (1988-89 data are from Mike Hennessey and Dale Habeck).

Transect / Species	1988	1989	1997	1998
Long Pine Key				
Anaea t. floridalis	2.8 (1.1)	0.0	0.0	1.7 (0.7)
Strymon a. bartrami	0.2 (0.1)	0.5 (0.2)	0.5 (0.2)	2.0 (0.8)
Watson's Hammock				
Anaea t. floridalis	0.9 (0.4)	0.0	0.0	2.4 (1.0)
Strymon a. bartrami	0.3 (0.1)	0.3 (0.1)	1.7 (0.7)	2.0 (0.8)
North Key Deer Refuge				
Anaea t. floridalis	1.4 (0.6)	NR	0.2 (0.1)	0.6 (0.2)
Strymon a. bartrami	0.0	0.4 (0.1)	0.0	0.0
Central Key Deer Refuge				
Anaea t. floridalis	1.4 (0.6)	NR	0.7 (0.3)	2.0 (0.8)
Strymon a. bartrami	0.0	1.9 (0.8)	1.3 (0.5)	0.9 (0.4)

NR = Data not recorded.

twice daily for one full year beginning July 1997 and ending June 1998. The transect established at Long Pine Key employed the same dimensions as those of Big Pine Key, but was interrupted by a large open man-made prairie at its midpoint. This area was not considered part of the transect proper. Visits to each study area were alternated daily with one area being monitored in the morning hours (0900-1100), the other in the afternoon (1300-1500). This allowed these butterflies to be monitored during their most active daily flight periods.

Anaea t. floridalis and *S. a. bartrami* adults were captured by net and marked using the 1-2-4-7 numbering system (Ehrlich and Davidson, 1960). Adult densities were transformed to the square root (X + 0.5) and analyzed using ANOVA: Single Factor analysis in a completely randomized block design with all sampling dates and sites as sources of variance. Both butterflies are typical subtropical species maintaining broods throughout the year. Not having to adhere to one peak period of abundance unabled the survey to be conducted for 6 months in one year (July to December 1997) and 6 months in the following year (Jan to June 1998).

Hennessey and Habeck (1991) used the term "host terminal" to refer to the Crotons' raceme, which can grow to 4 inches in length and bears staminate flowers (Fig. 4). Both butterflies are dependent on host terminals for oviposition; *A. t. floridalis* will make use of these terminals during all stages of growth but early instar larvae of

Table 3. *Croton linearis* terminal density estimates per ha (acre) in the Everglades and on Big Pine Key for 1988-89 and 1997-98 (1988-89 data are from Mike Hennessey and Dale Habeck).

Transects	1988-89 Terminal density per ha (acre)	1997-98 Terminal density per ha (acre)
Long Pine Key	6,300 (2,550)	3,413 (1,365)
Watson's Hammock	33,350 (13,497)	17,025 (2,500)
North Key Deer Refuge	8,650 (3,501)	9,525 (4,780)
Central Key Deer Refuge	7,875 (2,944)	7,359 (3,187)

S. a. bartrami apparently mimic the Crotons' white flowers, thus requiring fresh growth. Host terminal densities were determined at each transect. To accomplish this, eight 25 m x 2 m (0.005 ha) plots were chosen at each transect and all *C. linearis* terminals within them were isolated and counted to provide per hectare estimates. This allowed for a direct comparison among the status of these three taxa a decade later. A review of all available burn data (natural, prescribed or otherwise) was investigated at the offices of U. S. Fish and Wildlife Service, both at the National Key Deer Refuge and at Everglades National Park. Climatic data (daily temperatures and precipitation) for all survey periods were obtained from the National Climatic Data Center.

RESULTS

Populations of *A. t. floridalis* have retained their largest densities at Watson's Hammock (Big Pine Key) and continue to maintain small populations at two other sites in the National Key Deer Refuge (NKDR), when compared to Hennessey and Habeck (1991) (Tables 1-2). However, this species' numbers have significantly decreased in Everglades National Park (ENP) over the past decade. The density of *C. linearis* terminals in both the Everglades and at Watson's Hammock has decreased by one half at each location during the past decade (Table 3). This significant reduction in terminal density, combined with the absence of *C. linearis* from two Long Pine Key (ENP) transects surveyed previously, may explain the apparent disappearence of *S. a. bartrami* from ENP, as well as smaller densities of *A. t. floridalis* (Tables 1-2). However, unlike Long Pine Key and Watson's Hammock, terminal density appears to have remained relatively constant in the pineland grass-savanna areas of Big Pine Key. Areas in the northern portion of the NKDR increased in terminal density from 8,650 terminals/ha in 1989 to 9,525/ha in 1999, while those in the central portion of the refuge dropped only slightly from 7,875 terminals/ha in 1989 to 7,359 in 1999. *Strymon a. bartrami* maintained its largest density within these open grass prairie transects of NKDR but was also found in Watson's Hammock.

DISCUSSION

Big Pine Key maintains the last population of *C. linearis* in the keys. The present host density on Big Pine would seem capable of maintaining consistently larger populations for both *A. t. floridalis* and *S. a. bartrami.* Increases in population numbers were recorded during this survey for both species. However, historically, these butterflies rarely share a simultaneous favorable change in density. The most likely scenarios for this type of alternate density-changing behavior in *A. t. floridalis* and *S. a. bartrami* appear tied to their relationship with the Croton host (Erhlich and Raven, 1964).

Oviposition sites are chosen carefully by both species. For *S. a. bartrami* the female requires several minutes of probing before laying eggs singly on the developing *Croton* terminal. This long duration likely enables female *S. a. bartrami* to serve as one of the major pollinating species for this plant. First and second instar larvae of (Fig. 1e) *S. a. bartrami* remain well camouflaged among the white *Croton* flowers, while later stages roam the entire plant (Fig. 1f). Adult *S. a. bartrami* actively visit the flowers of *C. linearis*, and are rarely encountered more than a few meters from this host source. *Anaea t. floridalis* females, on the other hand, lay eggs singly on both the upper and lower surfaces of host leaves, not restricted to the developing terminals. Unlike *S. a. bartrami*, adult females of *A. t. floridalis* may fly more than 30m in search of suitable host and usually require less than a minute to oviposit.

The first three larval instars of *A. t. floridalis* begin what continues throughout the larval development; that is, to be remarkable cryptic mimics of the host (resembling dead leaves) that while resting during daylight hours allows them to remain concealed (Fig. 1g). Early instars tend to eat leaves to the midvein and dangle from them in camouflage. The later two instars are light green in color (Fig. 1h), tapering from the cephalad to the caudal end, so that when at rest, they also mimic a *Croton* leaf. The head capsule during all stages bears many tiny setae, presenting the granular appearence of *Croton* seeds. Adults are rarely observed visiting flowers of *C. linearis* or any other species for nectar. They apparently rely on rotting fruit for nurishment (Baggett, 1982; Opler and Krizek, 1984; Minno and Emmel, 1993). See Schwarz *et al.*, (1995) and Salvato (1999) for a more detailed account of the natural histories of these butterflies.

The reproductive behavior shown by phytophagous insects that synchronize oviposition to allow for optimal larval feeding with their host must be very adaptive. *Eurema laeta,* an Australian pierid butterfly, is able to switch reproductive activity on and off (reproductive diapause) according to the climatic conditions present. A correlation between gravid *E. laeta* females and rainfall suggests that rainfall itself or some other aspect of the environment associated with the rains might serve as an environmental cue (Jones and Rienks, 1987). Similar reproductive diapause is thought to be experienced by several Florida species (Opler and Krizek, 1984). Such a relationship with the *Croton* host tends to correlate precisely with the life-cycle of *S. a. bartrami*, which requires abundant fresh growth for it's larvae to develop.

Above-average rainfall and seasonal temperatures were recorded in the winter/early spring periods of 1997 and 1998. These climatic factors, in part, may have helped to facilitate *Croton* abundance and bloom, thereby leading to the large densities of *S. a. bartrami* reported across Big Pine Key during these periods (Salvato, 1999).

This leads to a potential inverse correlation between *S. a. bartrami* and *A. t. floridalis*, which seemed to increase in number during the drier periods of the survey.

It would appear that when optimum conditions for *C. linearis* begin to decline, *S. a. bartrami* also declines while *A. t. floridalis* is quick to increase in numbers. The relationship between the *S. a. bartrami* and the *Croton* could be considered mutualistic and necessary for pollination purposes; outbreak densities of *S. a. bartrami* might well serve this function. *Anaea t. floridalis*' mimicry and use of dead parts of the *Croton* host in its early larval stages further suggests this species has adapted to starting its development under drier, less than favorable host conditions.

Another strong correlation to *A. t. floridalis* abundance is the relationship between host abundance and frequency of burns. Although areas of NKDR were burned from the 1950s onward, fire suppression was the primary fire management practice for over 25 years in the Lower Keys. Only in the past two decades have prescribed burns been admistered in NKDR, most of these are done experimentally and on a small scale. *Anaea t. floridalis* maintains its largest populations at Watson's Hammock in NKDR and at Gate 4 of Long Pine Key (ENP). However, both areas have been partially fire-treated over the past decade and this appears to have had little effect in returning native plants to these habitats. As the rate of succession from pineland to hardwood hammock ecosystem continues, populations of *C. linearis* become more fragmented. The strong flight abilities of *A. t. floridalis* probably have allowed this butterfly to make use of all *Croton*-bearing areas in Watson's Hammock and Long Pine Key, thereby allowing the butterfly to retain its stable densities, despite rapidly declining host. Another possible contributor to the stability of *A. t. floridalis* may lie in one of Watson's Hammock's more unique and fortunate features. This area in NKDR represents the only pineland location within the Lower Keys not treated with mosquito control pesticide applications (see Salvato (1999) and Hennessey and Habeck (1991, 1992) for discussion and comparision of butterfly densities in chemically treated/non-treated ecosystems of this region).

The pineland grass-savannas of interior Big Pine Key have remained unchanged over the past decade. *Croton linearis* is better adapted to the drier conditions of this exposed rockland habitat. In this ecosystem, the numerous invasive species that are out-competing *C. linearis* in transitional areas such as in Watson's Hammock, appear to be at a disadvantage. In these more open areas, *S. a. bartrami* thrived in the summer and winter months of this survey. During the years that followed this survey, visits by the author to these locations never documented *S. a. bartrami* in such large densities.

An inconsistent burn regime that advocated fire suppresion had also been in place at LPK. Low densities of *Croton* were reported by Hennessey and Habeck (1991) at three locations at LPK, accompanied by severely dwindling populations of both *A. t. floridalis* and *S. a. bartrami* at two of these (Gates 3 & 8). As mentioned, only Gate 4 maintained *C. linearis* in densities required for butterfly use. *Anaea. t. floridalis* maintains a stable, year-round, population at this location. However, *S. a. bartrami* was not observed in LPK during the entire survey period. This butterfly, possibly unable to negotiate the distance between the previous host stands, appeared extirpated or reduced to undetectable levels in the ENP. Fortunately, *S. a. bartrami* was observed amid fresh Croton growth at Gate 4 in March 1999 following a prescribed burn in part of the area. This offers hope that new burn agendas being implemented at LPK will, in time, allow for a stable population of this butterfly as well.

ACKNOWLEDGMENTS

I thank Thomas C. Emmel, J. Howard Frank, Dana G. Griffin III and Jaret C. Daniels for their advice and encouragement while conducting this research. I thank John V. Calhoun, T. C. Emmel and James L. Nation for reviewing this paper. I thank Kent Perkins for his assistance in my attempts to document the historic range of *Croton linearis*. I thank Jane Ruffin, Clarence Postmus and Kerri Schwarz for providing photos, and Dawn M. Rosner for preparing the figures page (photos are as follows: Mark Salvato (© 2005), Fig. 1b,d; Clarence Postmus (© 2005), Fig. 1a,c,h; Kerri Schwarz (© 2005), Fig. 1e-f; Jane Ruffin (© 2005), Fig. 1g). I would also like to thank the staff at the National Key Deer Wildlife Refuge, The Nature Conservancy, and Everglades National Park for their support with permits and various technical assistance.

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