Distribution and Population Size For Three Pine Rockland Endemic Candidate Plant Taxa on Big Pine Key, Florida

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Introduction

Three plant taxa which occur in pine rockland habitat on Big Pine Key, Florida are being considered by the U.S. Fish and Wildlife Service (hereafter "Service") as candidates for listing as Endangered or Threatened under the U.S. Endangered Species Act. Wedge sandmat (*Chamaesyce deltoidea* subsp. *serpyllum*) is endemic to Big Pine Key. Big Pine Partridge Pea (*Chamaecrista lineata* var. *keyensis*) is endemic to the lower Florida Keys. Sand flax (*Linum arenicola*) is known from Miami-Dade County and the lower Florida Keys. Big Pine Key is thought to contain the largest population of each of these taxa in the Florida Keys and the only population of *C. deltoidea* subsp. *serpyllum* (Bradley and Gann 1999; Gann et al. 2002; Hodges and Bradley 2006).

The population sizes and distributions of each of these taxa on Big Pine Key have never been determined. Long-term ecological changes on the island associated with fire suppression, land clearing, sea level rise, changes in hydrology, fluxes in Key Deer densities, and invasion of exotic pest plants may have had and will continue to have impacts on the population sizes of these three taxa. It is possible that there have been major changes, most likely declines, in the population sizes of each of these taxa because of human-caused ecosystem changes. A detailed study to determine the current status of each of these taxa was needed to determine if changes have occurred, and, with future surveys, if populations will continue to change.

Study Area

Big Pine Key, covering approximately 2,400 ha, is the largest of the islands in the Lower Florida Keys, Monroe County. Folk (1991) estimated that pine rockland historically covered 1,049 ha, about 44% of the island. Pine rockland forest dominated the interior of the island. Pine rocklands on the north (405 ha) and south (177 ha) portions of the Key were separated by a freshwater wetland.

Pine rocklands on Big Pine Key occur on Miami oolitic limestone, overlaying Key Largo Limestone. Unlike most pine rocklands in Miami-Dade County, the ground surface in Big Pine Key pine rocklands consists of flat slabs of limestone, probably representing dried marls (Dickson 1955). Uprooted trees have broken and uplifted the slabs revealing the underlying oolitic limestone. The limestone slabs and oolite have few soil deposits and plants grow from the few fissures that do exist and hold soil, or from shallow deposits of sand. Plants are often in a clumped distribution surrounded by large areas of bare open rock that do not support plant growth.

Following permanent human settlement which started in the middle 1800s (Simpson 1982), much pine rockland area was lost due to land clearing. In addition to land clearing for homes and business, a complex of roads were built through the pine rocklands which destroyed habitat and fragmented the community. Additional pine rockland has probably been lost due to sea level rise. On nearby Upper Sugarloaf Key, Ross et al. (1994) found that approximately 58 ha of pine rockland had been lost in the last century due to sea level rise. Similar effects have probably occurred on Big Pine Key. Not only has sea level rise probably been a factor in increasing salinities and forcing habitat succession, but canals and mosquito ditches that have been constructed across the island have also increased inland salinities and have probably caused habitat changes (Langevin et al. 1998).

Pine rocklands are a fire subclimax ecosystem. They require periodic fires to prevent succession to a hardwood dominated ecosystem. Fires kill woody plant species, maintain habitat for herbs and grasses, remove the duff layer, and recycle nutrients. Historical fire periodicity on Big Pine Key is estimated to have been from 3-7 years (Snyder et al. 1990) to 10-20 years (Carlson et al. 1993). Natural fires were historically started by lightning (Bergh and Wisby 1996). Following human settlement the fire regime on Big Pine Key has changed (Carlson et al. 1993; Bergh and Wisby 1996). Fires were believed to have been set by hunters to enhance habitat for Key Deer from the 1840s to about 1950. Hunter's fires were probably set in the winter rather than early summer, possibly at a higher frequency than would have occurred naturally. Around

1950, fire suppression became the standard and natural or accidental fires were extinguished. In recent years there have been new attempts at reintroduction of fire, but they have had limited success (Bergh and Wisby 1996).

Pine rockland now covers approximately 582 hectares of the island, 55.5% of the historical estimate by Folk (1991). There are 405 ha in the northern pinelands and 177 ha in the southern pinelands. Most of the pine rockland that remains on Big Pine Key is preserved within the National Key Deer Refuge and properties owned by the Nature Conservancy, the State of Florida, and Monroe County. About 478 ha are protected, 82% of the pine rocklands on the island. The northern and southern pine rockland areas differ in amount of protection and habitat quality. The northern areas are less dissected by roads and have burned more frequently than those in the south. The southern pinelands have been extensively fragmented by road construction. They have burned less frequently and have denser palm/hardwood under stories and deeper duff accumulations.

Study Taxa

Chamaecrista lineata var. *keyensis* is endemic to the lower Florida Keys (Bradley and Gann 1999; Hodges and Bradley 2006). Its native range historically encompassed pine rocklands on Big Pine, Cudjoe, No Name, and Ramrod Keys (Irwin and Barneby 1982; Bradley and Gann 1999; Hodges and Bradley 2006). At present it is known only from pine rocklands on Big Pine Key and Cudjoe Key and last year it was discovered on a road shoulder on Sugarloaf Key (Hodges and Bradley 2006). The populations on Cudjoe and Sugarloaf Keys are small, consisting of only about 100 plants and 2 plants, respectively (Hodges and Bradley 2006). The reproductive ecology, demography, and relationship to fire of the taxon has been well studied (Liu 2003; Liu and Koptur 2003; Liu et al. 2005).

Chamaesyce deltoidea (Engelm. ex Chapm.) Small subsp. *serpyllum* (Small) D.G. Burch is endemic to Big Pine Key (Small 1913; Small 1933; Burch 1966; Herndon 1993; Bradley and Gann 1999; Gann et al. 2002). The distribution, population size, and ecology of the taxon have been poorly studied. Neither Dickson (1955) nor Carlson et al. (1993) recorded it in their study plots. Herndon (1993) noted that populations were scattered on the island and that the total number of plants did not appear to be large. Ross and Ruiz (1996) found it in 32 of 145 study plots (5 m radius) only in the northern and eastern portions of Big Pine Key, sometimes at densities exceeding 2 plants/m^2. They found that sites with low hardwood density, low total understory cover, and extensive amounts of exposed rock were more likely to support the taxon.

Linum arenicola (Small) H.J.P.Winkler is endemic to Monroe County in the lower Florida Keys and to Miami-Dade County. It is currently known from 4 occurrences in the Florida Keys, including Big Pine Key, and 5 occurrences in Miami-Dade County. Hodges and Bradley (2006) estimated that there were between 101 and 1,000 plants in the Keys outside of Big Pine Key. The population size in Miami-Dade County is unknown. Like *C. deltoidea* subsp. *serpyllum*, the distribution and population size on Big Pine Key have been poorly studied. No studies have been conducted on the ecology of the species. Neither Dickson (1955) nor Alexander and Dickson (1972) reported it. Carlson et al. (1993) recorded it at a maximum frequency in study plots (0.5 m^2) of only 1.3%. Ross and Ruiz (1996) found it in only 11.0% (16 of 145) of study plots (5 m radius), all east of Key Deer Blvd. They found maximum densities just above 0.5 plants/m^2. They found that sites with abundant grasses, high pine regeneration, and high cover of exposed rock were the most likely places to support the species.

<u>*Other Rare Plant Taxa*</u>

The pine rocklands on Big Pine Key support additional rare plant taxa, most of which are not candidates for listing under the Endangered Species Act (Gann et al. 2002). These are mostly tropical taxa which occur in the Caribbean, but not the Florida mainland. *Argythamnia blodgettii* is an endemic to the Florida Keys and Miami-Dade County which is a candidate for Federal listing (Bradley and Gann 1999; Hodges and Bradley 2006). Rare tropical taxa which do not grow on the Florida mainland include *Caesalpinia pauciflora, Catesbaea parviflora, Dodonaea elaeagnoides, Evolvulus* *grisebachii, Pisonia rotundata,* and *Strumpfia maritima* (Gann et al. 2002). In the United States, *E. grisebachii* is only found on Big Pine Key. Another plant which is critically imperiled in South Florida which grows in Big Pine Key Pine Rocklands is *Agalinis harperi* (*A. obtusifolia* misapplied) (Gann et al. 2002). This taxon is more widespread in the southeastern United States, but is known from only three occurrences in South Florida. *Argythamnia blodgettii*, which is endemic to Miami-Dade County and the Florida Keys also occurs in pine rockland on Big Pine Key.

<u>*Study Purpose*</u>

This study was conducted primarily to determine the current population size and distribution on Big Pine Key of three plant taxa which are candidates for listing under the Endangered Species Act: *C. lineata* var. *keyensis*, *C. deltoidea* subsp. *serpyllum,* and *L. arenicola.* In addition to these three taxa, the study was conducted to determine the population sizes and distributions of other rare pine rockland plant taxa on the island. Repetition of the study will allow for detection of changes in population densities and distribution in response to habitat management, fires, storm surges, sea level rise, and exotic plant invasions.

While the present study was conducted as a thorough baseline survey for the rare plants of Big Pine Key, the data can be used to assess changes that have already occurred on Big Pine Key. The data set from this study can be compared, at least in part, to some prior studies including Dickson (1955), Alexander and Dickson (1972), Carlson et al. (1993), and Ross and Ruiz (1996). In each of these studies vegetation data was collected in plots, although each study used different plot sizes, sample sizes, and geographical distributions. Where data was available in these publications, I compared the current population characters of the study taxa to previously reported values to assess long-term changes in population sizes.

Methods

A GIS coverage of all publicly owned pine rockland habitat on Big Pine Key was created (Figure 1). This coverage was generated by intersecting the parcels database from the Monroe County Property Appraiser with a habitat map of Big Pine Key created by the US Army Corps of Engineers. Once the coverage of publicly owned pine rocklands was created, points spaced at 200 m intervals were overlain on the coverage. One hundred and twenty three points fell within the coverage and were the locations used for sampling (Figure 1). Each sample location was navigated to with a Garmin GPS unit (accuracy <3 m). If a sample location occurred outside of pine rockland habitat it was discarded. At each of the 123 sample locations, five 2.5 m radius plots were sampled. They were not permanently marked. A single plot was placed at the sample point, and four additional 2.5 m radius plots were established 10 m from the point at each of the four cardinal directions. In each circular plot the total numbers of individuals of each of the three study taxa were counted. Individuals of other rare plant taxa were also counted. In addition, the vegetative coverage of every plant taxon in each plot was estimated using a standardized coverage scale (<1%, 1-5%, 6-25% 26-50%, 51-75%, 76-100%) (Daubenmire 1959).

In addition to the above sampling, positions of the three target taxa were recorded when seen outside of the plots when it was necessary, such as on roadsides or other unique areas. While not quantitative, these data were useful to augment the ranges of each taxon derived from the plot data. Locations of other rare plant taxa not specifically being targeted in the study were also recorded.

To quantify the population sizes of the study taxa on road shoulders, plots were established on the edges of Key Deer Blvd. and Wilder Rd. adjacent to pine rockland habitat. Plots were placed every 100 m (Figure 2). Individuals of each study taxon were counted in a 5 m wide strip perpendicular to the road, from the edge of the asphalt to the edge of the pine rockland.

Figure 1: Publicly owned pine rockland and location of sample locations on Big Pine Key, Florida

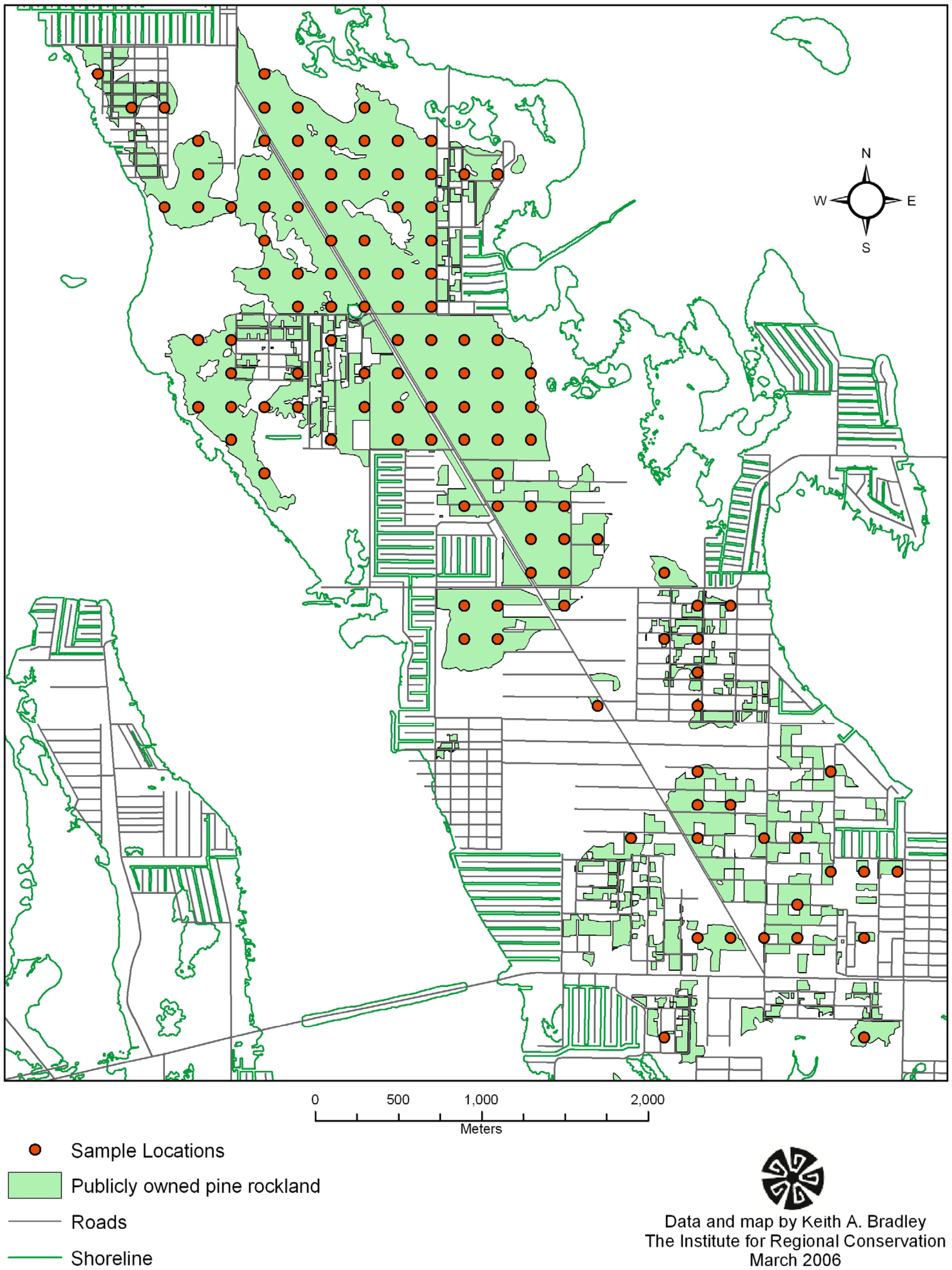
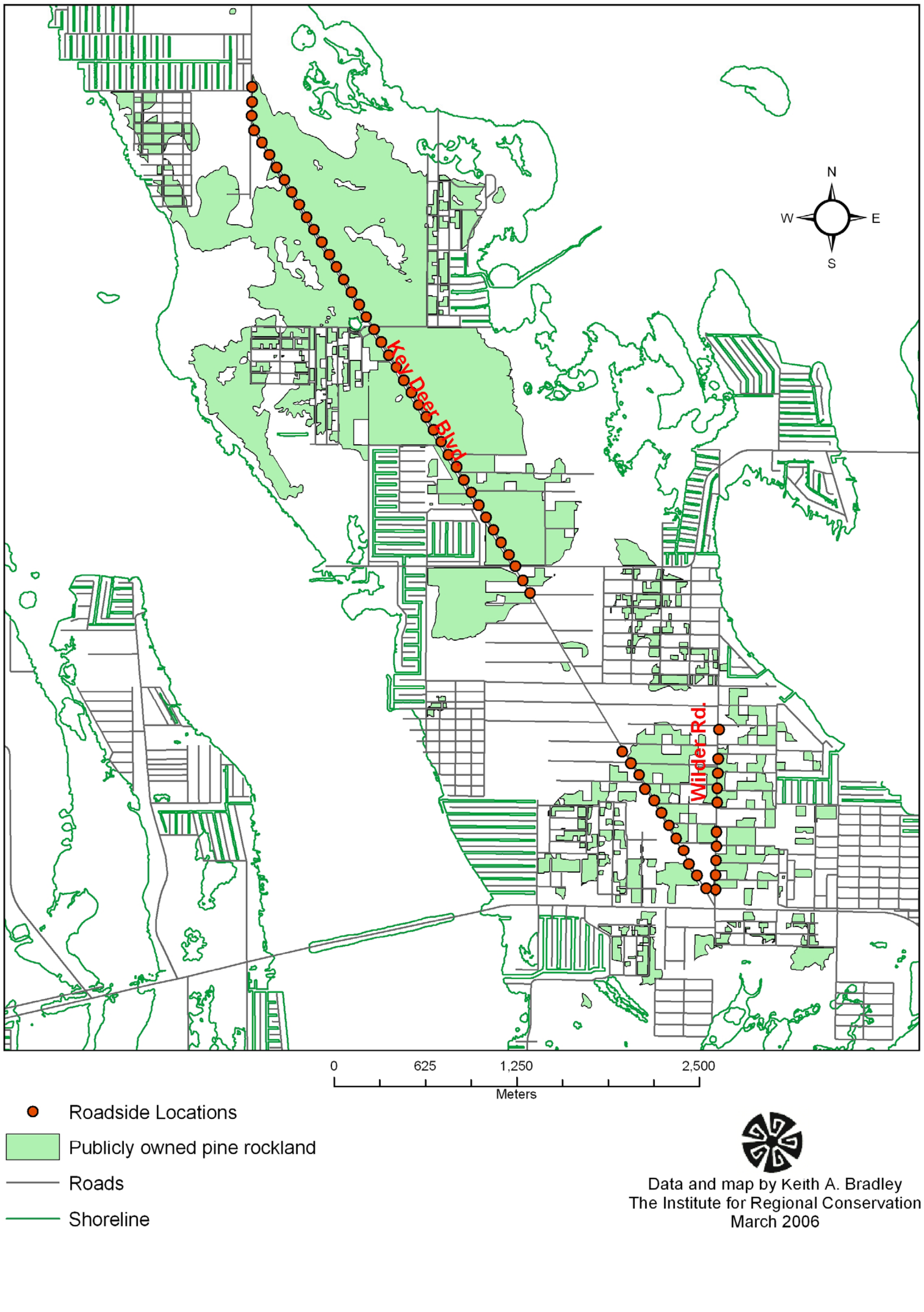


Figure 2: Location of road shoulder sample locations on Big Pine Key, Florida



SPSS 13.0 was used to generate descriptive statistics, compare means between two sample groups, and analyze correlations. To determine total population sizes of each study taxa, 95% confidence intervals were calculated. This was done separately for data collected before and after Hurricane Wilma. It was also done separately for the northern and southern pinelands. To compare mean densities of each study taxon in the northern and southern pine rocklands, and before and after Hurricane Wilma, Mann-Whitney U tests were performed as an alternative to t-tests because the data was not normally distributed. To test for correlations between the densities of the study taxa and vegetation composition in plots (e.g. hardwood cover, pine cover), Spearman Rank Correlation tests were performed.

PC-ORD 4.39 was used for multivariate analyses. Detrended Correspondence Analysis (DCA) was conducted with plot cover data to determine patterns of habitat preferences of each of the study taxa. Only data collected prior to Hurricane Wilma was used ($N = 298$). Taxa occurring in fewer than 15 plots were eliminated from the data set. Rare taxa were downweighted and axes were rescaled. The rescaling threshold was set to 0 and the number of segments was set to 26 (McCune and Grace 2002). Indicator Species Analysis (ISA) (McCune and Grace 2002) was conducted to identify plant taxa which indicate the present or absence of each of the study taxa. Only data collected prior to Hurricane Wilma was used ($N = 298$). ISA was done for each of the study taxa. Each indicator is reported with the Observed Indicator Value on a scale of 0 (no indication) to 100 (perfect indication), and probability of type I error.

All tests of significance were at the $P < 0.05$ level. Standard deviations are given for each mean that is reported.

Results

Sampling was conducted in May, June, and December, 2005. Nine sample locations (each with five plots) were discarded because they occurred in inappropriate habitat or were thought to be on private property (Figure 3) and an additional 29 plots were not established for the same reasons, although other plots at each sample location were completed. In summary, a total of 541 2.5 m radius plots were sampled at 114 locations. This represents an area of 1.06 ha, about 0.18% of the pine rockland on the island and 0.22% of Big Pine Key's preserved pine rockland. Four hundred and twenty seven (78.9%) of the subplots are in the northern pinelands and 114 (21.1%) in the southern pinelands.

On October 24, 2005 Hurricane Wilma passed over Big Pine Key. The hurricane created storm surge in the lower Keys of up to 10 feet. The surge flooded much of Big Pine Key with saltwater (Goodhue 2005), including much of the pine rockland. Sampling of 332 plots (61.4%) was completed before the hurricane and 209 plots (38.6%) were sampled in December, 8 and 9 weeks after the storm (Figure 3). All 128 road plots were sampled in December, 9 weeks after Hurricane Wilma. While conducting sampling after the hurricane, it was readily apparent that much of the pine rockland vegetation had been impacted by the saltwater flooding. The herb layer in pine rocklands in close proximity to the coast was brown with few plants having live material above ground, including *C. lineata* var. *keyensis*. Data on the densities of each of the study taxa was analyzed pre- and post-hurricane.

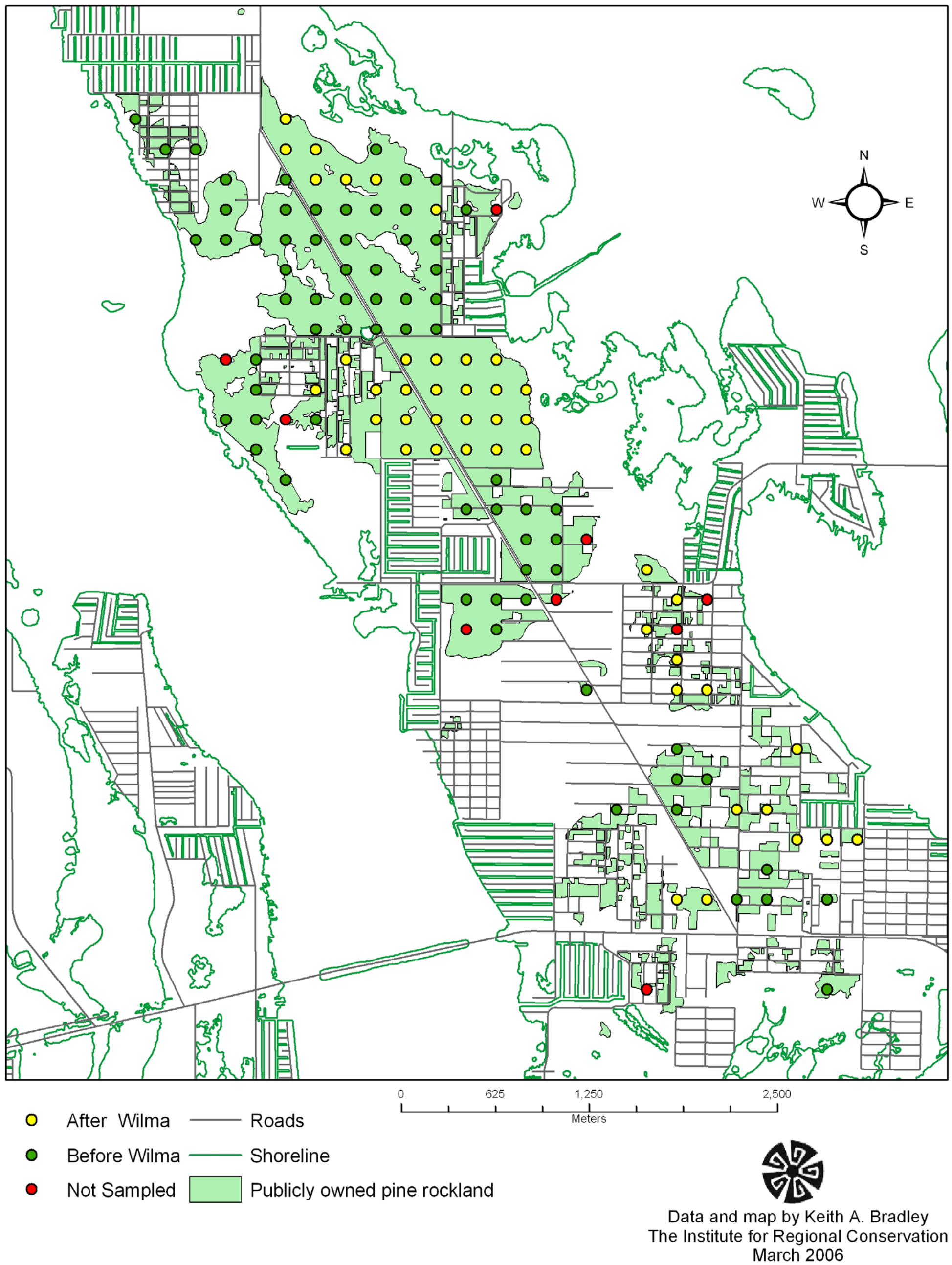
<u>*Count Data*</u>

Each of the three study taxa were recorded in the plots. *C. lineata* var. *keyensis* was the most abundant with 1,927 plants counted. *L. arenicola* was the rarest with only 33 plants (Table 1).

Table 1: Summary of count data for each of three study taxa (N = 541)

Taxon	**Total Number of Plants**	**Total Frequency**	**Percentage**
C. lineata var. *keyensis*	1,927	201	37.2%
C. deltoidea subsp. *serpyllum*	785	40	7.4%
L. arenicola	33	7	1.3%

Figure 3: Timing of data collection for sample locations, before and after Hurricane Wilma



Chamaecrista lineata* var. *keyensis

Chamaecrista lineata var. *keyensis* was wide ranging. It was found in plots nearly throughout the study area (Figure 5). It was also observed in pine rockland fragments at the southwest corner of the island where there were no plots. Plots without the taxon were more commonly near the coastal edges of pine rockland forests rather than the interior. It was recorded more frequently in plots in the northern pine rocklands than the southern. In the northern pinelands it was recorded in 178 of 427 plots (41.7%) with a mean of 4.2 ± 9.3 plants/plot (Figure 4). In the southern pinelands it was recorded in 23 of 114 plots (20.2%) with a mean of 1.3 ± 3.4 plants/plot. This difference in density was significant (U = 19,060.0, P < 0.001). Before Hurricane Wilma the taxon was found in 200 of 332 plots (60.2%) and after the hurricane 38 of 209 plots (18.2%). Density decreased from 4.6 ± 8.9 to 1.9 ± 7.7 plants/plot, a significant decrease (U = 23,804.0, P < 0.001) (Figure 4). Figure 5 shows densities at each sample location. Density decreases within each island location were also significant; in the northern pinelands density decreased from 5.0 ± 9.4 to 2.6 ± 8.7 plants/plot (U = 14,603.0, P < 0.001); in the southern pinelands density decreased from 2.4 ± 4.3 to 0.4 ± 2.0 plants/plot (U = 1,126.0, P < 0.001). Table 2 summarizes densities by island location before and after Hurricane Wilma. Before Hurricane Wilma there was a mean of 2,516 plants/ha. Calculating 95% confidence intervals, the mean is between 1,986 and 3,046 plants/ha. Extrapolating from these upper and lower bounds and 478 ha of pine rockland, there were between 949,308 and 1,455,988 individuals of *C. lineata* var. *keyensis* on Big Pine Key prior to Hurricane Wilma. Individuals were counted pre- and post-hurricane in 60 plots. Before the hurricane there were 48 individuals in these plots, a mean of 0.8 ± 1.6 plants/plot. After the hurricane only 3 plants were found, a mean of 0.05 ± 0.2 plants/plot. This difference was significant (U = 1,300.5, P < 0.001).

Table 2: Density/Plot of *Chamaecrista lineata* var. *keyensis* by island location, before and after Hurricane Wilma with 95% Confidence Intervals

	Island Location	
	North	**South**
Before Wilma	5.01 ± 1.11	2.35 ± 1.20
After Wilma	2.56 ± 1.43	0.40 ± 0.50

Figure 4: Chamaecrista lineata var. *keyensis* plot density by island location, before and after Hurricane Wilma

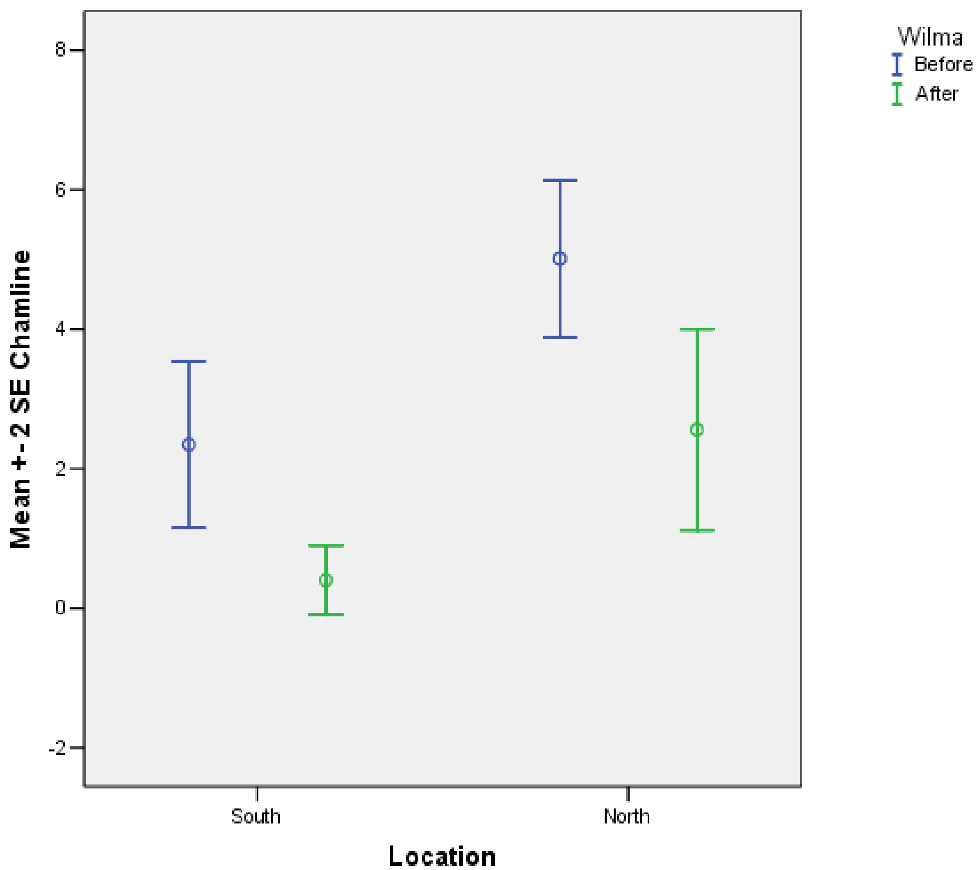
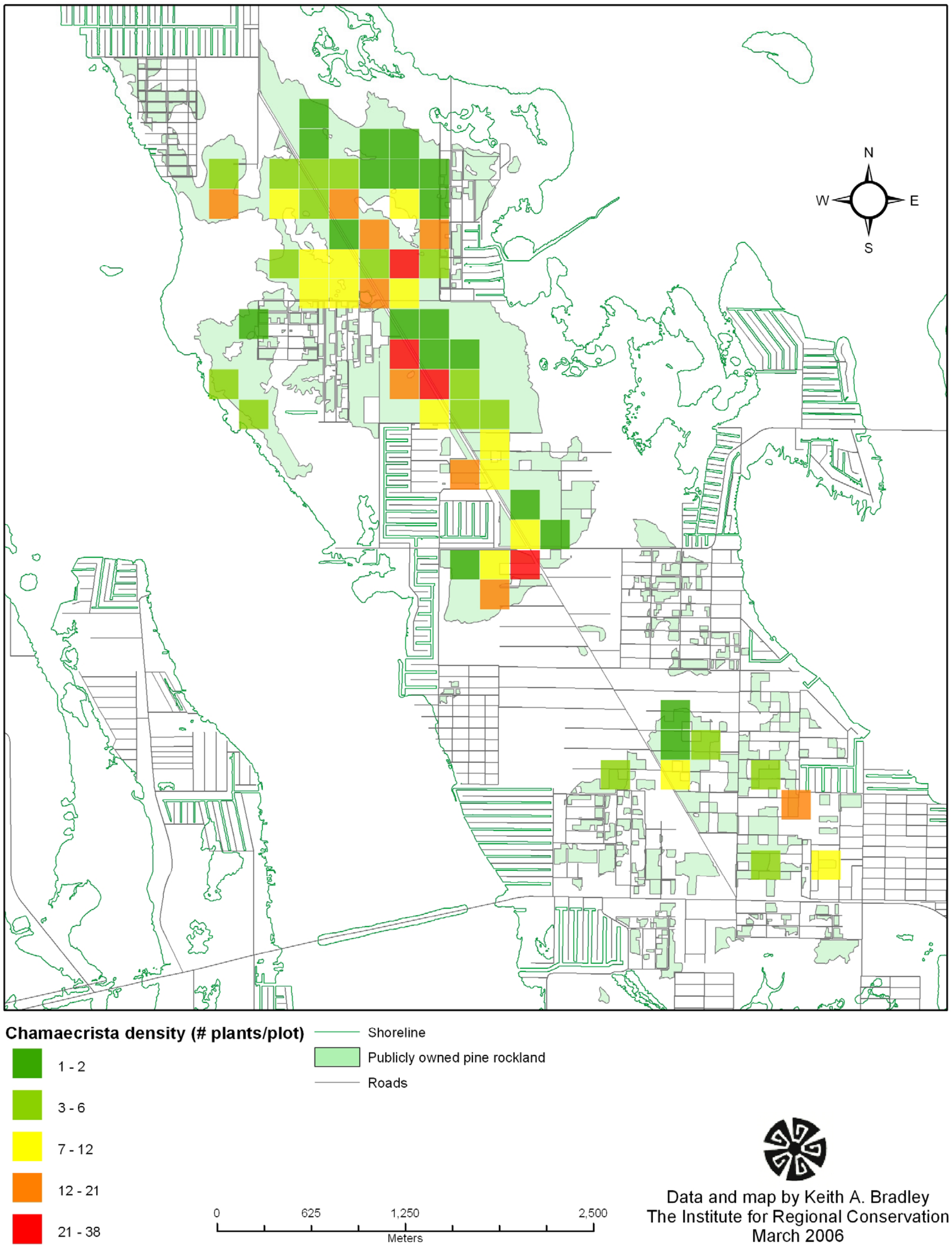


Figure 5: Distribution and density of *Chamaecrista lineata* var. *keyensis* at sample locations



Chamaesyce deltoidea* subsp. *serpyllum

Chamaesyce deltoidea subsp. *serpyllum* was absent from much of the island's pine rocklands (Figure 7). In the northern pinelands it was found in 37 of 427 plots (8.7%) with a density of 1.79 ± 9.0 plants/plot. These plots were mostly in a line parallel to Key Deer Blvd., far from the coastal edges of pine rockland forests. It was found in only three of 114 plots (2.6%) in two sample locations in the southern pinelands with a density of 0.18 ± 1.4 plants/plot (Figure 6). These densities were significantly different (U = 22,847.5, P = 0.027). These sample locations were at the northern edge of the southern pinelands almost halfway between the east and west coasts. This difference in density was significant (U = 22,847.5 , P = 0.027). Before Hurricane Wilma the taxon was found in 31 of 332 plots (9.3%) and after the hurricane in 9 of 209 plots (4.3%). Density decreased from 1.7 ± 8.9 to 1.0 ± 6.5 plants/plot, a significant decrease (U = 32,978.5, P = 0.027) (Figure 6). Table 3 summarizes densities by island location before and after Hurricane Wilma. Before Hurricane Wilma there was a mean of 951 plants/ha. Calculating 95% confidence intervals the mean is between 416 and 1,486 plants/ha. Extrapolating from these upper and lower bounds and 478 ha of pine rockland, there were between 198,848 and 710,308 individuals of *C. deltoidea* subsp. *serpyllum* on Big Pine Key prior to Hurricane Wilma.

Table 3: Density/Plot of *Chamaesyce deltoidea* subsp. *serpyllum* by island location, before and after Hurricane Wilma with 95% Confidence Intervals

	Island Location	
	North	**South**
Before Wilma	1.99 ± 1.13	0.38 ± 0.56
After Wilma	1.41 ± 1.26	0

Figure 6: Chamaesyce deltoidea subsp. *serpyllum* plot density by island location, before and after Hurricane Wilma

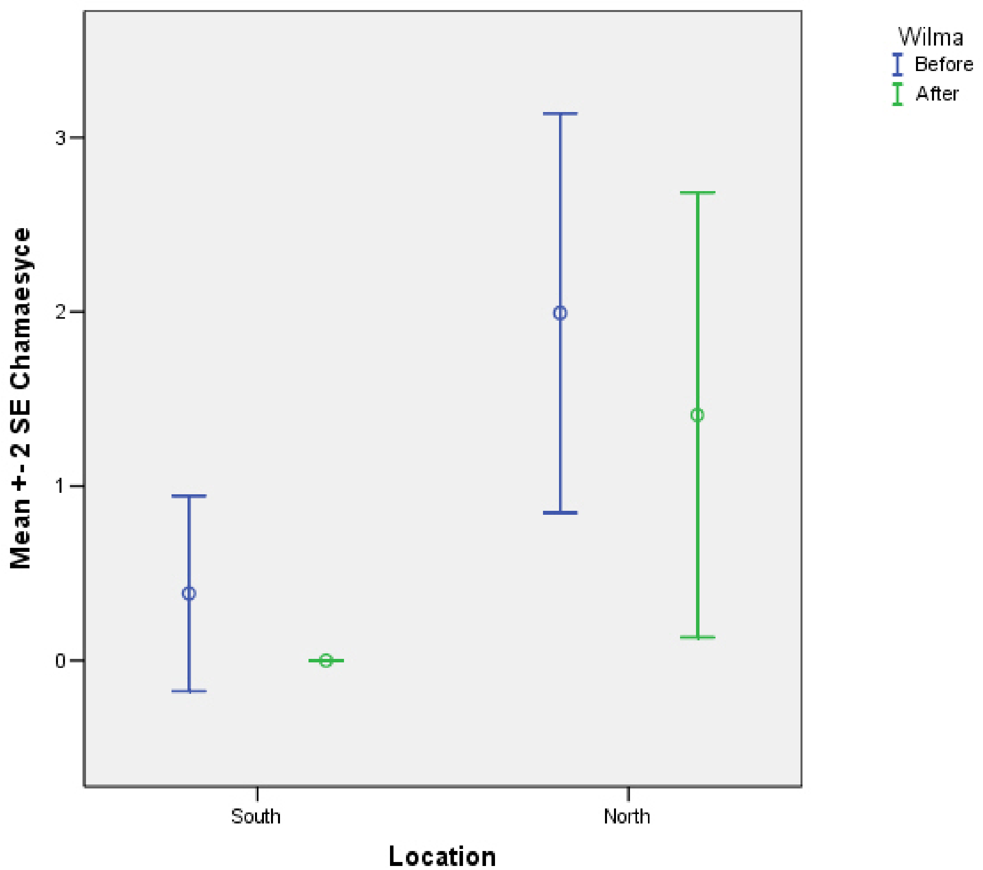
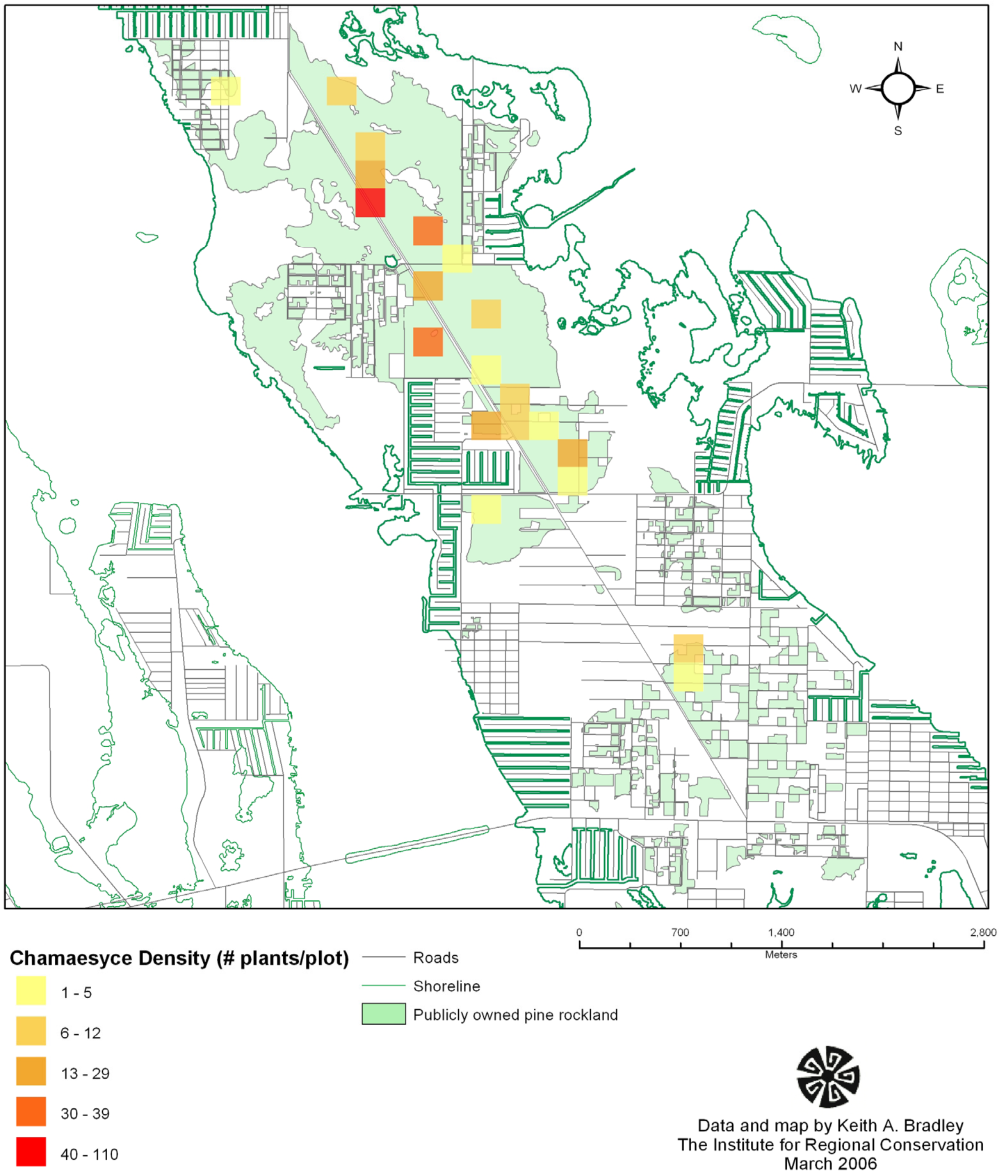


Figure 7: Distribution and density of *Chamaesyce deltoidea* subsp. *serpyllum* at sample locations



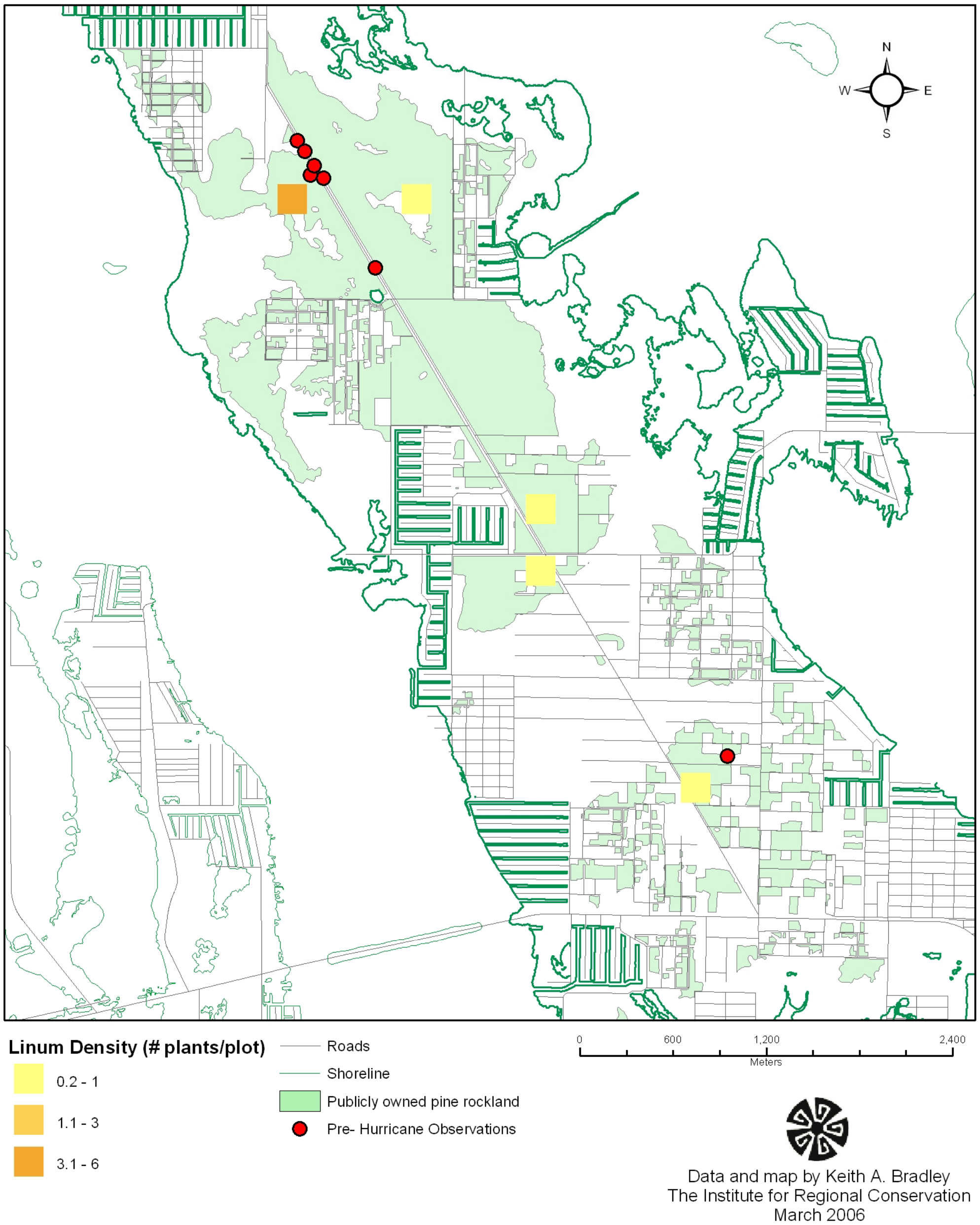
Linum arenicola

Linum arenicola was found to be extremely rare. It was found at only five sample locations throughout the island (Figure 8). It was also observed at three places not associated with sample locations. Like *C. deltoidea* subsp. *serpyllum*, it was found mostly in the interior of the island away from the coast. In the northern pinelands it was found in six of 427 plots (1.4%) at a density of 0.07 ± 0.09 plants/plot. In the southern pinelands it was found in one of 114 plots (0.9%) at a density of .009 ± 0.91 plants/plot. This difference in density was significant (U = 32,978.5, P = 0.033). All plants were found prior to Hurricane Wilma. Table 4 summarizes densities by island location before and after Hurricane Wilma. Before Hurricane Wilma there was a mean of 56 plants/ha. Calculating 95% confidence intervals indicated a mean of below 0 (-7) and 118 plants/ha. There was a maximum of 56,404 individuals of *L. arenicola* in the 478 ha of publicly owned pine rockland on Big Pine Key.

Table 4: Density/Plot of *Linum arenicola* by island location, before and after Hurricane Wilma with 95% Confidence Intervals

	Island Location	
	North	**South**
Before Wilma	0.11 ± 0.13	0.02 ± 0.04
After Wilma	0	0

Figure 8: Distribution and density of *Linum arenicola* at sample locations, and addition pre-Hurricane Wilma observations



Road Shoulder Data

A total of 128 plots were surveyed on the shoulders of Key Deer Blvd. and Wilder Rd. (Figures 9 and 10). These surveys were conducted in December 2005, 9 weeks after Hurricane Wilma. Saltwater from the Wilma storm surge killed much of the vegetation on the road shoulders. In addition, there was extensive post-hurricane dumping of storm debris by island residents which continued through the time of the surveys. Debris was being removed at the time of sampling, but in the process the machinery used for the cleanup scarified the substrate, removing much of the roadside vegetation. Because of this extensive disturbance there is a high likelihood that rare plant densities were depressed at the time of the surveys.

Chamaecrista lineata var. *keyensis* was found in 13 plots (10.2%) where there were 53 individuals, a mean of 0.4 ± 1.7 plants/plot (Figure 9). Plants were primarily in the northern pinelands – it was found in only a single plot in the southern pinelands, on Wilder Rd. *C. deltoidea* var. *serpyllum* was found in 8 plots (6.3%) where there were 181 individuals, a mean of 1.5 ± 8.2 plants/plot (Figure 10). It was only found in the northern pinelands. Despite several observations on road shoulders prior to the Hurricane, *L. arenicola* was not found. Nine of the plots were unvegetated because of post-hurricane dumping and subsequent debris removal.

Figure 9: Distribution and density of *Chamaecrista lineata* var. *keyensis* on road shoulders, Big Pine Key, FL

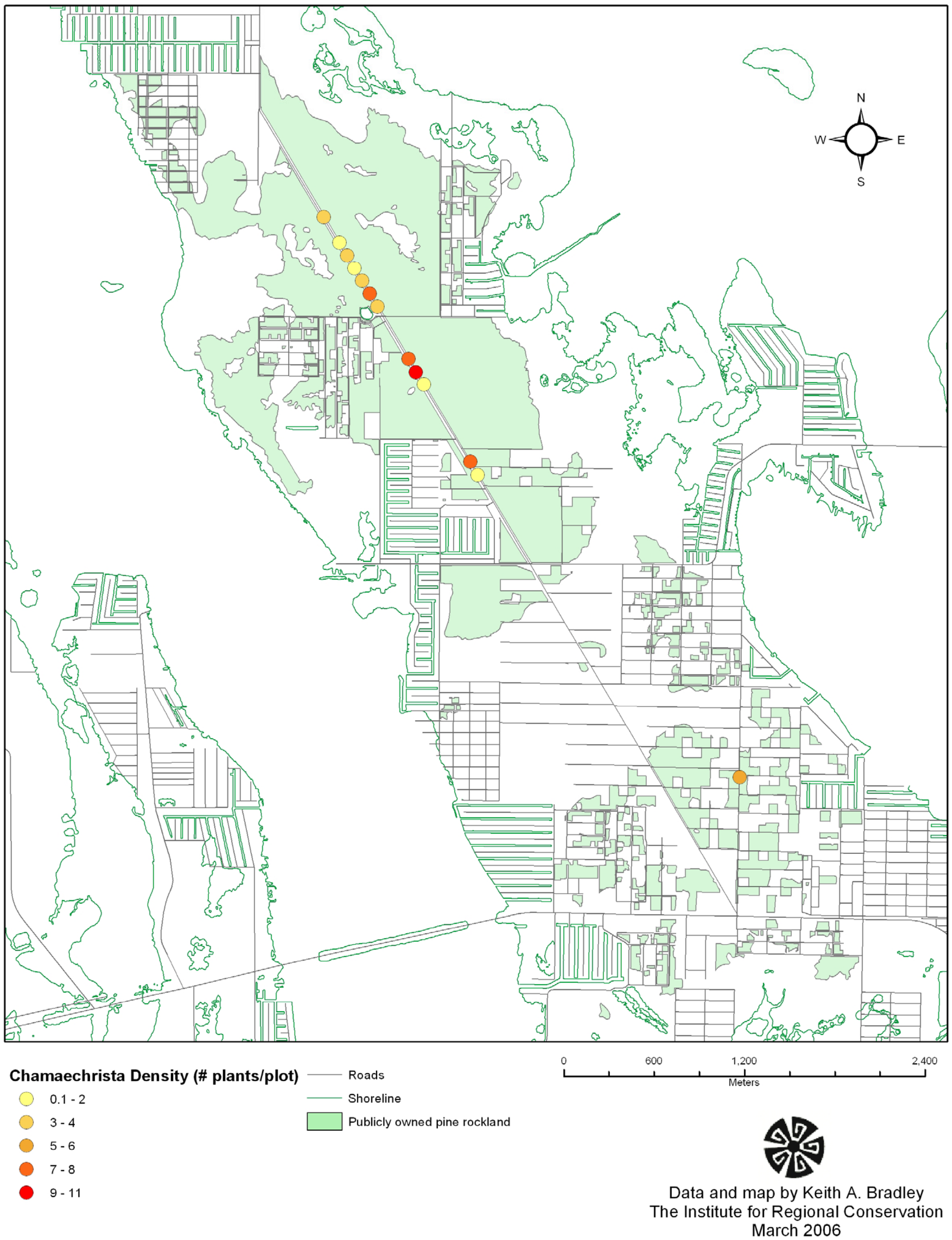
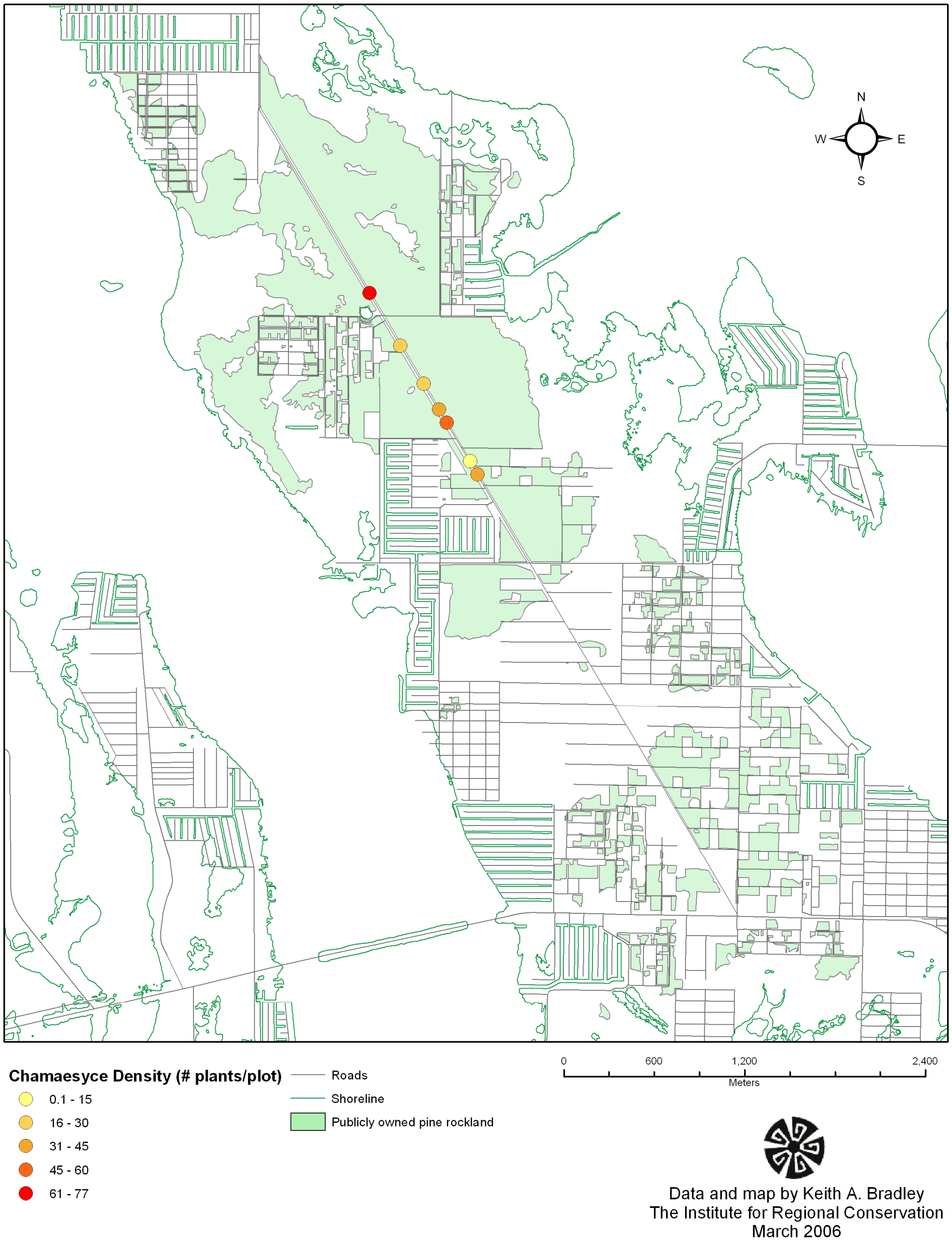


Figure 10: Distribution and density of *Chamaesyce deltoidea* subsp. *serpyllum* on road shoulders, Big Pine Key, FL



Species Associates

One hundred and eighty one plant taxa were recorded in the plots. The majority of these, 165 (91.2%) were native. This includes 105 herbs, 51 trees or shrubs, 17 vines, 4 palms, and 3 epiphytes. The most frequently encountered taxa were *Thrinax morrisii* (90.2%), *Pinus elliottii* var. *densa* (77.0%), *Psidium longipes* (65.9%), *Pisonia rotundata* (61.6%), *Smilax havanensis* (57.8%), *Pithecellobium keyense* (57.1%), *Metopium toxiferum* (56.5%), *Coccothrinax argentata* (52.5%), *Byrsonima lucida* (51.6%), and *Morinda royoc* (51.0%). *C. lineata var. keyensis* was the 14th (of 181) most common taxon and the 3rd most common herb (below *Rhynchospora floridensis* and *Schizachyrium rhizomatum*). *C. deltoidea* subsp. *serpyllum* was the 43rd most common taxon and the 20th most common herb (of 105). *Linum arenicola* was the 100th most common taxon and the 51st most common herb. Table 5 includes a list of the 25 most frequent taxa.

Table 5: Taxa with highest frequency in study plots

Scientific Name	Common Name	Percentage
Thrinax morrisii	Silver thatch palm	89.6%
Pinus elliottii var. *densa*	South Florida slash pine	76.5%
Psidium longipes	Longstalked-stopper	65.3%
Pisonia rotundata	Smooth devilsclaws	61.0%
Smilax havanensis	Havana greenbrier	57.4%
Pithecellobium keyense	Florida Keys blackbead	56.7%
Metopium toxiferum	Poisonwood	55.9%
Coccothrinax argentata	Florida silver palm	52.2%
Byrsonima lucida	Locustberry	51.4%
Morinda royoc	Yellowroot	50.8%
Ernodea littoralis	Beach-creeper	36.3%
Rhynchospora floridensis	Florida whitetop	34.5%
Schizachyrium rhizomatum	Rhizomatous bluestem	34.1%
Chamaecrista lineata var. *keyensis*	Keys partidge-pea	33.9%
Sorghastrum secundum	Lopsided Indian grass	32.4%
Schizachyrium gracile	Wire bluestem	31.3%
Anemia adiantifolia	Pine fern	25.8%
Rapanea punctata	Myrsine, Colicwood	25.0%
Serenoa repens	Saw palmetto	19.8%
Paspalum caespitosum	Blue paspalum	19.2%
Myrica cerifera	Wax myrtle	17.9%
Conocarpus erectus	Buttonwood	17.9%
Pteris bahamensis	Bahama ladder brake	17.5%
Croton linearis	Pineland croton	15.4%

The taxa with the highest overall cover were *T. morrisii, P. elliottii* var. *densa, P. longipes, M. toxiferum,* and *B. lucida.* The top 10 taxa are all palms, trees, or shrubs. Herbaceous taxa with the highest cover include *Sorghastrum secundum, S. rhizomatum, Cladium jamaicense, Schizachyrium gracile,* and *Schizachyrium sanguineum.* Table 6 includes a list of the 25 taxa with the highest cover.

Table 6: Taxa with highest vegetative cover in study plots

Scientific Name	Common Name	Mean Cover
Thrinax morrisii	Silver thatch palm	17.80%
Pinus elliottii var. *densa*	South Florida slash pine	12.92%
Psidium longipes	Longstalked-stopper	5.87%
Metopium toxiferum	Poisonwood	5.15%
Byrsonima lucida	Locustberry	4.73%
Pithecellobium keyense	Florida Keys blackbead	4.16%
Coccothrinax argentata	Florida silver palm	2.96%
Serenoa repens	Saw palmetto	2.57%
Conocarpus erectus	Buttonwood	1.95%
Sorghastrum secundum	Lopsided Indian grass	1.61%
Schizachyrium rhizomatum	Rhizomatous bluestem	1.59%
Pisonia rotundata	Smooth devilsclaws	1.59%
Cladium jamaicense	Saw-grass	1.40%
Schizachyrium gracile	Wire bluestem	1.31%
Myrica cerifera	Wax myrtle	1.26%
Ernodea littoralis	Beach-creeper	1.25%
Pteridium aquilinum var. *caudatum*	Lacy bracken fern	1.16%
Rapanea punctata	Myrsine	1.12%
Coccoloba uvifera	Seagrape	0.64%
Schizachyrium sanguineum	Crimson bluestem	0.55%
Rhynchospora floridensis	Florida whitetop	0.46%
Piscidia piscipula	Jamaica-dogwood	0.43%
Acacia pinetorum	Pineland acacia	0.41%
Morinda royoc	Yellowroot	0.41%

Sixteen exotic plant taxa were recorded in the study plots (Table 7). Exotic plant taxa were found in 64 plots (12.1%). Most plots with exotics were in the southern pinelands. In the southern pinelands 56 plots (49.1%) had exotics while in the northern pinelands only 8 plots (1.9%) had exotics. The most frequent exotic was *Schinus terebinthifolius* which occurred in 29 plots (5.5%). Other taxa which occurred in five or more plots (>1%) were *Fimbristylis cymosa* (3.3%), *Swietenia mahagoni*[1] (2.8%), *Stenotaphrum secundatum* (1.3%), and *Dactyloctenium aegyptium* (1.0%). *S. terebinthifolius* was the exotic with the highest cover (0.29%), the 28th highest mean cover of all taxa. Exotics overall had a mean cover of only 0.57%.

Table 7: Exotic plant taxa recorded in study plots

Scientific Name	Common Name	Total Frequency	Percentage	Total Cover
Albizia lebbeck	Woman's tongue	1	0.18%	0.5
Alysicarpus vaginalis	White moneywort	1	0.18%	0.5
Casuarina equisetifolia	Australian-pine	2	0.37%	3.5
Dactyloctenium aegyptium	Crow's-foot grass	5	0.9%	7.5
Eleusine indica	Indian goose grass	1	0.18%	0.5
Eragrostis ciliaris	Gophertail love grass	1	0.18%	0.5
Fimbristylis cymosa	Hurricane sedge	18	3.3%	16.5
Schinus terebinthifolius	Brazilian-pepper	29	5.5%	156.5
Spermacoce verticillata	Shrubby false buttonweed	4	0.7%	2.0
Sporobolus indicus var. *pyramidalis*	West Indian dropseed	3	0.6%	9.0
Stenotaphrum secundatum	St. Augustine grass	7	1.3%	74.5
Swietenia mahagoni	West Indian mahogany	15	2.8%	28.0
Urochloa subquadripara	Signal grass	1	0.18%	0.5
Vernonia cinerea	Little ironweed	1	0.18%	0.5
Zamia furfuracea	Cardboard-palm	2	0.37%	1.0
Zoysia tenuifolia	Mascarene templegrass	3	0.6%	6.5

Chamaecrista lineata var. *keyensis* had significant negative correlations with total vegetation cover (r_s = -0.193, P = 000), native cover (r_s = -0.185, P < 0.001), exotic cover (r_s = -0.146, P = 0.001), hardwood cover (r_s = -0.159, P < 0.001), and exotic richness (r_s = -0.146, P = 0.001). It had significant positive correlations with herb cover (r_s = 0.358, P < 0.001) and native richness (r_s = 0.584, P < 0.001). There were negative, but non-significant correlations with pine and with palm cover.

[1] *Swietenia mahagoni,* West Indian Mahogany is not native to the lower Florida Keys. Its historical range extended from the lower mainland south through Key Largo and Plantation Keys, and at most to Lower Matecumbe Key (Little 1978).

Chamaesyce deltoidea subsp. *serpyllum* had significant negative correlations with total vegetation cover (r_s = -0.144, P = 0.001), native cover (r_s = -0.140, P = 0.001), hardwood cover (r_s = -0.109, P = 0.012), and palm cover (r_s = -0.117, P = 0.007). It had significant positive correlations with herb cover (r_s = 0.158, P < 0.001) and native richness (r_s = .262, P < 0.001). There were negative, but non-significant correlations with pine cover and exotic cover.

Linum arenicola had significant positive correlations with herb cover (r_s = .120, P = 0.006) and native richness (r_s = 0.172, P = <0.001). It was not significantly correlated with total vegetation cover, native cover, exotic cover, pine cover, palm cover, hardwood cover, or exotic richness.

Detrended correspondence analysis showed clear patterns along Axes 1 and 2 representing hydrology and vegetation structure. Axis 1 represents dry to wet conditions and represented 39.5% of the variation. Axis 2 represents woody to herbaceous conditions and represented 25.9% of the variation. Plots with *C. lineata* var. *keyensis* or *C. deltoidea* subsp. *serpyllum* showed observable patterns in relation to Axis 1 and Axis 2. Plots with *C. lineata* var. *keyensis* occupy all conditions trending towards dry and herbaceous (Figure 11). In contrast, *C. deltoidea* subsp. *serpyllum* shows a narrower range of habitat preferences. Like *C. lineata* var. *keyensis*, it was found in plots that were dry and herbaceous, but was not found in plots at the extremes of the woody/herbaceous axis, not occupying plots that were too herbaceous (Figure 12). A pattern was not as clear with *L. arenicola,* which occurred in very few plots (Figure 13), but tended to occur in drier, more herbaceous plots.

Figure 11: Detrended Correspondence Analysis of plots sampled prior to Hurricane Wilma, with and without *C. lineata* var. *keyensis*

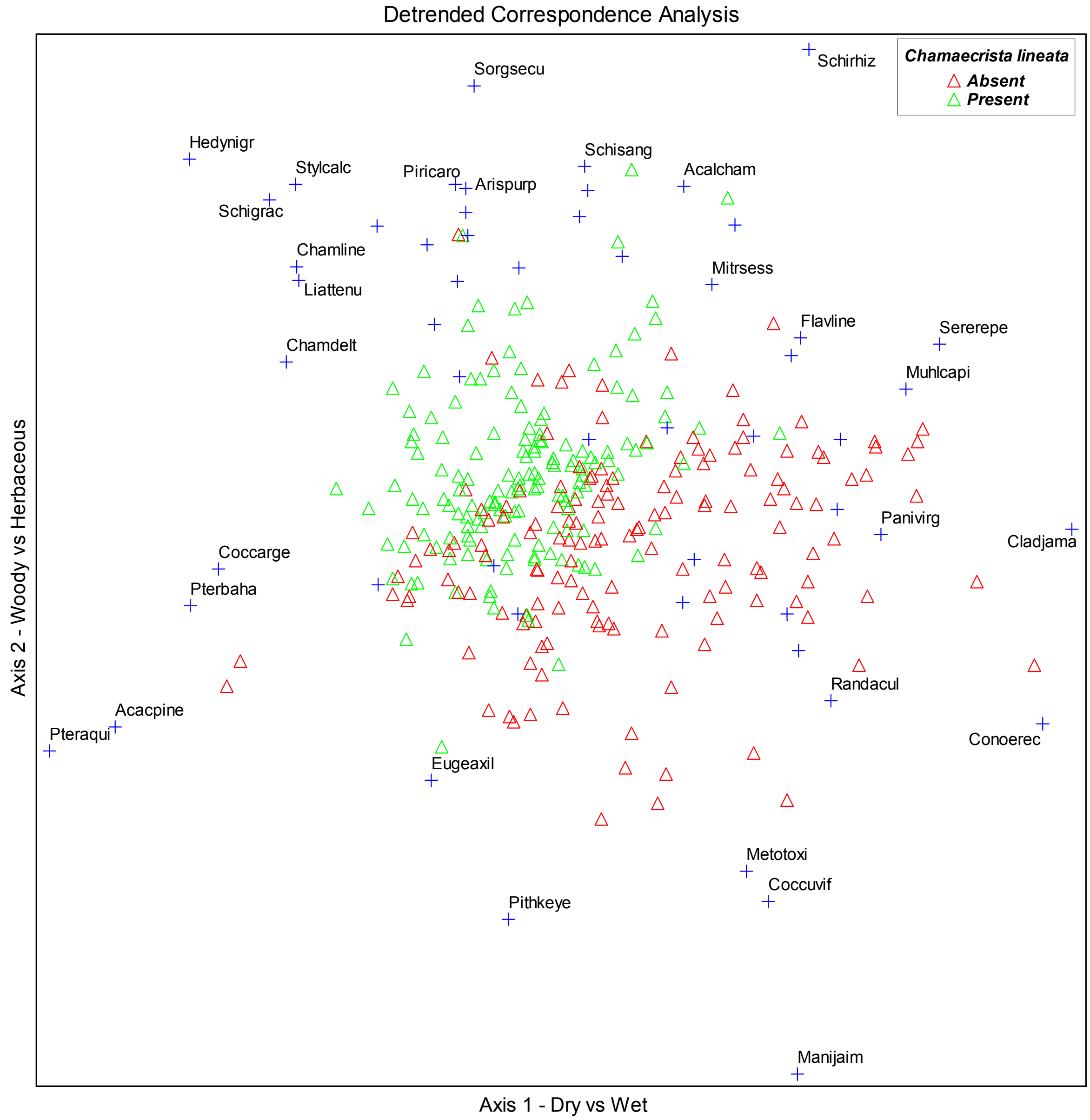


Figure 12: Detrended Correspondence Analysis of plots sampled prior to Hurricane Wilma, with and without *C. deltoidea* subsp. *serpyllum*

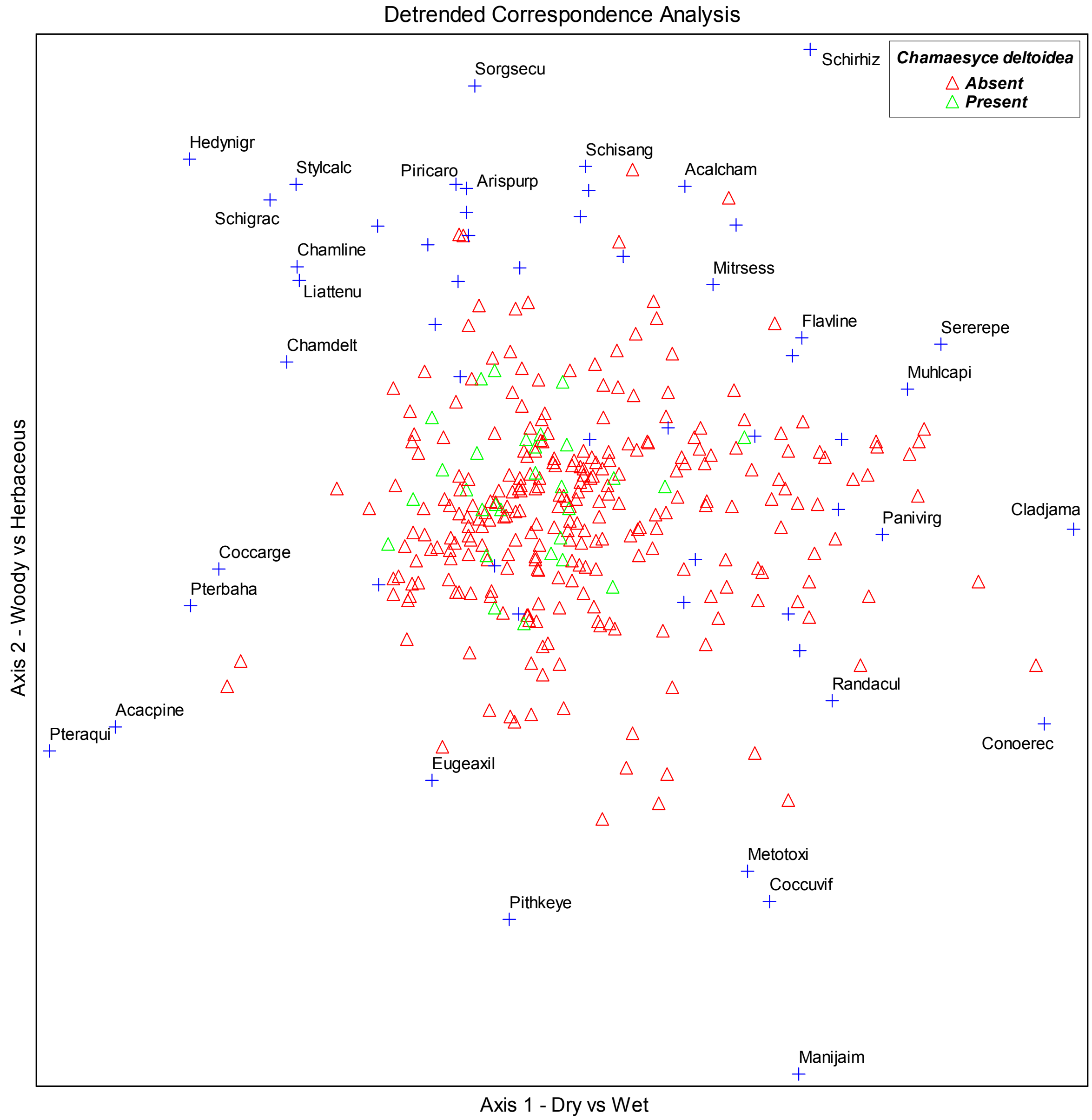
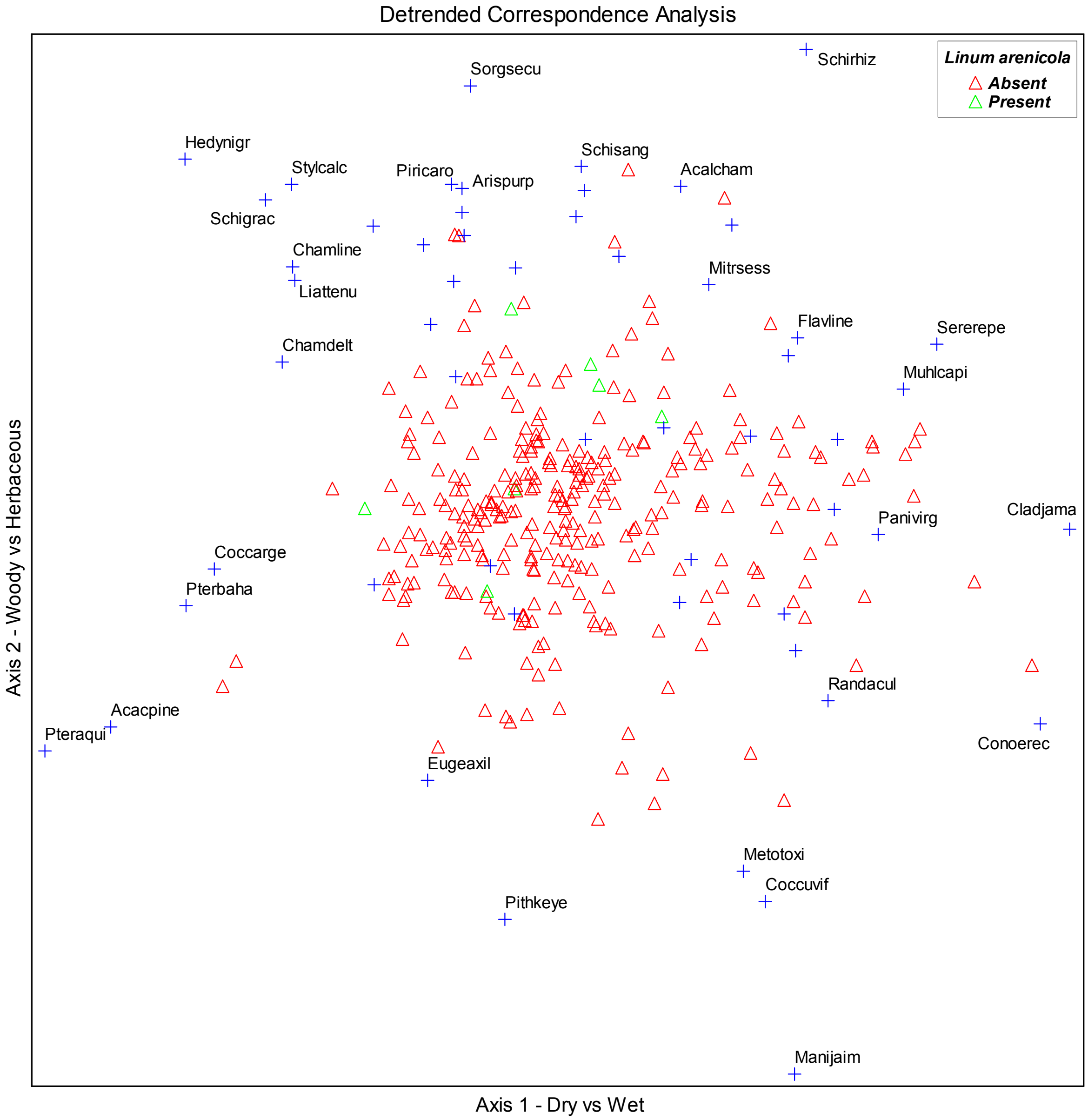


Figure 13: Detrended Correspondence Analysis of plots sampled prior to Hurricane Wilma, with and without *L. arenicola*



Indicator Species Analysis showed significant ($P < .05$) relationships with 30 taxa for plots with *C. lineata* var. *keyensis* (Table 8). The taxa with the highest indicator values (on a scale of 0 – 100) were *Rhynchospora floridensis* (51.7), *Schizachyrium gracile* (49.7), and *Anemia adiantifolia* (47.2). There were 22 significant indicator taxa for plots without *C. lineata* var. *keyensis* (Table 8). Taxa with the highest indicator values for plots lacking *C. lineata* var. *keyensis* were *Metopium toxiferum* (56.6), *Conocarpus erectus* (40.0), and *Pithecellobium keyense* (35.4).

Table 8: Indicator taxa for plots with and without *C. lineata* var. *keyensis*

Plots with *Chamaecrista*			**Plots without *Chamaecrista***		
Taxon	**Indicator Value**	**P**	**Taxon**	**Indicator Value**	**P**
Rhynchospora floridensis	51.7	0.001	*Metopium toxiferum*	56.6	0.001
Schizachyrium gracile	49.7	0.001	*Conocarpus erectus*	40	0.001
Anemia adiantifolia	47.2	0.001	*Pithecellobium keyense*	35.4	0.027
Psidium longipes	45.7	0.004	*Rapanea punctata*	30.8	0.001
Sorghastrum secundum	45.6	0.001	*Cladium jamaicense*	29.9	0.001
Coccothrinax argentata	37.9	0.003	*Serenoa repens*	27.1	0.001
Galactia volubilis	28	0.001	*Randia aculeata*	26.2	0.001
Rhynchosia parvifolia	26.1	0.001	*Coccoloba uvifera*	17.3	0.001
Pteris bahamensis	24.8	0.004	*Muhlenbergia capillaris*	14.3	0.023
Phyllanthus pentaphyllus var. *floridana*	23.9	0.001	*Eugenia axillaris*	13.4	0.003
Schizachyrium sanguineum	23.6	0.001	*Panicum virgatum*	11.3	0.002
Croton linearis	21	0.001	*Manilkara jaimiqui* subsp. *emarginata*	10.3	0.001
Polygala grandiflora	20.6	0.001	*Fimbristylis spadicea*	9.3	0.001
Centrosema virginianum	18.6	0.001	*Flaveria linearis*	7.4	0.008
Aristida purpurascens	18	0.008	*Aster bracei*	6	0.001
Piriqueta caroliniana	17.9	0.001	*Ximenia americana*	5.8	0.047
Stylosanthes calcicola	14.6	0.001	*Piscidia piscipula*	5.7	0.031
Liatris tenuifolia	13	0.001	*Sabatia stellaris*	5.3	0.018
Cirsium horridulum	9.5	0.001	*Guapira discolor*	4.6	0.035
Chamaesyce pergamena	8.8	0.001	*Pluchea rosea*	4.6	0.022
Rhynchosia cinerea	8.8	0.001	*Reynosia septentrionalis*	4.6	0.043
Hedyotis nigricans var. *floridana*	8.5	0.002	*Sideroxylon celastrinum*	4.6	0.01
Evolvulus sericeus	8.2	0.001			
Sachsia polycephala	8.2	0.002			
Pityopsis graminifolia	7.5	0.001			
Acalypha chamaedrifolia	6.6	0.015			
Andropogon longiberbis	6.3	0.013			
Pterocaulon pycnostachyum	6.2	0.006			
Tragia saxicola	6.1	0.002			
Agalinis fasciculata	4.9	0.025			

Indicator Species Analysis for plots with and without *C. deltoidea* subsp. *serpyllum* showed significant (P < .05) relationships with 18 taxa for plots with the taxon (Table 9). The taxa with the highest indicator values were *Rhynchospora floridensis* (67.9), *Psidium longipes* (52.7), and *C. lineata* var. *keyensis* (47.2). There was one significant indicator taxon for plots without *C. deltoidea* subsp. *serpyllum, Rapanea punctata* (33.5) (Table 9).

Table 9: Indicator taxa for plots with and without *C. deltoidea* subsp. *serpyllum*

Plots with *Chamaesyce*			**Plots without *Chamaesyce***		
Taxon	**Indicator Value**	**P**	**Taxon**	**Indicator Value**	**P**
Rhynchospora floridensis	67.9	0.001	*Rapanea punctata*	33.5	0.012
Psidium longipes	52.7	0.007			
Chamaecrista lineata var. *keyensis*	41.7	0.025			
Schizachyrium gracile	39.4	0.006			
Aristida purpurascens	32.6	0.001			
Polygala grandiflora	24.5	0.012			
Liatris tenuifolia	23.5	0.001			
Mitreola sessilifolia	21.2	0.001			
Phyllanthus pentaphyllus var. *floridanus*	21.2	0.029			
Hedyotis nigricans var. *floridana*	20.6	0.001			
Polygala boykinii	20.4	0.003			
Chiococca parviflora	16.1	0.027			
Pityopsis graminifolia	15.3	0.001			
Agalinis spp.	15	0.004			
Flaveria linearis	14.2	0.012			
Sisyrinchium nashii	12.8	0.001			
Eragrostis elliottii	10.9	0.008			
Catesbaea parviflora	9.2	0.023			

Indicator Species Analysis for plots with and without *Linum arenicola* showed significant (P < .05) relationships with 18 taxa for plots with this taxon (Table 10). The taxa with the highest indicator values were *Phyllanthus pentaphyllus* var. *floridanus* (73.4), *Pinguicula pumila* (42.5), and *Abildgaardia ovata* (50.9). There were no significant indicator taxa for plots without *L. arenicola*.

Table 10: Indicator taxa for plots with and without *L. arenicola*

Plots with *Linum*		
Taxon	**Indicator Value**	**P**
Phyllanthus pentaphyllus var. *floridanus*	73.4	0.001
Rhynchospora floridensis	69.4	0.003
Chamaecrista lineata var. *keyensis*	62.3	0.019
Anemia adiantifolia	57.9	0.006
Sorghastrum secundum	52	0.03
Abildgaardia ovata	50.9	0.002
Galactia volubilis	42.6	0.038
Pinguicula pumila	42.5	0.001
Pterocaulon pycnostachyum	40.3	0.003
Chamaesyce pergamena	39.7	0.002
Sachsia polycephala	39.4	0.003
Piriqueta caroliniana	33.3	0.043
Rhynchosia parvifolia	31.7	0.048
Indigofera miniata var. *floridana*	27.3	0.006
Hypoxis wrightii	27	0.01
Angadenia berteroi	26.1	0.023
Evolvulus sericeus	25	0.038
Mitreola sessilifolia	24.5	0.046

Other Rare Plant Taxa

Seven additional rare plant taxa were recorded in the study plots (Table 11). *Pisonia rotundata* was included initially, but counting was discontinued because of its common occurrence.

Table 11: Additional rare plant taxa recorded in study plots (N = 541)

	Pre Wilma		**Post Wilma**	
Scientific Name	Total Individuals	Total Frequency	Total Individuals	Total Frequency
Argythamnia blodgettii	5	3	0	0
Caesalpinia pauciflora	0	0	96	13
Catesbaea parviflora	16	5	13	5
Dodonaea elaeagnoides	3	1	0	0
Evolvulus grisebachii	7	1	24	4
Indigofera miniata var. *florida*	1	1	0	0
Strumpfia maritima	48	3	32	7

Comparison with Prior Data Sets

Dickson (1955) and Alexander and Dickson (1972) reported densities of *C. lineata* var. *keyensis* from plots they established on Big Pine Key in 1951 and 1969, respectively. In each of these studies individuals of *C. lineata* var. *keyensis* were counted in 30, 3' x 3' plots. In neither study were the locations of these plots reported. Dickson (1955) reports a mean density of 10,764 plants/ha. Alexander and Dickson (1972) report a mean density of 27,871 plants/ha. I found that before Hurricane Wilma there was a mean density of 2,339 plants/ha, considerably lower than previously found. In only 2 plots (of 541) did densities equal or exceed that reported by Alexander and Dickson (1972). In these two plots I found 66 plants (33,613 plants/ha) and 60 plants (30,557 plants/ha).

Discussion

In this study it was found that prior to Hurricane Wilma there were between 949,308 and 1,455,988 individuals of *C. lineata* var. *keyensis* and between 198,848 and 710,308 individuals of *C. deltoidea* subsp. *serpyllum* in publicly owned pine rockland on Big Pine Key. *L. arenicola* was found at such low densities in so few plots that the mean density had an extremely broad range; 95% confidence intervals showed a range from -3,353 to 56,404 individuals. *C. lineata* var. *keyensis* was the third most frequent herb in the study plots.

I found that even pre-hurricane, population sizes of *C. lineata* var. *keyensis* were much lower than reported in studies in 1951 and 1969. They reported densities of 10,764 plants/ha and 27,871 plants/ha, respectively, whereas I estimated a density of 2,516 plants/ha, 23.4% and 9.0% of the previous estimates. This difference may in part be due to sampling issues. Dickson (1955) and Alexander and Dickson (1972) sampled a much smaller area than I did, covering only 25.1 m^2 whereas I sampled 422 times as much area (10,600 square meters). They may have by random chance sampled areas with higher densities of the taxon, resulting in a high estimated density. Another explanation is that there has been an actual decrease in the density of *C. lineata* var. *keyensis*.

That there has been a decrease in the total population size, rather than just density, of each of the study taxa is certain. There is only about 56% of the historical pine rockland left on Big Pine Key. Much of the pine rockland that does exist is in various states of degradation due to fire suppression, exotic plant invasion, saltwater intrusion, and sea-level rise. Quality of the southern pine rocklands is visually lower than the northern pine rocklands due to increased fire suppression and exotic plant invasion. I found significantly lower densities of both *C. lineata* var. *keyensis* and *C. deltoidea* subsp. *serpyllum* in the southern pinelands. *C. deltoidea* subsp. *serpyllum* in fact was almost completely absent from the southern pinelands.

Hurricane Wilma significantly reduced the observable live plants of each of the three study taxa 8-9 weeks post-storm. Density of *C. lineata* var. *keyensis* in plots sampled after Hurricane Wilma was 38% lower than plots sampled before the hurricane. Similarly, *C. deltoidea* subsp. *serpyllum* densities were 52% lower in plots sampled after the hurricane than those sampled before the hurricane. *L. arenicola* was not found at all in surveys 8-9 weeks after the Hurricane. The impact of Hurricane Wilma to the population sizes of each of these taxa is further evidence that stochastic events probably cause large year to year changes in population sizes of each taxon. Liu (2003) found that fires have a great effect on *C. lineata* var. *keyensis,* killing most adults. However, post-fire recover was rapid and vital rates were highest just 2 years after a fire. In my surveys 8 – 9 weeks after the hurricane, I saw a few plants re-sprouting. I expect that many more plants survived the storm but at the time of my observations had not yet produced new growth. Post-hurricane recovery via seed germination may also probably occur.

Liu (2003) reported two potential factors that may be causing the density declines that I found. She found a decrease in *C. lineata* var. *keyensis* pollinator activity following mosquito spraying. Mosquito spraying is common on Big Pine Key, and its suppression of pollinator populations may have a long term impact on reproduction rates. She also found decreases in seed production in urban areas due to increased seed predation. Similar problems with mosquito spraying and effects of forest fragmentation and proximity to homes and business may also be impacting *C. deltoidea* subsp. *serpyllum* and *L. arenicola.*

Additional research is needed to quantify the amount of *L. arenicola* on Big Pine Key. In this study the species was rarely encountered. I found only 33 plants in 7 plots. This detection rate did not allow for a precise estimate of total population size, producing a large range from -3,353 to 56,404 plants. Because of the rarity of the taxon and its often clumped distribution, a different sampling strategy is needed to determine the population size. Adaptive cluster sampling (Philippi 2005) would probably produce better results. This sampling strategy was considered when I designed my study, but was impractical for sampling three taxa at once.

Road shoulders are a potentially important habitat for each of the study taxa. Unfortunately, I did not sample road shoulders until after Hurricane Wilma and subsequently found no *L. arenicola* and little *C. lineata* var. *keyensis* or *C. deltoidea* subsp. *serpyllum*. Not only did the storm surge kill the road shoulder vegetation, but much of the vegetation was heavily disturbed by dumping and removal of storm debris. Before the storm I had observed (but not quantified) many more individuals of all three taxa, including *L. arenicola.* Where these taxa are found on shoulders, the ground cover is dominated mostly by native herbs and grasses where exotic lawn grasses have not been planted. Maintaining the roadsides in this native condition through regular mowing without planting sod, should continue to provide good habitat for each taxon. Roadside dumping and any other kind of mechanical disturbance should be strongly discouraged.

Spearman rank correlations and Detrended Correspondence Analysis showed that both *C. lineata* var. *keyensis* and *C. deltoidea* subsp. *serpyllum* preferred dry habitats with lower density shrub layers and more diverse herb layers. Habitat preferences for *L. arenicola* are probably similar, but it was difficult to detect significant correlations with anything but herb diversity and density because of the small sample size. Surprisingly, no significant negative correlations with pine cover were found. Pines create much of the organic duff layer in pine rocklands and I anticipated that areas with more pine cover may have had lower densities of the study taxa. Indicator Species Analysis for each of the study taxa corroborated the results of these other analyses. Good indicators were found to be upland herbs and grasses, as opposed to wetland taxa or hardwoods. Good indicators for all three taxa included *Rhynchospora floridensis* and *Phyllanthus pentaphyllus* var. *floridanus,* both of which prefer dry, open conditions and do not tolerate competition from hardwoods or palms.

Long-term management of each taxon should be done through ensuring that pine rockland habitat receives regular burns. No researcher has conclusively stated an ideal fire regime for pine rocklands on Big Pine Key, but based on historical estimates, fires should probably occur within a range of about 5-15 years. Fires would preferably occur at different times of years and at different intensities to maintain a mosaic of habitat structures. This should not only maintain appropriate habitat for these three taxa, but also for Key Deer (Carlson et al. 1993), and additional rare plant taxa.

Restoration of degraded pine rocklands of the south end of Big Pine Key will also be important in increasing the total population sizes of the study taxa. I found that the southern pine rocklands had consistently lower densities of each of the study taxa. These southern pine rocklands have been dissected by more roads, creating more edges, and reducing the likelihood of fire management. Hardwood and palm densities are greater than in the north and cover of exotic pest plants is higher. Mechanical hardwood and exotic plant control and the reintroduction of fire will provide better habitat for rare plants and animals on Big Pine Key.

Proper management of pine rocklands on Big Pine Key may be beneficial to the range of *C. lineata* var. *keyensis* throughout the lower Keys. The taxon formerly occurred not only on Big Pine Key but also on No Name, Cudjoe, and Ramrod Keys. Hodges and Bradley (2006) found only a small population on Cudjoe, but not on No Name or Ramrod. It is possible that on these smaller islands with limited areas of pine rockland, periodic hurricane storm surges and fires cause temporary declines in population sizes and extirpations. New populations may reestablish via a seed bank or recolonization and build until the next storm or fire. Maintaining pine rockland habitat with large numbers of *C. lineata* var. *keyensis* on Big Pine Key may provide a suitable source for seed range so that the taxon can recolonize smaller islands if they become extirpated there.

Repetition of the this study in subsequent years will provide valuable data on long term trends in the population sizes and distributions of rare plants on Big Pine Key and, to a lesser extent, changes in overall vegetation structure. The densities of each of the study taxa most likely vary widely from year to year depending upon time since fire and time since storm surges. However, repetition of the study should allow large trends to be detected. Repetition in the near term, possibly later 2006 or 2007, would allow detection of response of each taxon to the Hurricane Wilma storm surge.

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