DISTRIBUTION AND DISPERSAL OF *CACTOBLASTIS CACTORUM* (LEPIDOPTERA: PYRALIDAE), AN EXOTIC *OPUNTIA*-FEEDING MOTH, IN FLORIDA

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ABSTRACT

The recent arrival of *Cactoblastis cactorum* Berg in Florida has raised concern for Florida's native *Opuntia* cacti. Moreover, the potential for movement of the moth across the gulf states and into the southwestern United States may endanger cacti in the *Opuntia*-rich areas of Texas, Arizona, New Mexico, and Mexico. However, the spread of the moth northward through Florida has either slowed since the invasion or the rate of spread for the first two years was over estimated. The mortality rate of pads and the distribution of egg sticks at six sites in Florida were recorded on *O. stricta* Haworth, the most common host in Florida. While the percentage of cactus pads with *C. cactorum* damage is as high as 60%, the data indicates that most mature cacti are not being reduced in size. However, small cacti and new growth pads are particularly susceptible to mortality by *C. cactorum*, thus, over time we may expect to see a reduction in the number of plants as a result of an increase in the mortality rate of recruits.

Key Words: pest, biological control, herbivory, moth, cactus

RESUMEN

La reciente introducción a la Florida de *Cactoblastis cactorum* Berg a causado preocupación en cuanto a los cactos indígenas de la Florida de la especie *Opuntia*. Además, la posibilidad de que la palomilla avance a través de los estados del Golfo hacia el suroeste de los Estados Unidos amenaza áreas con abundancia de *Opuntia* en Texas, Arizona, Nuevo México, y México. Sin embargo, la expansión de la palomilla hacia el norte a traves de Florida desde que la invasión empezó ha disminuido o el cálculo de la tasa de expansión durante los dos primeros años fué exagerado. La tasa de la mortalidad de las pencas de cacto y la distribución de grupos de huevos en seis localidades en Florida fueron registrados en *O. stricta* Haworth, que es el hospedero más común dentro de Florida. Aunque el porcentaje observado de pencas dañadas por *C. cactorum* es tan alto como el 60%, los datos indican que los cactos más maduros no están siendo reducidos en tamaño. Sin embargo, cactos pequeños y pencas nuevas son particularmente susceptibles a mortalidad causada por *C. cactorum*; en consecuencia, en un futuro podríamos contar con una reducción del número de plantas debido al aumento de la tasa de mortalidad de cactos jóvenes.

In 1957, the moth *Cactoblastis cactorum* Berg was introduced onto the Caribbean island of Nevis as a biological control agent for pest *Opuntia* spp. and in 1960 was introduced onto Montserrat and Antigua (Simmonds & Bennett, 1966). The moth dispersed to other islands such as Cuba, Puerto Rico, Hispaniola, the Bahamas, and Cuba (Habeck & Bennett, 1990).

A Florida Keys record for *C. cactorum* in October, 1989, was a new record for the continental United States (Habeck & Bennett, 1990). The moth likely arrived in Florida by one of two methods: (1) natural dispersal via flight/wind from the Caribbean or (2) via shipments of cacti to Miami from the Caribbean (Pemberton, 1995). This species may disperse beyond Florida, and eventually reach the *Opuntia*-rich desert southwest. The moth successfully dispersed several times from one island to another in the Caribbean; thus, spread across long distances is possible. The moth may have already invaded the Yucatan (Pemberton, 1995), thus, the moth also may disperse to the southwestern United States via Mexico.

Florida has six species of native *Opuntia* (*O. stricta* Haworth, *O. humifusa* (Rafinesque) Rafinesque, *O. spinosissima* (Martyn) Miller, *O. triacantha* (Willdenow) Sweet, *O. cubensis* Britton & Rose, and *O. pusilla* (Haworth) Haworth) (Benson, 1982). *Cactoblastis cactorum* has been found on all of the natives except *O. pusilla* (Bob Ehrig, The Nature Conservancy, pers. comm.; pers. obs.). The United States ranges of three of these cacti, *O. spinosissima*, *O. triacantha*, and *O. cubensis*, are limited to local populations in the Florida Keys. Only 12 *O. spinosissima* plants remain in one location in the Florida Keys and *O. triacantha* and *O. cubensis* are rare.

This study focuses on the attack of *C. cactorum* on *O. stricta*. *O. stricta* is a common cactus throughout coastal Florida, growing in sandy soils and shell mounds. We investigated the rate of the moth's spread throughout Florida, distribution of egg sticks and larval damage, and extent of damage to *O. stricta*. This information, coupled with the information from oviposition and larval choice experiments (Johnson & Stiling, 1996), could be useful in setting future management goals for *C. cactorum* in the continental United States.

Materials and Methods

Damage and Egg Stick Distribution

We repeatedly visited ten sites throughout south and central Florida (Fig. 1). Upon each visit to every site, we counted the total number of cactus pads on 20 to 100 *O. stricta* plants, the number of pads with old *C. cactorum* damage (those that had been fed upon but the larvae had since abandoned them), the number of pads with new larval damage (pads with larvae currently feeding on them), and the number of egg sticks per plant. The same population of plants was surveyed at every census. From October, 1991 to November, 1992, each site was sampled approximately monthly. The sites were sampled less frequently in 1993.

We are confident that the vast majority, if not all, of old damage, new damage, and egg sticks measured at the eight sites were attributable to *C. cactorum* and not the native cactus-feeding moth, *Melitera prodenialis* Walker, for the following reasons. First, at all sites where *C. cactorum* larvae were not detected, the percentage of pads with old damage was less than one percent, while within a year after *C. cactorum* larvae were detected, old damage increased to over ten percent. Secondly, cactus pads with new damage were randomly cut open and the larvae were identified. All Pyralidae larvae encountered at the sites were *C. cactorum*. Lastly, the widths of *C. cactorum* egg sticks are narrower than *M. prodenialis* egg sticks and the ranges of width are non-overlapping (DMJ, unpublished data). Three-hundred eighty-two hatched egg sticks were collected from the sites and compared to egg sticks known to be laid by *C. cactorum* and *M. prodenialis*. All of the egg sticks were determined to be laid by *C. cactorum*. Thus, while we can not be certain that *M. prodenialis* was always absent, we are confident that its contribution was insignificant.

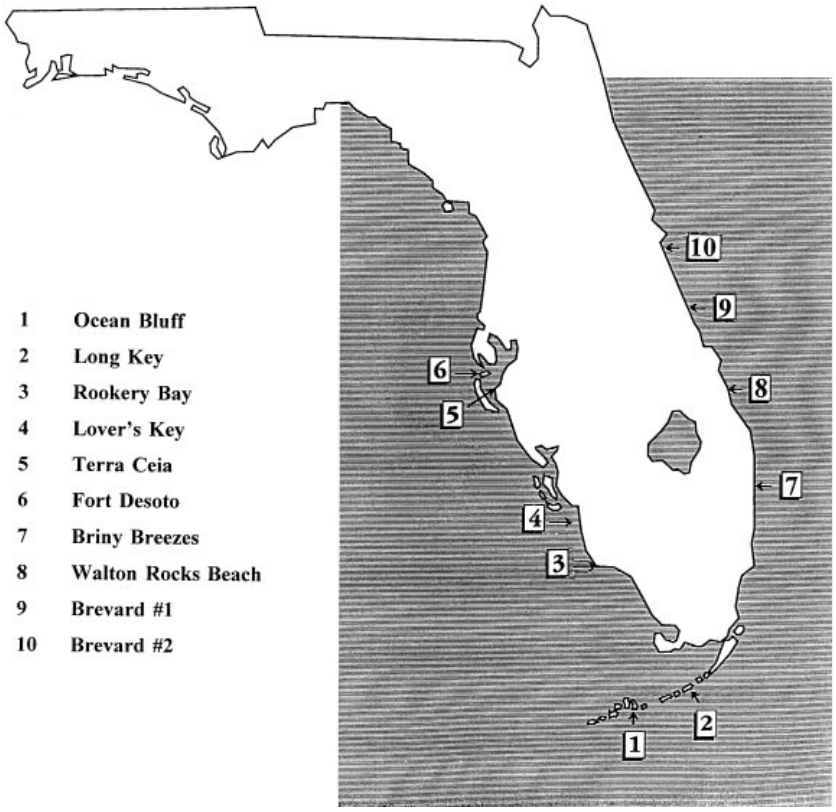

Fig. 1. *Opuntia stricta* populations surveyed for *Cactoblastis cactorum* from October 1991 to October 1993.

The distribution of egg sticks on cacti was measured by using the Morisita Index of Dispersion (Krebs, 1989). The Kruskal-Wallis test (Sokel & Rohlf 1981) was used to determine whether the number of egg sticks on a plant and the number of egg sticks per pad was related to plant size (as measured by the total number of pads). The Kruskal-Wallis test was also used to determine whether the percent damage was related to the size of the plant.

In addition, all reports of *C. cactorum* detected in new locations around Florida were examined to determine when the moth extended its known range northward along both the east and west coastlines. These reports included personal observations, reports to the Florida Department of Agriculture and Consumer Services (FDACS), and other sources.

Growth and Mortality of *Opuntia stricta*

From January to March 1992 all individual pads on 10 *O. stricta* plants at the Walton Rocks Beach site were marked. In 1993 10 additional plants were marked. Each pad was numbered using permanent ink. Upon every subsequent visit, once per

month in 1992 and less frequently in 1993, pad mortality and the number of new growth pads were recorded. These data were used to determine net growth of the attacked plants. The Rank Sum Test (Ambrose & Ambrose 1987) was used to determine whether smaller cacti had a significantly higher mortality. The Wilcoxon Signed Ranks Test (Sokel & Rohlf 1981) was used to determine whether new pads suffered a higher mortality caused by *C. cactorum* than did old pads.

RESULTS

Damage and Egg Stick Distribution

Peaks in new larval damage and percentage of pads with egg sticks varied temporally and spatially (Figs. 2 and 4). No *C. cactorum* was recorded at Lover's Key or Rookery Bay. Larval activity was generally highest from May to September, but larval activity also heightened in late fall and early winter of 1991 at most sites. Larval damage measurements, the percentage of pads with both old and new damage, increased at every site from the fall of 1991 to the fall of 1992. Overall, measurements of damage decreased slightly from the fall of 1992 to the fall of 1993 at all of the sites except Ocean Bluff, Terra Ceia and Brevard #2. Over the 2 year period, the percentage of dead or damaged pads increased (range 9-37%) at all 6 sites (Fig. 3). Percent damage and plant size were not significantly related ($p > 0.05$).

Egg sticks were clumped among plants (Table 1). At two of the six sites tested, significantly more egg sticks were laid on either medium or large-sized plants (Table 1). At the other four sites with a sufficient number of egg sticks the trend was present but not significant. The number of egg sticks per pad was not significantly different between small, medium, and large plants at any of the sites ($p > 0.10$) (Table 1).

At the peak of old *C. cactorum* damage, 90% of the plants with over 10 pads had old damage (Table 2). Excluding plants at the Terra Ceia site, which had a lower percentage of old damage than the other sites, 172 out of 173 plants (99.4%) with over 10 pads showed evidence of previous larval damage as compared to 14 of 28 plants (50%) with 10 pads or fewer having previous larval damage.

The Spread of *Cactoblastis cactorum*

The spread of *C. cactorum* up Florida's east coast, assuming that the moth first colonized the lower Florida Keys and migrated north, has been relatively well documented as compared to Florida's west coast. The moth was first discovered in the United States on Big Pine Key in October, 1989 (Habeck & Bennett, 1990). In less than a year, the moth was discovered at Key Biscayne State Park in Miami (FDACS, unpublished), approximately 200 km east northeast of Big Pine Key. One year later, in August, 1991, the moth was discovered at Brevard #1 (FDACS, unpublished), approximately 240 km north of Key Biscayne. The most northerly record of *C. cactorum* was at Brevard #2 (Patrick Air Force Base), 50 km north of Brevard #1 (pers. obs.). The moth arrived at this site in June 1992 and has established there.

The spread of *C. cactorum* up the west coast of Florida has not been so well documented. The first west coast record was in Terra Ceia, Manatee County, in May 1991 (FDACS, unpublished), one year and seven months after its discovery in the Florida Keys and approximately 360 km north. Six months later, the moth was discovered at Fort Desoto State Park in Pinellas County (pers. obs.), approximately 16 km north of Terra Ceia. The most northerly record of *C. cactorum* on the west coast of Florida was at Upper Tampa Bay Park in Hillsborough County, February, 1992 (pers. obs.). This site is approximately 50 km north of Fort Desoto.

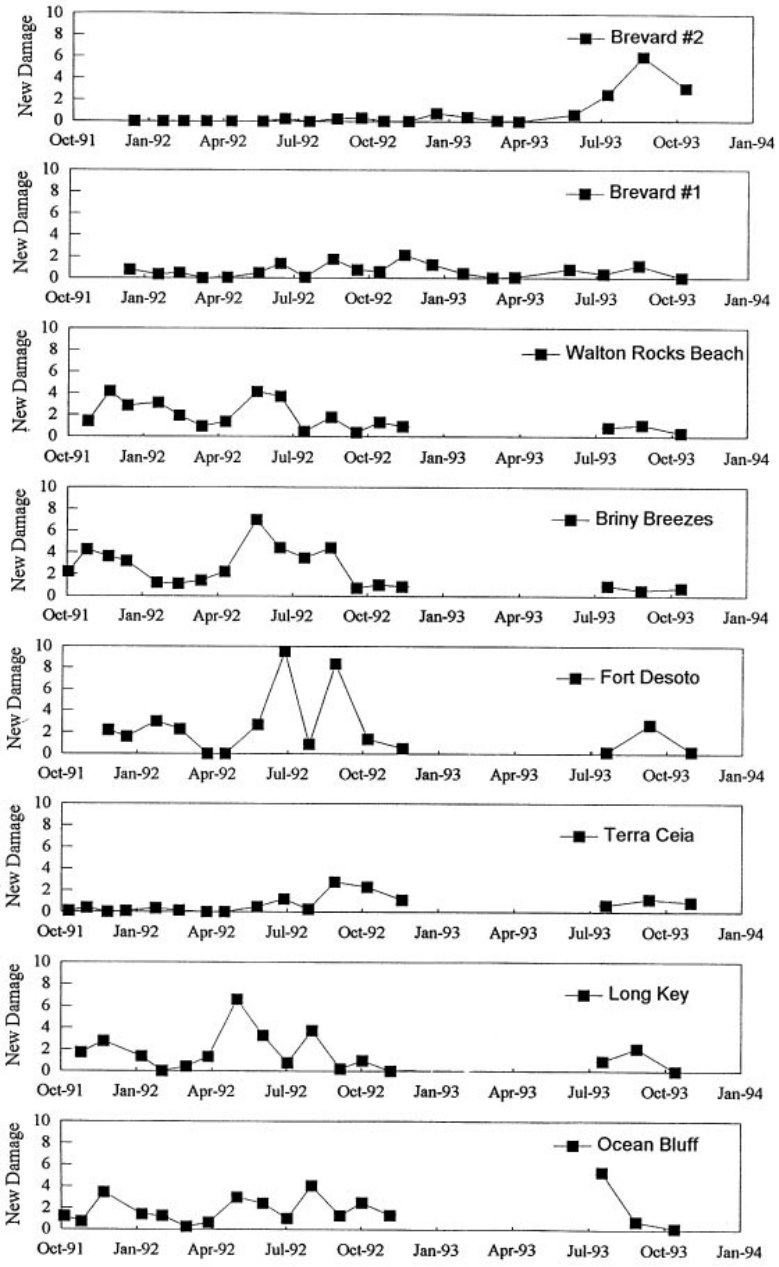

Fig. 2. Percentage of *Opuntia stricta* pads with new damage due to *Cactoblastis cactorum* larval feeding at eight sites in central and south Florida (see Fig. 1 for locations).

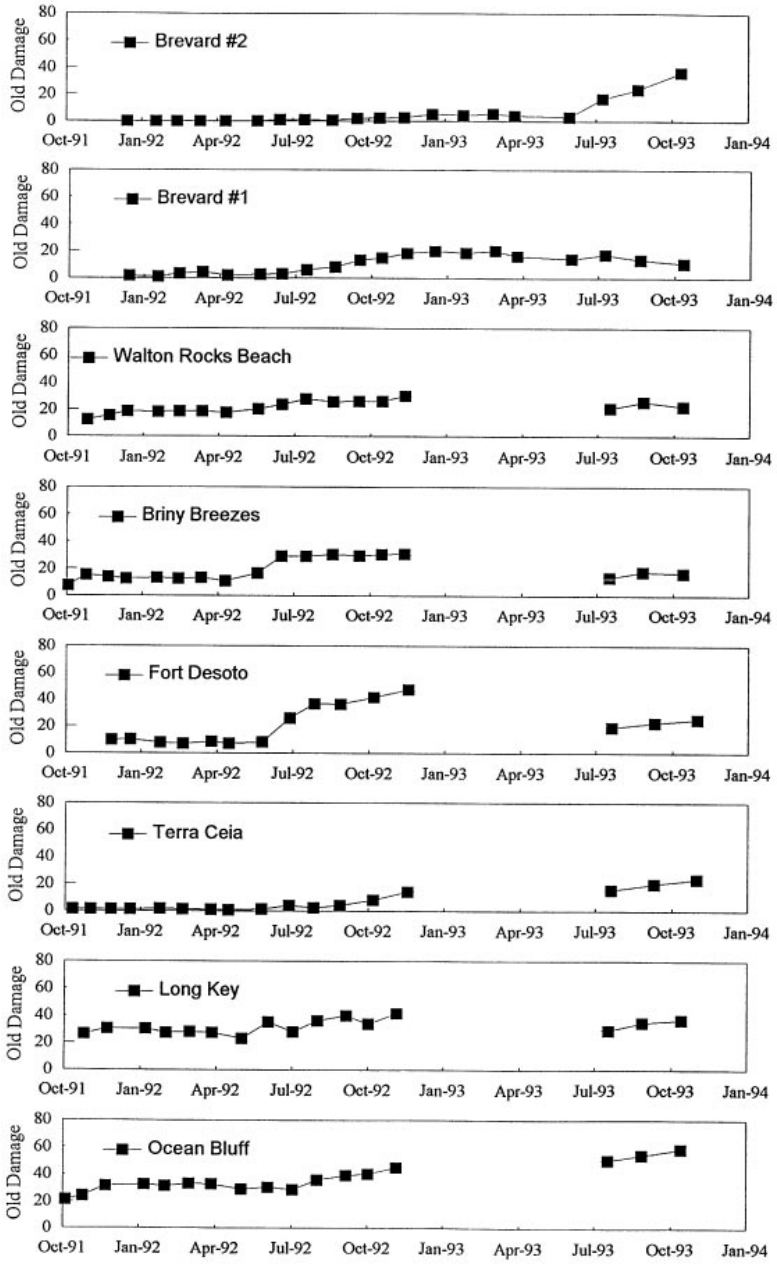

Fig. 3. Percentage of *Opuntia stricta* pads with old damage due to *Cactoblastis cactorum* larval feeding at eight sites in central and south Florida (see Fig. 1 for locations).

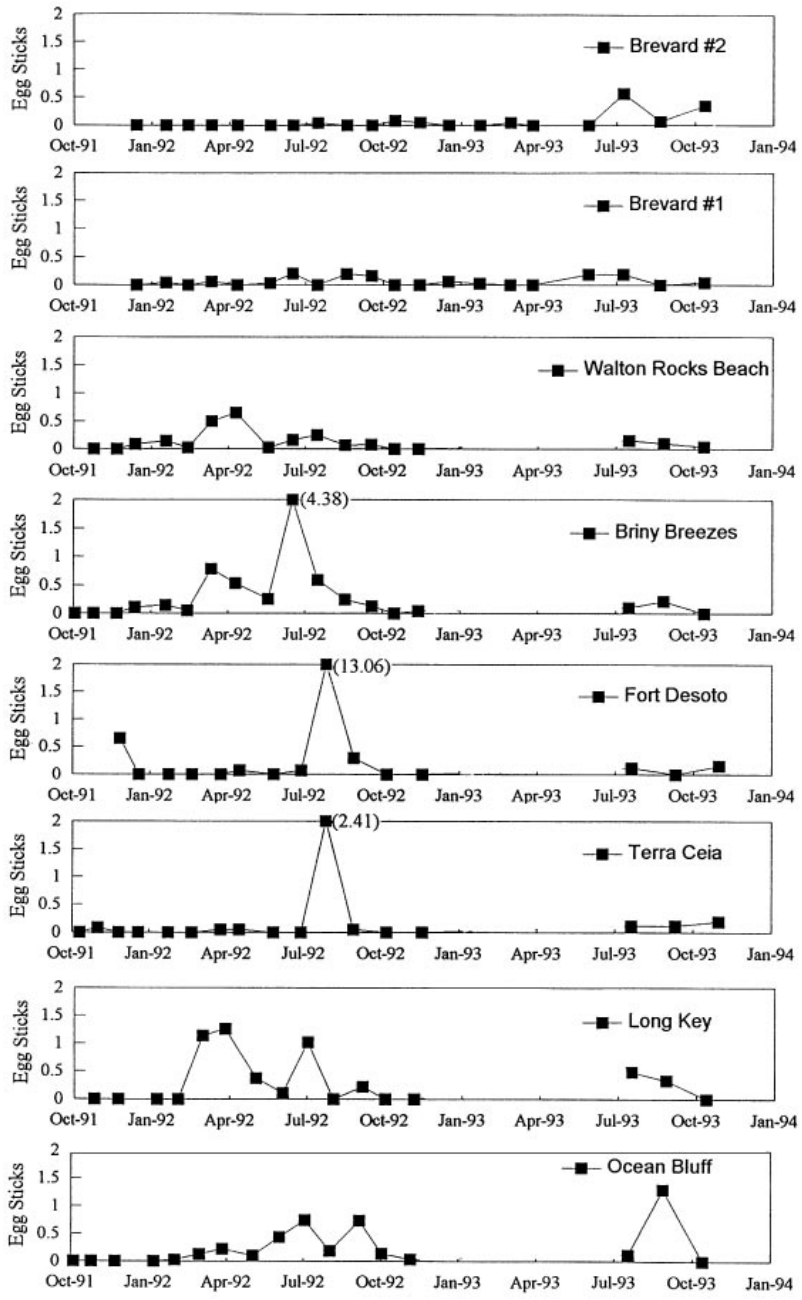

Fig. 4. Percentage of *Opuntia stricta* pads with *Cactoblastis cactorum* egg sticks at eight sites in central and south Florida (see Fig. 1 for locations).

TABLE 1. *CACTOBLASTIS CACTORUM* EGG STICK DISTRIBUTIONS ON SIX POPULATIONS OF *OPUNTIA STRICTA*.

Site	Egg Stick Distribution			
	Among Plants[a]	By Plant Size[b]	Plant Size Preferred	Egg Sticks per Pad by Plant Size[b]
Ocean Bluff	Clumped	N. S.	—	N. S.
Long Key	Clumped	Signif., $p < 0.05$	Medium	N. S.
Briny Breezes	Clumped	N. S.	—	N. S.
Walton Rocks Beach	Clumped	N. S.	—	N. S.
Terra Ceia	Clumped	Signif., $p < 0.01$	Large	N. S.
Fort DeSoto	Clumped	N. S.	—	N. S.

[a]Tested using the Morisita index of dispersion (significant at $p < 0.05$).
[b]Tested using the Kruskal-Wallis test (significant at $p < 0.05$).

There has been almost no confirmed records of inland movement of over a few of kilometers by *C. cactorum* in Florida. The discovery of the moth in Loxahatchee, Palm County in June of 1992 (FDACS, unpublished), 24 km inland from the Atlantic Ocean, is the most inland of confirmed records.

Growth and Mortality of *Opuntia stricta*

Growth in nine plants marked in 1992 ranged from a loss of 100% of the pads to an increase of 87%. One of the 10 plants marked in 1992 was not located until 1 year later. Some of the marks had worn off of the pads, so this plant was omitted from analysis. Two of the nine plants died from larval feeding during 1992. These were two of the three smallest marked plants (each having nine pads). The net growth of all of the plants in 1992 was +5%.

During the second year of monitoring, plant growth ranged from -100% to +56%. The net mean growth of all of the plants was +6%. The smallest of the original nine plants, having eight pads, was the only plant in this group to die (killed by *C. cactorum*) during 1993. Thus, over the two year period the three smallest plants died. Plants with nine or fewer pads had a higher mortality rate than plants with greater than nine pads (Rank Sum Test; $p < 0.05$).

The 10 plants that were marked and monitored in 1993 had a much higher growth rate. Only 1 of the 10 plants decreased in number of pads (-27%) and the highest growth rate was +170%. The mean net growth of the 10 plants was +86%. In 1992 and 1993 combined, new growth pads sustained a higher mortality rate due to larval damage than did old growth pads on 22 out of 25 plants (Wilcoxon Signed Ranks Test; $n = 25$, $p < 0.05$) (Fig. 5).

DISCUSSION

Cactoblastis cactorum in Florida is more active in the spring and summer. The distribution and spread of the moth largely has been restricted to the coastal regions of south and central Florida. The lack of inland reports of the moth may be because *O.*

TABLE 2. RELATIONSHIP BETWEEN THE SIZE OF *OPUNTIA STRICTA* AND DAMAGE BY *CACTOBLASTIS CACTORUM*.

Site	Damage	Size of plant	
		0-10 pads	11-more pads
Ocean Bluff	Present	3	39
	Absent	1	0
Long Key	Present	2	18
	Absent	6	0
Briny Breezes	Present	2	24
	Absent	4	0
Walton Rocks Beach	Present	6	61
	Absent	2	1
Terra Ceia	Present	6	42
	Absent	30	22
Fort Desoto	Present	1	33
	Absent	1	0
Total	Present	20	217
	Absent	44	23
Percentage of plants with damaged pads		31%	90%

stricta is more common in coastal areas (Benson 1982) or because of other biotic and abiotic factors. Future work should address why *C. cactorum*'s distribution is mainly coastal so we can determine whether it will, in time, invade inland populations of *Opuntia*.

Previous studies in Australia and South Africa found that the females lay their egg sticks in a clumped distribution based on plant size, plant color, and shelter from the wind (Myers et al., 1981; Robertson, 1987). Similarly, egg sticks were clumped at all of our sites and more were laid on medium or large-sized plants at two of the sites. There was no difference, however, in the number of egg sticks per pad among plants of different sizes. Thus, pads on large plants are no more likely to have egg sticks laid on them than pads on small plants. This is consistent with our finding that there is no relationship between *C. cactorum* damage and plant size.

The moth is doing significant damage to *O. stricta* individuals in Florida, but is the moth reducing the populations? Overall, the number of pads on marked individual cacti at Walton Rocks Beach increased in 1992 and 1993. However, while fewer small plants received moth damage than did medium or large-sized plants, small cacti with moth damage were most susceptible to mortality. Thus, *C. cactorum* could strongly reduce the survivorship of maturing *O. stricta*. We may reach a scenario in Florida whereby large *O. stricta* can withstand the attack, but, in the ensuing years, as these plants die, there are fewer individuals to replace them. Only then would the total adverse effect of *C. cactorum* become noticeable. Forecasting such a process necessitates a more detailed study in which recruitment as well as the fates of the plants are measured. Also, *O. stricta* populations in Australia partially recovered a few years after

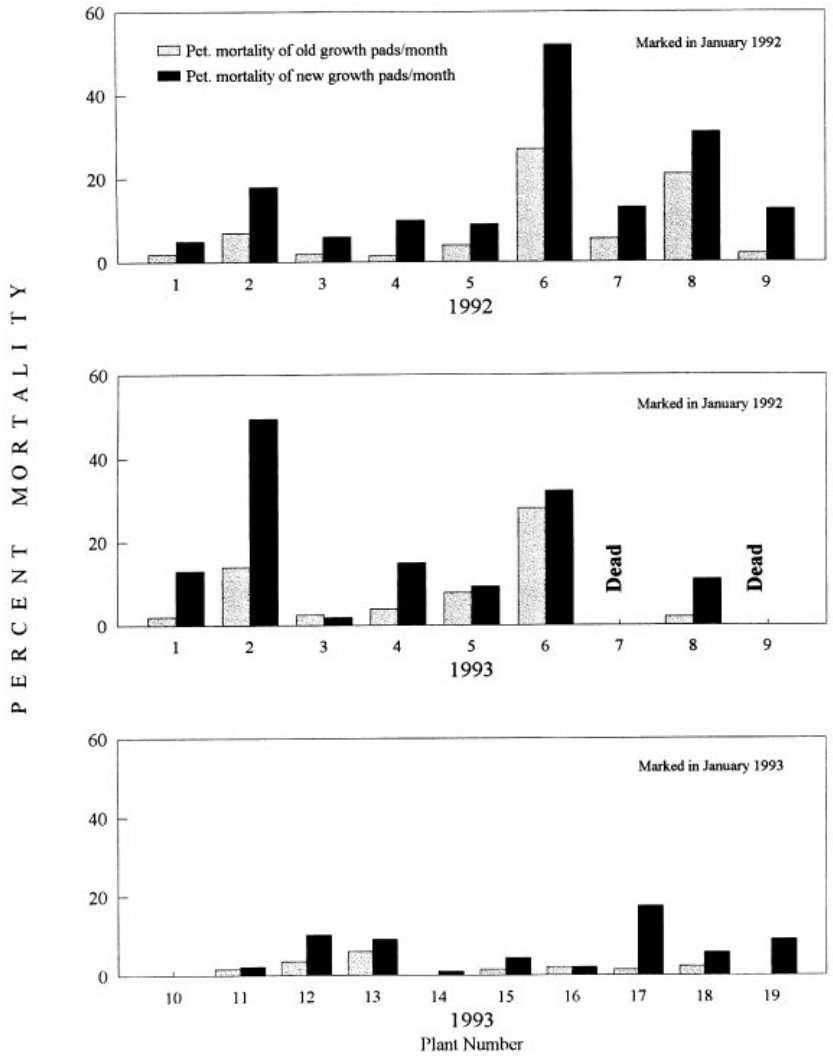

Fig. 5. Percent mortality of old growth vs. new growth pads on marked *Opuntia stricta* in 1992 and 1993.

the introduction of *C. cactorum*, only to be decimated greater within the next few years (Dodd 1940).

Soon after *C. cactorum* was discovered in Florida, its rapid invasion northward prompted concern not only for native Florida cacti but for those native to the rest of the North American continent (especially the *Opuntia*-rich desert southwest). The movement of the moth northward through Florida from 1989 to 1991, assuming it dispersed from the lower Florida Keys, averaged over 160 miles per year. From 1991 to

1993, however, the spread averaged only 24 miles per year. Recent information (Pemberton, 1995) indicates that *C. cactorum* may have invaded Florida via imported cacti through Miami rather than natural dispersal, in which case the dispersal rate reported for 1989 to 1991 is an over estimate. Determining the true rate of spread of *C. cactorum* and which biotic and/or abiotic factors affect this rate, would be valuable because then we could determine if and when the moth may be expected to attack *Opuntia* in other regions of North America (barring accidental introduction on imported cacti).

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