# THE LIKELY CAUSE OF EXTINCTION OF THE TREE SNAIL *ORTHALICUS RESES RESES* (SAY)

E.A. FORYS,[1] A. QUISTORFF,[1] C.R. ALLEN,[2] AND D.P. WOJCIK[3]

[1] *Environmental Studies, Natural Science Collegium, Eckerd College, 4200 54th Avenue South, St. Petersburg, Florida 33711, U.S.A., email forysea@eckerd.edu*

[2] *U.S. Geological Survey, Biological Resources Division, South Carolina Cooperative Fish and Wildlife Research Unit, Clemson University, Clemson, SC 29634, U.S.A.*

[3] *United States Department of Agriculture, ARS, CMAVE, Gainesville, FL, 32604, U.S.A.*

(Received 30 June 2000; accepted 19 February 2001)

## ABSTRACT

The Stock Island tree snail, *Orthalicus reses reses,* went extinct in its native range in the Florida Keys in 1992. Fortunately, *O. r. reses* has been introduced elsewhere and further reintroductions are currently planned. Before these reintroductions are implemented, it is important to try and determine which factors were most likely to have caused the decline and extinction. While habitat destruction was probably the ultimate reason why there were so few tree snails, it is likely that an interaction of habitat fragmentation and the invasion of an exotic predator caused the final decline that lead to the extinction in 1992. We examined the last 93 *O. r. reses* shells to infer cause of death. In addition, using surrogate Florida tree snails, *Liguus fasciatus*, we conducted experiments on two previously unstudied causes of mortality: predation by red imported fire ants, *Solenopsis invicta,* and mortality from falls caused by wind.

We found that the majority of the last *O. r. reses* shells were intact, indicating that mammalian and bird predation were not the greatest causes of mortality. Mortality caused by wind knocking tree snails onto the rocky hammock substrate appeared to be a potential source of mortality, but few of the tree snails exhibited signs of breakage. Mortality from fire ants appears to be one of the most likely causes of the recent decline and extinction of *O. r. reses*. Experiments indicated that in a semi-natural enclosure, fire ants were capable of killing all ages of *L. fasciatus*, even during aestivation. Fire ants are currently found throughout the last known habitat of *O. r. reses* and were first discovered in this area at the time of the decline.

## INTRODUCTION

In 1992, in the wake of a large hurricane, the last few Stock Island tree snails, *Orthalicus reses reses* (Say), were removed for a captive-breeding project from a 3 ha forest patch in the Lower Keys of Florida. Despite several intense searches conducted over the next several years, no additional snails were found, indicating that this subspecies has gone extinct in its historic range. Fortunately, the snail had been reintroduced outside this range and there are several small remaining populations. In addition, individuals have been found in a residential yard in Key West, although it is possible that this population was recently introduced (U.S. Fish and Wildlife Service, 1999). Currently, debate exists as to whether to reintroduce the snails to several remaining patches of hardwood forests in their native range. Before such a reintroduction occurs, it is important to determine why *O. r. reses* went extinct. Unlike many extinctions of small, secretive organisms, the decline of this subspecies has been relatively well documented and the last 93 shells were collected soon after death and preserved.

*Orthalicus r. reses* is a tree snail that has a large (up to 7.5 cm length) white to buff conical shell with narrow, flame-like purple-brown axial stripes (Binney, 1885). Historically it occurred in hardwood hammocks (tropical evergreen forests) throughout Stock Island and Key West (Fig. 1). Relatively little is known about the natural history or ecology of this tree snail, however, they are most active immediately following rains during the wet season (May–October) and aestivate for much of the dry season (November–April).

In addition, research on reproduction indicates that *O. r. reses* is hermaphroditic and mates during the wet season. Eggs are laid in a shallow hole in the ground beneath a tree, approximately two weeks after copulation and young emerge during rainy periods at the end of the dry season (Deisler, 1987). Throughout its life it feeds on epiphytic lichens, fungi, and algae on tree surfaces.

In museum collections, the last *O. r. reses* was

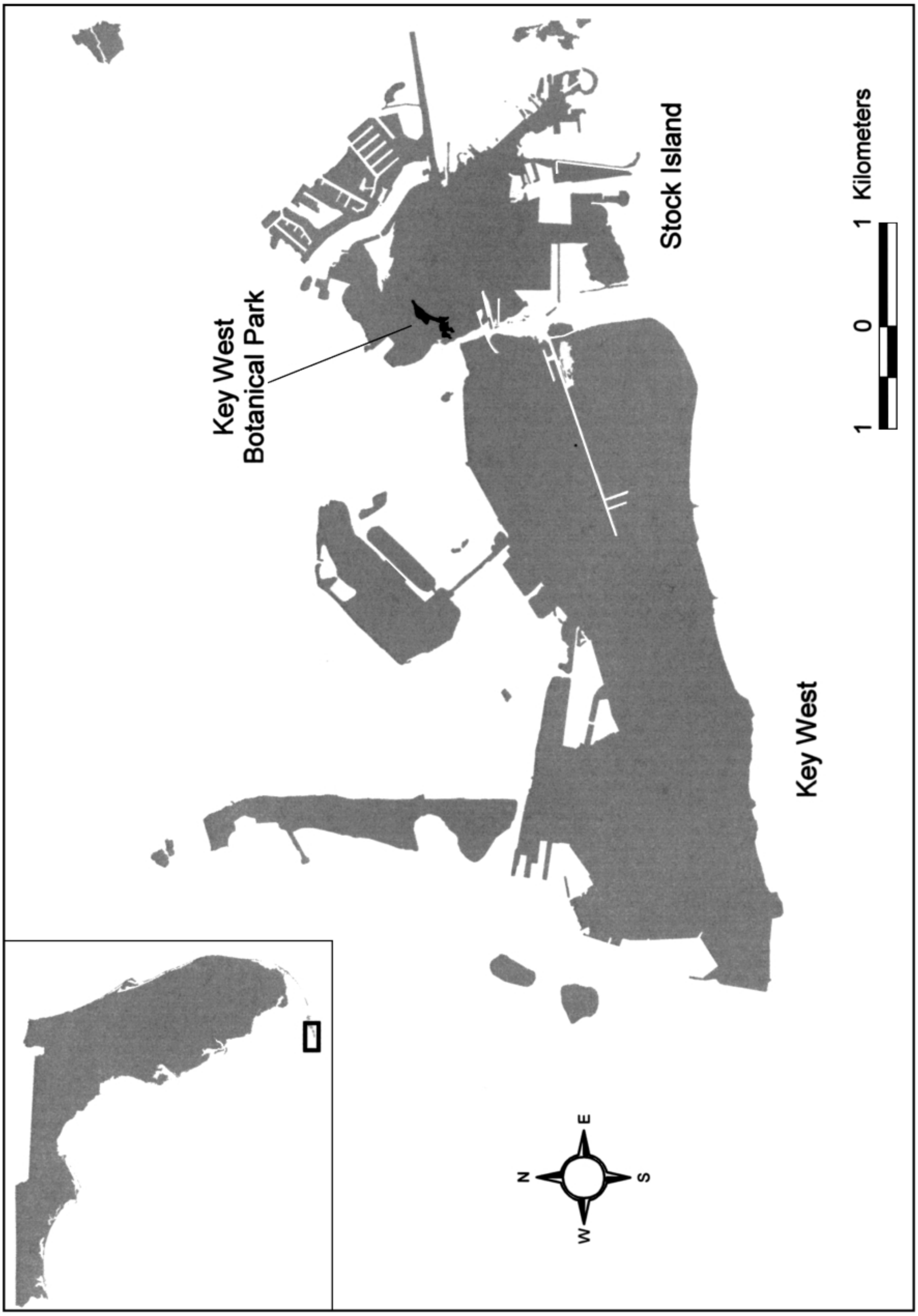


**Figure 1.** The historic range of the *O. r. reses* (*Orthalicus reses reses*). The area shown in black is the current extent of the Key West Botanical Garden located on Stock Island.

collected on Key West in 1938 (U.S. Fish and Wildlife Service, 1982). The extirpation on Key West occurred after a period of intense habitat destruction and collection of snails by humans (Forys, Frank & Kautz, 1996). Since 1975, several status surveys have been conducted on the tree snail (see Forys et al., 1996, U.S. Fish and Wildlife Service, 1999). In each survey, existing hardwood hammock patches were searched from the ground and arboreal searches were conducted during the wet season when the snails are most active. When tree snails were found, density was estimated by thoroughly counting the tree snails in a sample of trees and extrapolating to the entire patch.

The first survey in 1975 found there were approximately 500 snails occupying <10 ha of hardwood hammock fragmented into five patches. The largest of these patches was the Key West Botanical Park on Stock Island. Three smaller patches occurred in a nearby golf course, and one patch occurred along a road. In the same areas in 1980, the number of snails was estimated to be between 200–800. In 1983, the number was estimated to be 200 snails. By 1986, snails on the four smallest habitat patches were extinct and the total estimated number of snails at the botanical park was 50–120. Early in 1992, <20 snails were found in the hammock and a captive-breeding plan was established by removing the remaining snails from the wild. The Key West Botanical Park is currently 3 ha in a linear configuration. The average width of the hammock is 50 m (Fig. 1).

Because of its limited range and small population size, the *O. r. reses* was probably at risk of extinction due to numerous stochastic and deterministic factors. The ultimate cause of the extinction is probably habitat loss, although an increase in habitat fragmentation and increased amount of edge habitat associated with fragmentation also may be involved in the decline seen in the 1980s. This increase in habitat fragmentation could have lead to an increase in predators as well as changes in the microclimate (e.g., humidity, wind) in the hammock (Murcia, 1995).

The objective of our research was to examine the last 93 shells collected of *O. r. reses* to infer cause of death. In addition, we explored the potential for predation by exotic fire ants and mortality due to wind because these two sources of mortality have not been previously examined for tree snails.

## METHODS

To gain insight into factors possibly contributing to the decline of *O. r. reses* we inferred cause of death from shell condition, conducted experiments to determine if wind or fire ants could cause mortality, and measured the abundance of fire ants at the Key West Botanical Park. The experiments were conducted using a non-endangered surrogate species, the Florida tree snail, *Liguus fasciatus* (Müller), a species that occurs throughout the Florida Keys and south Florida. Florida tree snails are similar to *O. r. reses* in habitat use and life history traits (Deisler, 1987).

### *Shell condition*

Numerous studies of tree snails (Voss, 1976; Tuskes, 1981; Deisler, 1987; Hadfield, Miller, & Carwile, 1993) have used shell condition to infer cause of death. Our sample of 93 *O. r. reses* shells was collected from Stock Island during a 3.5 year (August 1985 to February 1989) study of *O. r. reses* behavior and ecology. Condition of each shell was noted, as well as observations concerning the possible cause of death (McNeese, 1997). Shells were examined and classified as either being intact or having signs of predation from mammals or birds. Depressions or holes in the shell were attributed to bird pecks (Voss, 1976; Tuskes, 1981), while mammalian predation was assumed if the apex or other sections of the shell are broken off and exhibit jagged edges resembling teeth marks (Pilsbry, 1946; Voss, 1976). The sample of *O. r. reses* shells was classified according to these specifications whereby shells with holes or jagged breaks were recorded as resulting from avian and mammalian predation, respectively. Shells with no significant visible damage were considered to have died from desiccation, invertebrate predation, disease, or pesticide poisoning.

### *Wind mortality experiment*

To determine if it was possible that snails falling from the trees onto the ground could potentially cause mortality, we conducted a study using *L. fasciatus*. We were concerned that shells with holes or cracks that were assumed to having been made by birds or mammals could have been made by the snail shell making contact with the ground after having fallen from a tree.

We obtained a fresh sample of *L. fasciatus* shells from the ground of a hammock in Key Largo, Monroe County, Florida. Ten pairs of 10x4m strip transects, each spaced 1 km apart, were established on either side of a road that bisected the hammock. Corners of the transect were permanently marked and all old shells on the ground were removed. After a two week period, all newly fallen shells without major cracks, holes, and fissures were collected.

To determine the height from which snails might fall from trees, at each of the strip transects we counted the number of live tree snails four times during one year (March, June, September, and December, 1997) and measured the height of each snail on the tree. To determine the composition of the substrate below the trees at each of the 20 transects we randomly chose one 1 $m^2$ plot and measured the depth of the leaf litter to the underlying limestone rock substrate.

Based on this information, a tray was filled with rocks and leaf litter to mimic the floor of the Key Largo hammock which is limestone bedrock with a thin covering of leaves. To simulate the body of the snail the shells were partially filled with raw oysters, which are similar in density to the snail body. The weight of the portion of oyster used to fill the shell was similar to the weight of a tree snail. The filled shells were then dropped from the average height at which tree snails are found, onto the simulated hammock floor.

The condition of the shells was noted before they were dropped so that new marks could be distinguished from those already present. Additionally, from the severity of the damage it was possible to postulate whether or not the snail would have 'survived' the fall. For example, if the shell was broken in half the snail would probably not 'survive', but minor cracks and holes would pose no serious threat.

### *Fire ant experiment*

To determine the attractiveness of *O. r. reses* to red imported fire ants, *Solenopsis invicta* (Buren), we conducted an experiment using the surrogate species (i.e., *L. fasciatus*) from north Key Largo. The exotic, predatory red imported fire were officially documented on Stock Island (Porter, 1992) in the mid 1980s, although it is likely that they were present earlier. The fire ant was inadvertently introduced into the United States at the port of Mobile, Alabama, around 1930 and rapidly spread to many southeastern states, including Florida (Callcott & Collins, 1996). Fire ants are known to prey on or compete with a wide range of invertebrates (Porter & Savignano, 1990) and recent research indicates they will prey on apple snails (*Pomacea paludosa Say*) in south Florida (Stevens, Stevens, Darby & Percival, 1999). These non-native predators are most abundant in disturbed, fragmented habitats (Wojcik, 1994).

For the experiment, 22 live snails were collected along the Key Largo roadside in March, 1997, by cutting the portion of the branch where the snail was aestivating. We built 10 enclosures (61 × 36 × 13 cm) and stocked each enclosure with an active mound of fire ants and a food supply of honey. The enclosures were housed in an open shed at the USDA fire ant laboratory in Gainesville, FL. In the center of each an enclosure we placed a 2 m branch of wild tamarin (*Lysiloma latisiliquum*) in an upright position. Several species of arboreal tree snails occur on wild tamarin (Deisler, 1987). The 22 aestivating snails and the sticks they were aestivating on were tied 2 m above the ground to the wild tamarin branches. The enclosures were monitored for 3 days.

### *Fire ant abundance*

We measured the abundance of fire ants in the Stock Island Botanical Garden along four transects that bisected the hammock. Each transect was ~50 m long and transects were spaced >50 m apart. The transects began at the parking lot edge of the hammock and continued until the golf course edge. Each 5 m, starting at the edge, paired terrestrial baits (one honey, one meat) were paced directly on the ground on pieces of aluminum foil and paired arboreal baits (one honey, one meat) were placed in small plastic cups perforated with 10–20, 3–6 mm holes. Arboreal cups were placed 1–4 m from the ground in a tree as close to the terrestrial bait as was possible.

Bait transects were placed in the morning (0700–1000 hours) because the temperature was favorable for fire ant foraging. After placement, baits were left out for 1.5 hours to attract ants and then were collected and placed in cups, frozen, and transported to the Imported Fire Ant Laboratory (Gainesville, Fla). In the laboratory ants were picked from the bait, placed in alcohol, and identified to species

## RESULTS

### *Shell condition*

The 93 *O. r. reses* shells ranged in length from 1.7–7.1 cm (avg. = 4.7, std. = 1.0) and in age from 1 to 6 years old. The majority of the 93 shells were completely intact (64%, n = 58), 23% had signs associated with mammal predation (n = 21), 13% had signs associated with bird predation (n = 12), and 2% (n = 2) had signs associated with both mammal and bird predation. Smaller shells were more likely to have signs of predation while the larger shells were more likely to be completely intact (Fig. 2). At the time the shells were collected, eight fully intact shells were found on the ground covered with ants. While not professionally identified, based on behavior these ants were likely fire ants. Two intact shells were found still partially attached to trees, but covered in the fire ants. The snails within these shells were mostly gone.

### *Wind mortality experiment*

We counted 107 *L. fasciatus* on the 20 transects. Eight of these were found on the ground and were not included in the analysis. Tree snails were observed on trees from 1–22 m (avg. = 4.53, std. = 3.28). Based on this data, all tree snails in this experiment were dropped from a height of 4.5m.

Forty-seven empty shells were found on the ground with no obvious signs of predation and were used in the dropping experiment. After being dropped onto the simulated substrate, 56% (n = 26) were missing their apex or were punctured with holes or were cracked. When these marks were closely examined, 13% had marks that were remarkably close to those that are generally associated with mammal predation and 30% (n = 14) had holes that looked very similar to those thought to be produced by birds. Thirteen percent (n = 6) had cracks that are generally not associated with mammal or bird predation. The remainder of the shells had no marks after the fall (44%, n = 21). The smallest shells tended to remain intact after dropping and the largest shells tended to have cracks, holes, or a cracked apex (Fig. 3). Six of the shells (all >4 cm) were significantly compromised and it is unlikely that a live snail would have survived such injuries.

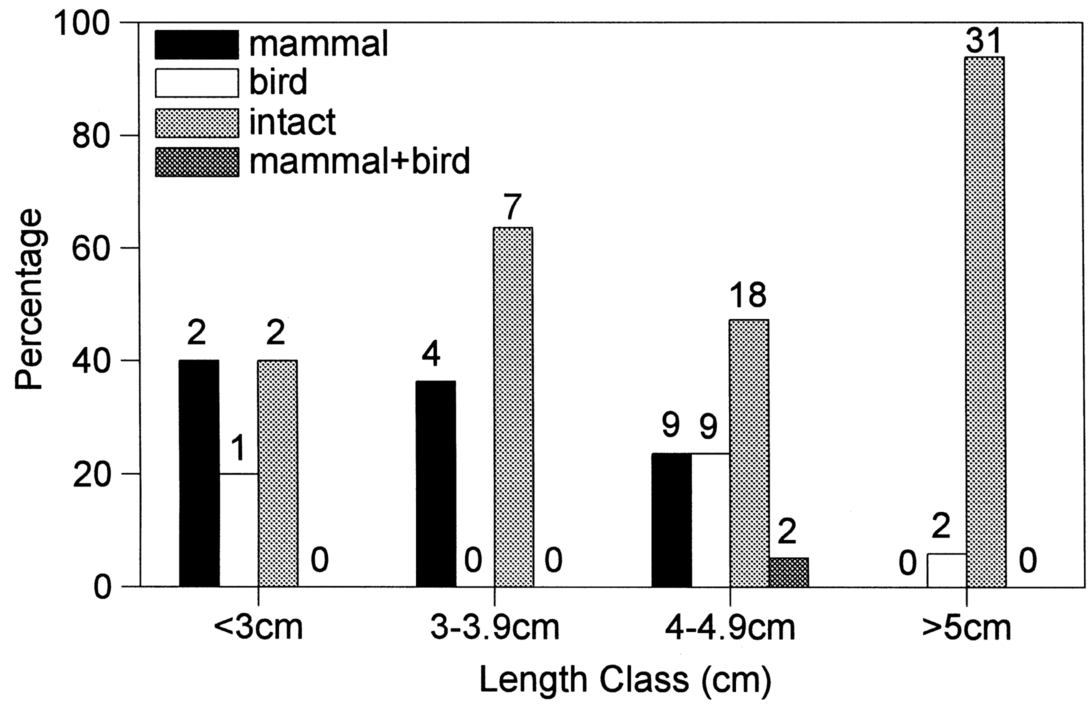


**Figure 2.** Percentage (sample size for each shell length class shown above bar) of *Orthalicus reses reses* shells that had marks on their shell commonly identified as resulting from predation by mammals, birds, mammals and birds, or that showed no signs of predation. Length (cm) was determined by measuring the distance from apex to lip of bottom whorl.

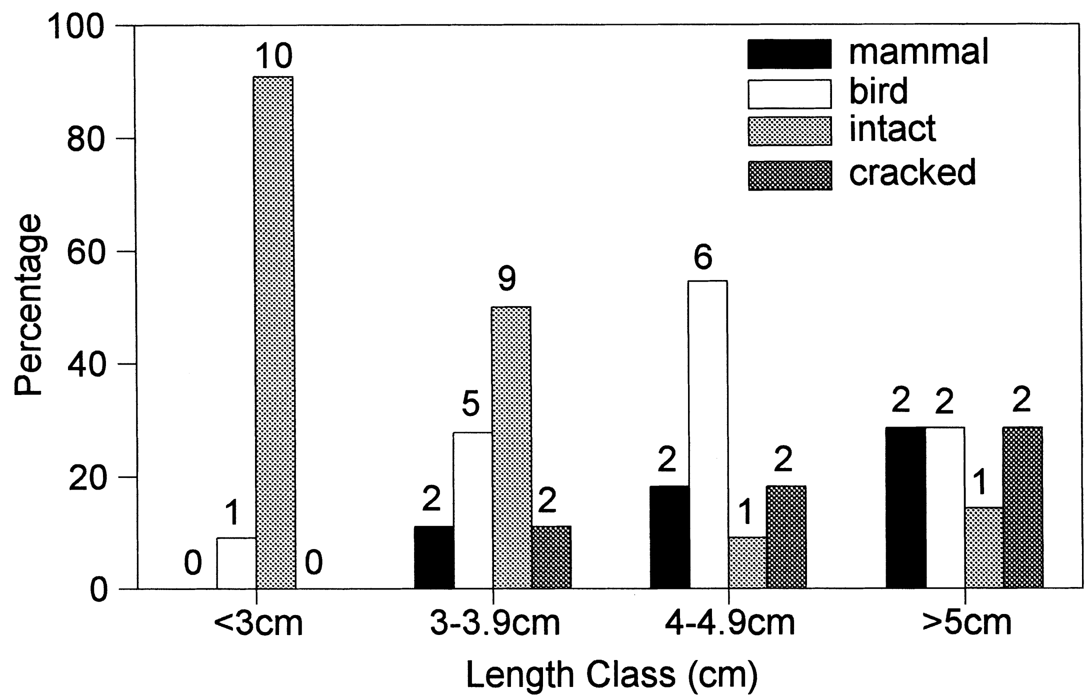


**Figure 3.** Percentage (sample size for each shell length class shown above bar) of *Liguus fasciatus* shells that were dropped from 4.5m and that had marks on their shell commonly identified as resulting from predation by mammals or birds, a crack not attributable to predation, or that showed no damage. Shell length (cm) was determined by measuring the distance from apex to lip of bottom whorl.

*Fire ant experiment*

Nineteen of the 22 *L. fasciatus* were killed by the fire ants within three days (Fig. 4). Twelve of the 19 snails died while actively foraging and seven of the snails were killed while aestivating. During the first day of the experiment, all of the tree snails were aestivating. Within three hours after initiation of the experiment, fire ants had breached the seal of three aestivating snails and began stinging. After several hours of stinging, the tree snails fell to the ground and were quickly buried by the fire ants.

On the second day of the experiment, snails were induced to forage by misting water directed on the shells and branch. Eight snails foraged at some point during the next two days. All of these snails were stung, forced from their branches, and subsequently buried. Snails that remained aestivating were also killed. The only snails that survived the experiment were three larger (older) snails that aestivated for the entire experiment. After the end of the experiment we excavated all of the buried shells and examined them for remaining snail tissue. Only trace amounts of snail were left in the shells.

*Fire ant abundance*

Fire ants were found on three of the four transects that bisected the hammock on Stock Island (Table 1). The ants were more abundant on the edges of the hammock, but were also found at a distance of 20 m from the edge. Only two of the arboreal baits attracted fire ants and both of these baits were on the parking lot edge of the hammock.

## DISCUSSION

Based on the last 93 *O. r. reses* shells that were collected in the mid-late 1980s, there were snails of nearly all ages present and a large proportion of these snails were of a size capable of breeding. The lack of very small snails could indicate that there was little successful breeding, high juvenile mortality, or that smaller snail shells are simply harder to detect.

**Table 1.** Baits that had fire ants present at the Key West Botanical Park hammock in the Florida Keys. (A = arboreal bait, T = terrestrial bait).

| transect | parking lot | 5m | 10m | 15m | 20m | 25m | 30m | 35m | 40m | golf course |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A,T | | T | T | T | | | | | T |
| 2 | | T | | | | | | T | | |
| 3 | A,T | | | | | | | | | |
| 4 | | | | | | | | | | |

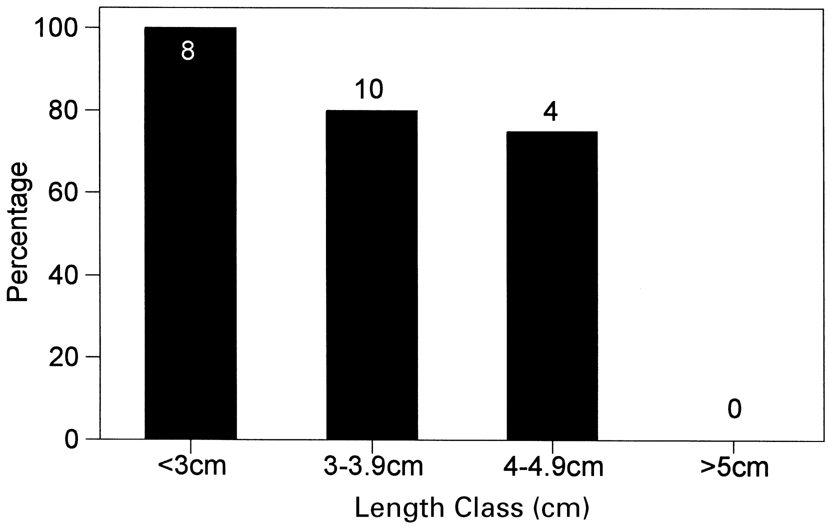


**Figure 4.** Percentage (sample size for each shell length class shown above bar) of *Liguus fasciatus* that were killed by fire ants during the enclosure experiment.

While an increase in bird and mammal predation may have played a role in the decline of the tree snail, the majority of tree snail shells found were intact. Perhaps some of the tree snails were carried off by bird or mammalian predators, but the majority of the shells that had signs of predation were the smaller shells and these are more likely to be carried away or ingested whole than the larger shells (Hadfield et al., 1993). Changes in the hammock's micro-climate that lead to a decrease in food (e.g., lichens) and desiccation may have played a significant role in the mid 1980s decline and the shells of these snails would probably have been left intact. Unfortunately, we do not have any direct data to support or refute this theory.

Mortality due to an increase in wind in the hammock could have contributed to the extinction, but our study found that mortality from wind is probably greatest for larger snails, and larger *O. r. rese*s shells tended to be intact. Because some of the break patterns produced were very similar to those thought to be caused by predation, it is important that studies of tree snail shell damage and mortality consider that falling, and impact with the ground, can be an important contributor to shell damage and snail mortality.

While the shells that were found intact indicate death from old age, disease, desiccation, or invertebrate predation (Tuskes, 1981), only some types of invertebrates and desiccation are more common with an increase in fragmentation. Some of the potential invertebrate predators such as the predatory gastropod, *Euglandina rosea*, and click beetle larva (*Aleus* sp.) have been documented foraging on *O. r. reses*, but neither is known to increase in fragmented or disturbed habitats (Voss, 1976; Deisler, 1987).

One likely factor in the immediate decline of the tree snail is the invasion by the fire ant. Fire ants were first recorded in Monroe County (which includes the Florida Keys) in 1976 (Callcott & Collins 1996) and Porter (1992) reported fire ants were present on Stock Island in the late 1980s. It is likely this means they were present on Stock Island during the period of time when the snail began its fastest decline. In addition, fire ants thrive in habitat edges and the increase in fragmentation of the hammock probably facilitated their access to *O. r. reses.* The majority of the fire ants found on the bait transects in the Botanical Park were on the edges, but because the hammock is so thin, nearly all of the hammock is near an edge.

While our fire ant experiment used another species of tree snail, it is very likely that ants would predate on *O. r. reses* and less likely that the *O. r. reses* would be significantly less palatable. Predation may have been more likely due to the sub-optimum conditions in the hammock. Fire ants have spread throughout the southeastern United States and may pose a significant threat to other rare and declining invertebrates. The climate in the southeastern United States is similar to the climate in part of Africa, Asia, and Australia, indicating that if an introduction were to occur in these areas that it might be successful.

Based on the results presented in this paper, we recommend that before *O. r. reses* are reintroduced, a fire ant control program should be implemented and efforts to expand the width of the Key West Botanical Park be attempted. This control program should look at ways of reducing fire ants while encouraging native ants. Fire ant density should first be decreased using an application of Amdro or similar ant bait. Once the exotic ant density has decreased, efforts to increase the native ant density and diversity should be made. Native ants can be encouraged by planting more native trees, decreasing the broad pesticide applications at the adjacent golf course, and planting buffer trees between the hammock and the golf course. The unique but endangered biological diversity of the Florida Keys may be best preserved by conserving blocks of habitat large enough to minimize fragmentation effects and constant vigilance to lessen the impact of harmful non-indigenous species.

## ACKNOWLEDGMENTS

We would like to thank The Nature Conservancy, Florida Department of Environmental Protection, and the United States Fish and Wildlife Service for permission to sample ants on their lands. J. Sullenger, B. Mayfield, and J. Hosford helped collect, sort, and identify ants. M. Pratt provided assistance with data entry and analysis. The Florida Game and Fresh Water Fish Commission provided funding for this project.

## REFERENCES

CALLCOTT, A.M., & COLLINS, H.L. 1996. Invasion and range expansion of fire ant (Hymenoptera: Formicidae) in North America from 1918–1995. *Florida Entomologist*, **79**: 240–251.

DEISLER, J. 1987. The ecology of the Stock Island tree snail *Orthalicus reses reses* (Say). *Bulletin of the Florida State Museum*, **31**: 107–144.

FORYS, E.A., FRANK, P.A. & KAUTZ, R.S. 1996. *Recovery Actions for the Lower Keys marsh rabbit, silver rice rat, and Stock Island tree snail.* U.S. Fish and Wildlife Service, Vero Beach, Florida.

HADFIELD, M.G., MILLER, S.E. & CARWILE, A.H. 1993. The decimation of endemic Hawaiian tree snails by alien predators. *American Zoology*, **33**: 610–622.

MCNEESE, P.L. 1997. Survey of Key West and Stock Island for the *O. r. reses Orthalicus reses reses.* Monroe County Environmental Resources Department, Marathon, Florida.

MURCIA, C. 1995. Edge effects in fragmented forests: implications for conservation. *Trends in Ecology and Evolution,* **10**: 58–62.

PILSBRY, H.A. 1946. Land Mollusca of North America (north of Mexico). *Monographs of the Academy of Natural Sciences of Philadelphia*. **3**: 1–520

PORTER, S.D. 1992. Frequency and distribution of polygyne fire ants (Hymenoptera: Formicidae) in Florida. *Florida Entomologist,* **75**: 248–257.

PORTER, S.D. & SAVIGNANO, D.A. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community. *Ecology*, **71**: 2095–2106.

STEVENS, A.J., STEVENS, N.M., DARBY, P.C., & PERCIVAL, H.F. 1999. Observations of fire ants (*Solenopsis invicta* Buren) attacking apple snails (*Pomacea paludosa* Say) exposed during dry down conditions. *Journal of Molluscan Studies*, **65**: 507–509.

TUSKES, P.M. 1981. Population structure and biology of *Liguus* tree snails on Lignumvitae Key, Florida. *The Nautilus*, **95**: 162–169.

U.S. FISH AND WILDLIFE SERVICE. 1982. *Stock Island tree snail recovery plan*. Atlanta, Georgia.

U.S. FISH AND WILDLIFE SERVICE. 1999. *South Florida multi-species recovery plan*. Atlanta, Georgia.

VOSS, R.S. 1976. Observations on the ecology of the Florida tree snail, *Liguus fasciatus* (Müller). *The Nautilus*, **90**: 65–69.

WOJCIK, D.P. 1994. Impact of the fire ant on native ant species in Florida. In: *Exotic ants: Biology, impact, and control of introduced species*. (D. F. Williams, ed), 269–281. Westview Press, Boulder, Colorado.