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ECOLOGICAL RELEASE OF AN EXOTIC SPECIES UPON SUPPRESSION OF ITS INVASIVE PREDATOR: A FIVE-YEAR CASE STUDY, WITH NOTES ON OTHER SPECIES, AND THE LIFE HISTORY OF THE MEDITERRANEAN GECKO, *HEMIDACTYLUS TURCICUS*

MALCOLM L. MCCALLUM[1] AND JAMIE L. MCCALLUM[2]

[1]*Department of Molecular Biology and Biochemistry, School of Biological Sciences, University of Missouri at Kansas City, Kansas City, Missouri, USA. Email: malcolm.mccallum@herpconbio.org*
[2]*Department of Biology and Earth Science, University of Central Missouri, Warrensburg, Missouri, USA.*

ABSTRACT: Ecological release allows a species to expand beyond its currently occupied niche upon removal of a limiting mechanism such as a predator or competitor. Unfortunately, these interactions between exotic and invasive organisms are relatively unknown. We examine how a small-scale, intensive Red Fire Ant (*Solenopsis invicta*) eradication program may influence the herpetological and formicid community on a 1.85 ha plot in northeast Texas. Red Fire Ant mounds were individually treated with a series of pesticides in 2005, with follow up treatments in 2006 and 2007. Populations of Red Fire Ants, other ant species, reptiles, and amphibians were monitored throughout the study. Other ant species showed signs of recovery after two years of Red Fire Ant suppression. Although reptile and amphibian diversity increased during the study, only populations of the Mediterranean Gecko (*Hemidactylus turcicus*) showed a dramatic response. The removal of Red Fire Ants provided this exotic Gecko with the opportunity to proliferate. The potential for these kinds of unexpected responses must be considered when removing introduced species from communities containing multiple exotic and potentially invasive organisms.

Key Words: conservation, ecological release, exotic species, invasive species, Red Fire Ant, Mediterranean Gecko, Formicidae.

INTRODUCTION

Ecological release is the expansion of a species' ecological niche beyond that previously utilized (Schoener, 1965; Thoday, 1972). Generally, the best colonists are ecological generalists (Diamond, 1975). However, ecological release is widespread across taxa and biogeographic regions (Diamond, 2001). Although ecological release often involves complex evolutionary changes, it actually encompasses any shift or change in patterned activities (Cody and Cody, 1972; MacArthur, 1972; Vassallo and Rice, 1982). Perhaps the most recognized examples of ecological release are the rapid expansion of many introduced species in Australia (Flannery, 2002). Ecological release often arises under reduced or negligible competition or predation (Vassallo and Rice, 1982; Keane and Crawey, 2002). We studied ecological release in a unique predator-prey system involving an exotic reptile, the Mediterranean Gecko (*Hemidactylus turcicus*), and an exotic invasive insect, the Red Fire Ant (*Solenopsis invicta*).

The Mediterranean Gecko is a small insectivorous lizard that arrived via anthropochore to port cities around the world. The species continues to disperse within regions by transport in trucks (Meshaka et al., 2006), the U.S. Mail (McCallum et al., 2008), and by individuals who introduce the lizards to their homes as insect control (M. McCallum, pers. observ.). It is now common throughout northeastern Texas (Jadin and Coleman, 2007).

The Red Fire Ant (*Solenopsis invicta*) is an invasive species that first colonized the United States in the early

1930s. It is the most widely distributed of four species of Solenopsis found in the United States, only two of which are introduced (http://ipmworld.umn.edu/chapters/lockley.htm, last visited 5 June 2013). This species is known for its competition with herpetofauna (Hook and Porter, 1990; Wojcik et al., 2001) and predation on vertebrates (Mount et al., 1981), including snakes and anurans (Wojcik et al., 2001) and turtles (Moulis, 1997). Fire ant aggression has been reported on *Alligator mississippiensis* (Allen et al., 1997; Reagan et al. 2000), *Caretta caretta* (Allen et al., 2001), and *Gopherus polyphemus* (Epperson and Heise, 2003). Furthermore, reports of fire ant predation on *Eumeces laticeps* (Flowers and McCallum, 2012), *Caretta caretta* juveniles (Parris et al., 2002), *Terrapene carolina* (Montgomery, 1996), turtle eggs (Buhlmann and Coffman, 2001), lizard eggs (Mount et al., 1981; Donaldson et al., 1994), and Mediterranean Geckos (McCallum and McCallum, 2006) saturate the literature. These observations provide widespread evidence that the Red Fire Ant is a notoriously aggressive herpetovore.

Because the Red Fire Ants prey on Mediterranean Geckos and other reptiles, we hypothesized that suppression of the ant populations could stimulate ecological release of reptile populations in the area. We predicted that if ecological release took place that population size of geckos, occurrence of other reptile species, and diversity of ants would increase. If it did not, these statistics would remained relatively unchanged.

MATERIALS AND METHODS

Our study site was at our home, a 1.85 ha lot (Figure 1) located in Liberty-Eylau (Bowie County, Texas). The acreage had three metal outbuildings located near the edges of the study site, and a house positioned centrally on the lot. We searched the entire property in August 2005, and we marked every fire ant mound with a red flag and then tallied the numbers. Each of these mounds was treated with Spectracide Once and Done™ fire ant bait (active ingredient: Indoxacarb). We checked all mounds one week after treatment and then treated the remaining live mounds with Spectracide Ant Killer Granules™ (active ingredient: L-cyhalothrin). The remaining mounds were repeat treated with Spectracide Once and Done™. All pesticides were applied according to the instructions on the label and this procedure was repeated once per month from 2006 - 2010. We treated all new fire ant mounds as they appeared throughout the study.

We searched all structures daily between 1-2 hr after sunset with a flashlight and recorded the air temperature (°C) and the number of geckos. At least 15 min were spent on each side of a building. The flashlight beam was fixed on the eave or the top of the exterior wall and scanned down to the ground. If vegetation was present, extra care was taken to ensure all wall surfaces were searched. We recorded the number of geckos present before the onset of mound treatments in Fall 2005 (n = 6 searches from Aug - Dec), and continued monitoring the population until the end of 2010 (2006: n = 33 searches; 2007: n = 20 searches; 2008: 4 searches; 2009: 6 searches; 2010: 13 searches). Sampling was randomly assigned throughout the year, except in 2006-2007 when we ensured random samples represented all four seasons. We also recorded the numbers of mounds belonging to other ant taxa and other species of amphibians and reptiles appearing during the study. We used a Simpson's Diversity Index ($D = \sum(n/N)^2$; where D = Diversity, n = the number of organisms of a particular species; N = the total number of organisms of all species) to compare herpetological diversity and ant diversity during the study. Data were statistically analyzed using regression and ANOVA (alpha = 0.05).

RESULTS

There were 152 fire ant mounds at the start of our study (July 2005). Nearly all of these mounds were greater than 30 cm in diameter, with one at least 4 m in diameter. After treating the mounds with pesticides in 2005, only 37 active mounds remained. By June 2007 there were 13 active mounds, and only 5 small (< 15 cm diameter) active mounds remained at the last census (2010). The number of fire ant mounds significantly declined during our study ($r^2_{1,83} = 0.404$, $P < 0.001$; Figure 2). Each year had significantly fewer mounds than the one before except for 2008 and 2009 which were not significantly different from each other ($F_{2,79} = 2.6$ vs. 104; $P < 0.001$; Tukey Test: 2005 vs. 2006 = 113.80 – 116.20;

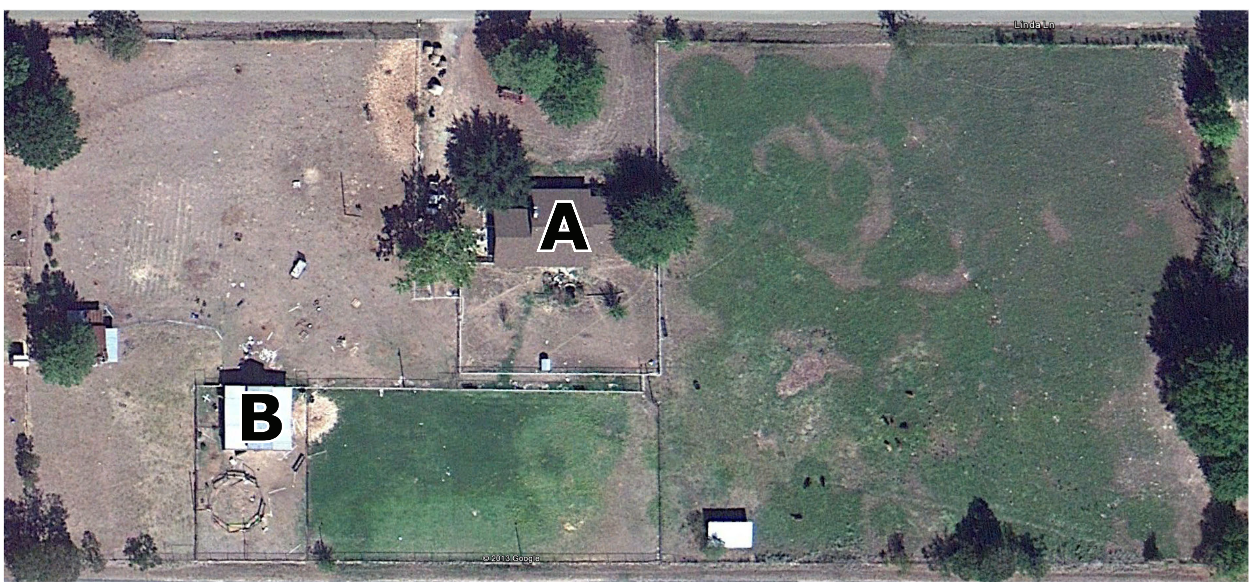

Figure 1. Study site located in Liberty Eylau area of Bowie County, Texas (33.334176°, -94.086915°). The study sight is pictured above on the aerial photograph (compliments of Google Earth). The 1.85 ha lot contains a house (A) and a barn (B).

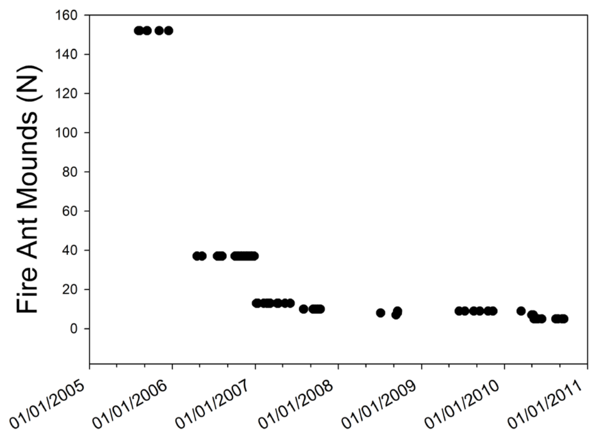

Figure 2. Response of Red Fire Ants (*Solenopsis invicta*) to small-scale eradication program from 2005-2010.

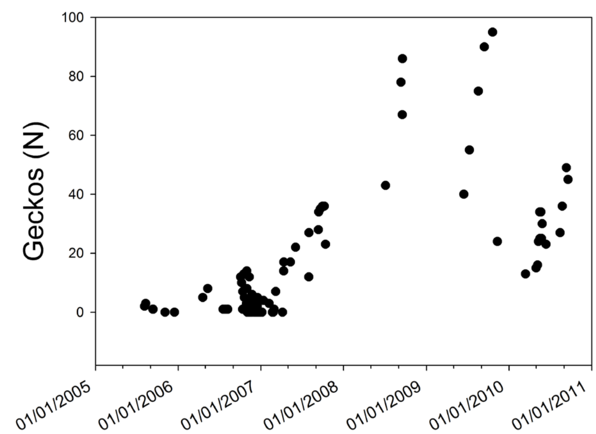

Figure 4. Increase in numbers of Mediterranean Geckos during the five-year Fire Ant eradication program.

2006 vs. 2007 = 24.54 – 26.04; 2007 vs. 2008 = 2.239 – 5.189; 2008 vs. 2009 = -2.75 – 0.75; 2009 vs. 2010 = 2.11 – 4.75).

Mediterranean Gecko's Response — Despite extensive searching, we never observed Mediterranean Geckos on any of the outbuildings during this study, nor on neighboring houses. In 2005 there were 1.17 (SE = 0.48) geckos present on the house per survey (n = 6). As fire ant mound numbers fell, the number of geckos observed grew rapidly each year thereafter (Figure 3; $r^2_{1, 39} = 20.7$, P = 0.003; geckos = 10.5 - 0.07 x $N_{fireant\ mounds}$). Mediterranean Gecko population grew significantly during our study (Figure 4; $r^2_{1,83} = 0.378$, P < 0.001). There were significant differences among observation years (Figure 5; $F_{5,79} = 46.55$, P < 0.001) The population in 2006 was not significantly larger than in 2005 (Tukey Test = -17.89, 12.69), but the population was significantly larger in 2007 than in 2006 (Tukey Test = -22.58, -3.41), and larger in 2008 than in 2007 (Tukey Test = -79.58, -32.90). The population in 2009 did not change from 2008 (Tukey Test = -16.96, 27.62), returning to near 2007 levels in 2010 (Tukey Test = -23.44, 0.39).

Gecko activity was closely tied to temperature (Figure 6; $r^2_{1,73} = 0.256$, P < 0.001) providing a possible confounding variable in our study. Fire ants (T = -5.96, P < 0.001) and Temperature (T = 6.29, P < 0.001) interacted to influence observations of Mediterranean Geckos (Figure 7; $r^2_{2,72} = 0.501$, P < 0.001) according to the following formula:

$$Geckos = 1.63 + (0.862 \times Temperature) - 0.182\ N_{fire\ ant\ mounds}$$

Gecko Activity varied according to month (Figure 8; $F_{11,73} = 3.32$, P = 0.001). Abundance was lowest in December – February, March and April saw somewhat larger abundance, followed by a sustained largest abundance running from May through October.

Mating was observed on occasion (Figure 9) and abundance of juveniles varied throughout the year (Figure 10). Young-of-the-year were observed in all months, but they were least abundant in July – September and numbers peaked in October – November. When geckos were observed in the open during the day, these were always juveniles (N =13). We made no effort to search for Geckos during the day, these were entirely opportunistic sightings. The abundance of juveniles increased from 2005 - 2007 (Figure 11), however we did not record numbers of juveniles after 2007. We did not observe eggs and we believe this is because the geckos were ovipositing in the walls of the house or behind the bricks. The interface between the brick walls and the soffits were not closely united so adult geckos would seek refuge in these locations (Figure 12).

Mortality of Mediterranean Geckos was observed via four sources: 1) human, 2) cats, 3) temperature and 4) Red Red Fire Ants. On several occasions we accidentally crushed geckos that had taken refuge under rocks,

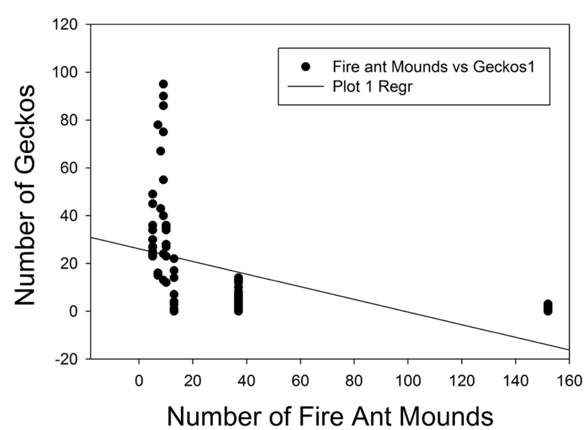

Figure 3. Increase in Mediterranean Gecko populations in relation to Red Fire Ant mound abundance.

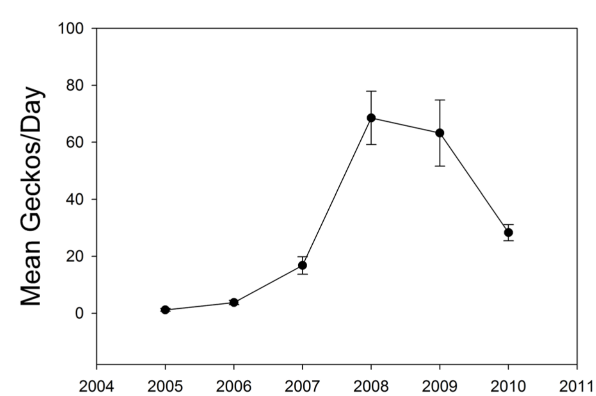

Figure 5. Mean annual number of Mediterranean Geckos observed each day during the Red Fire Ant eradication program.

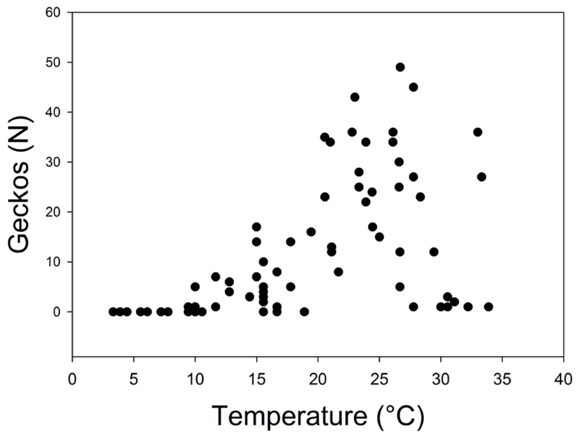

Figure 6. Number of Mediterranean Geckos observed at different temperatures during Red Fire Ant eradication program.

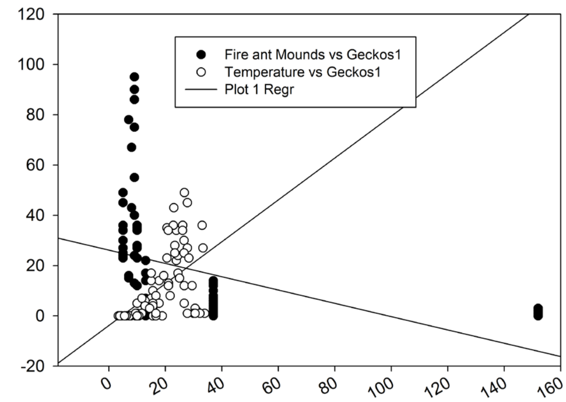

Figure 7. Interaction between temperature and Red Fire Ant mound abundance on the number of Mediterranean Geckos observed during Red Fire Ant eradication program. (x-axis = Temperature [°C] and Red Fire Ant mounds (N), y-axis = geckos (N).

tools, or other items around the home. Additionally, on 12 October 2006 during a service call by the electric cooperative, we observed 5 dead Mediterranean Geckos in the power box where electricity entered the home. Hypothetically, these died from contact with the electrical line. When discussing the issue with the serviceman, he informed me that it was not uncommon to find dead animals including lizards, mice, and snakes in the electrical box. Mortality from cats was not reported earlier in our Results, but the appearance of cats in 2010 certainly contributed to the reduction in gecko numbers (Figure 5). During January – February 2010 there was also an uncharacteristic cold spell that was followed by observations of dead geckos. We observed 3 dead under a front window shutter, 2 behind a panel in the carport. This may also have contributed to the reduced observations in 2010. Mortality due to fire ants was observed and previously published (McCallum and McCallum 2006).

Amphibian and Reptile Response — Herpetological species richness increased during the study. We observed no other species of amphibians or reptiles during 2005. Excluding Mediterranean Geckos, the first amphibian or reptile species observed was a Broadhead Skink (*Plestiodon laticeps*) in July 2006. Other reptiles observed between July 2006 and December 2006 included a Ground Skink (*Scincella lateralis*), a Western Rat Snake (*Pantherophis obsoletus*), a Three-toed Box Turtle (*Terrapene carolina triunguis*) and an Eastern Coachwhip (*Masticophis flagellum*). In 2007 we observed two Green Anoles, three Texas Rat Snakes (*Pantheropis obsoletus lindheimeri*), a Black-masked Racer (*Coluber constrictor*), a Green Tree Frog (*Hyla cinerea*), two Gray Treefrogs (*H. versicolor*), five Southern Leopard Frogs (*Rana sphenocephala*), and one juvenile American Bullfrog (*Rana catesbeiana*). The Simpson's Diversity Index for reptiles (D_r) fell ($r^2_{1,1}$ = -0.786, P = 0.306) from D_{r2005} = 1.0 to D_{r2006} = 0.303, D_{r2007} = 0.249 indicating that the reptile species diversity increased throughout the study.

Ant Community Responses — The numbers of ant mounds other than those belonging to fire ants increased during our study. In July 2005, we saw two mounds of Little Black Ants (*Monomorium minimum*), one of *Acanthomyops* sp., one mound of Pharaoh Ants (*Monomorium pharaonis*), and one Red Harvester Ant (*Pogonomyrmex barbatus*) mound. By April 2006, the number of Little Black Ants increased to 5 mounds, a single *Acanthomyops* sp., Pharaoh Ant, and Red Harvester Ant mound remained. In April 2007 we observed one mound of Little Black Ants, 10 mounds of Pyramid Ants (*Dorymyrmex* sp.), one mound of *Pheidole* sp., and a mound of ants that could not be identified but that were not among the taxa previously identified. In 2007 we found that a Red Fire Ant mound replaced the single Red Harvester Ant mound present in 2006. By September 2007, we observed two Black Carpenter Ants (*Camponotus pennsylvanicus*) but the colony could not be located. At this time we censused ant mounds on ~0.2 ha of the property and found nine Paraoh Ant, 14 Pyramid Ant, two Little Black

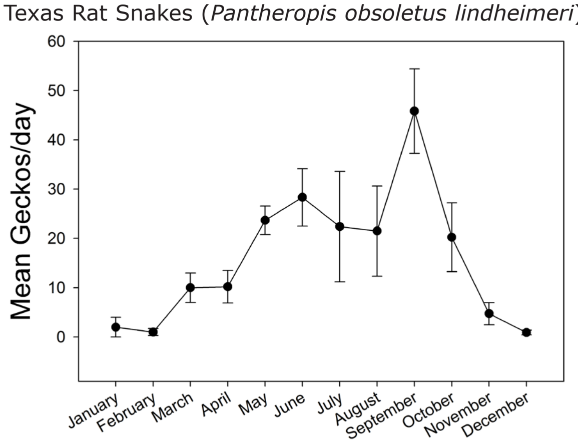

Figure 8. Variation in abundance of Mediterranean Geckos by month.

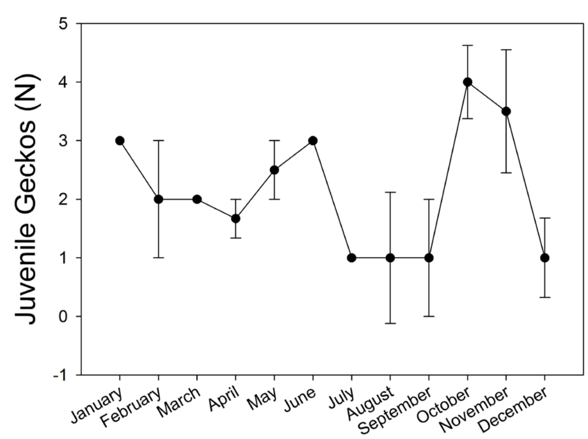

Figure 10. Monthly variation in juvenile Mediterranean Gecko abundance.

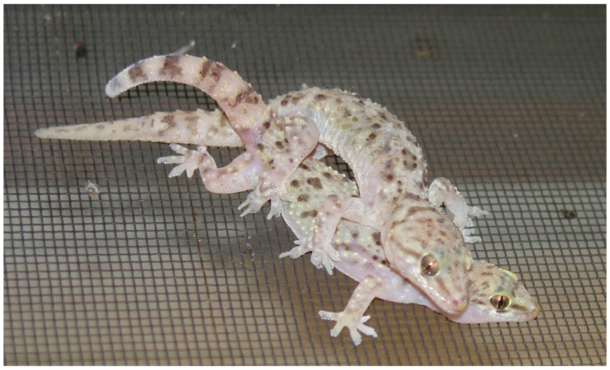

Figure 9. Mating Mediterranean Geckos observed 29 May 2010. (Photographed by Malcolm McCallum).

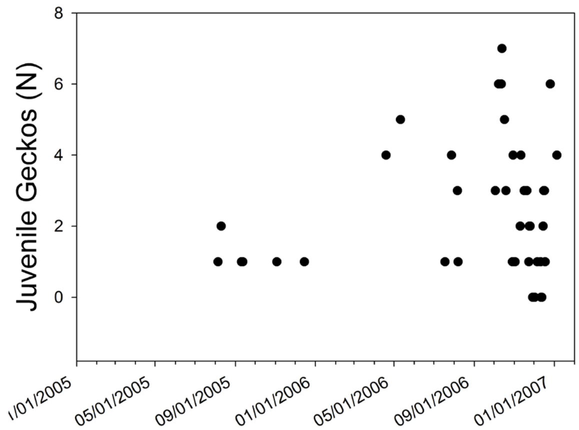

Figure 11. Change in juvenile Mediterranean Gecko observations from 2005 – 2007 during our Red Fire Ant eradication program.

Ant, and two Red Fire Ant mounds. One Red Fire Ant Mound had a maximum diameter of 22 cm and the other was 4 cm. If we extrapolate this to the entire property we predict that the entire property would have about 72 Paraoh Ant, 126 Pyramid Ant, 18 Little Black Ant, and 18 Fire Ant mounds. The actual number of Red Fire Ant mounds observed on the entire property by the end of the study was 10. The ant diversity increased during our study from $D_{a2005} = 0.937$, $D_{a2006} = 0.692$, $D_{a2007} = 0.364$ ($r^2_{1,1} = 0.78$, $P = 0.053$). Although we stopped counting native ant mounds, by 2010 the numbers of Pyramid Ant mounds were noticeably abundant, and a brief count recovered 83 mounds in the driveway alone (See Figure 1).

DISCUSSION

These results demonstrate that a small-scale, sustained, intensive Fire Ant eradication program can dramatically benefit sympatric species diversity and abundance. They also demonstrate that removal of a predatory invasive species can unintentionally benefit sympatric exotic species, such as Mediterranean Geckos.

Reports of ecological release occur across many taxa, including exotics. The toxic dinoflagellate *Gymnodinium catenatum* and the pelagophyte *Aureococcus anophagefferens* are commonly transported in ballast water resulting in ecological release of the population and producing toxic "brown tides" (Smayda, 2007). That study relates that ecological release proceeds through three stages on their way to establishment. These are (1) pioneering (colonization phase), (2) persistence, and (3) community entry.

Our study demonstrates that species may move through these stages at different rates. Among the Formicidae, Pyramid Ants rapidly recolonized the area upon Red Fire Ant removal. Other species responded more slowly, with Harvester Ants showing no recovery during our study. We observed no amphibians during 2005 or 2006, but some species appeared in 2007. The slow response of amphibians to Red Fire Ant removal may be due to the distance from wetland habitats reducing the opportunity for immigration to the study site (MacArthur and Wilson, 1967). More species of reptiles than amphibians appeared after the onset of Red Fire Ant suppression. Regardless, only Mediterranean Gecko populations demonstrated a marked increase, suggesting that these other reptiles were transients who remained on the property after arriving in a Red Fire Ant free zone.

Upon suppression of Red Fire Ant populations, Mediterranean Gecko populations grew dramatically with particularly large increases beginning in 2007 and continuing through 2008. This suggests that competition with, and predation by Red Fire Ants suppressed population growth of the Mediterranean Gecko and that removal of this aggressive invasive ant species stimulated ecological release. Later reduction in population may be re-

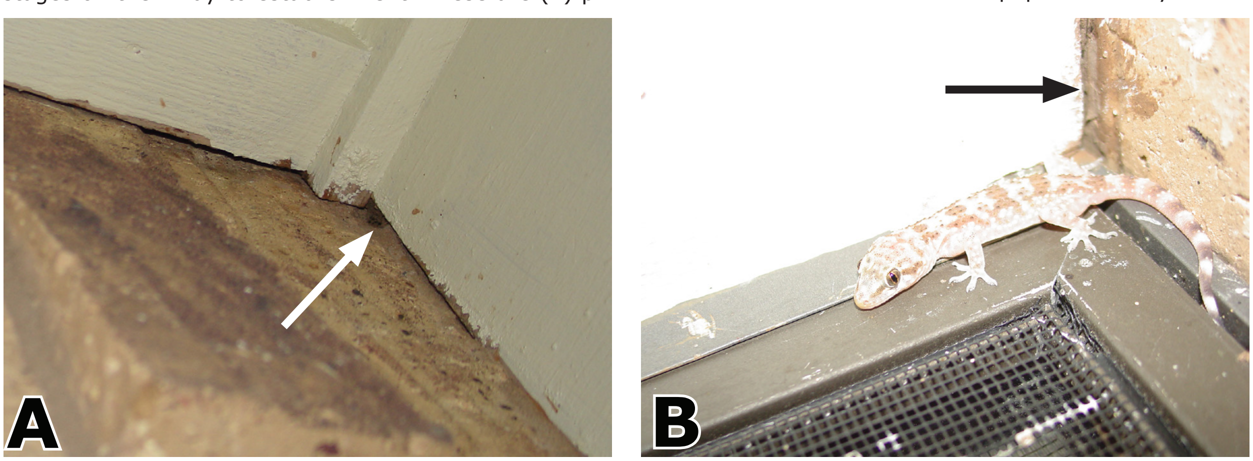

Figure 12. A) Gaps between the soffits and brick wall within which adult and juvenile Mediterranean Geckos sought refuge during the day, and probably the location of oviposition. The white arrow in (A) shows a Mediterranean Gecko within the space. B) Shows a Mediterranean Gecko resting near a large gap in soffit (black arrow). This gecko retreated into that space and disappeared after photo was taken. (Photographed by Malcolm McCallum).

lated to predation by house cats (*Felis catus*). In that year three house cats (neighbor's pets) began foraging around our house at night, including one that had kittens in the garage. Undoubtedly, this disrupted the growth of the population. House Cats are notorious predators of small lizards (Barrat 1997; Alterio and Moller 1997; Loss et al. 2012).

Previous studies with other species also show ecological release. Many studies with birds demonstrate that release from predators and competitors leads to population expansion and vice versa (e.g. Vassallo and Rice 1982; Baker-Gabb 1986; Crooks and Soule 1999). Additionally, similar results were found with fish (Azuma 2004), slugs (Hausdorf 2001), and nematodes (Procter 1990). Anuran populations expanded following removal of Bullfrog populations (Hecnar and M'Closkey 1996), which are well known predators of other frogs (Moyle 1973; Hayes and Jennings 1986; Adams 1999).

Several studies investigated ecological release in Squamata. Ecological release was not a factor in the evolution of anoles in the Greater Antilles (Losos and de Queiroz 1997; Eaton et al. 2002). Conversely, *Phrynosoma douglassi* and *Phrynosoma orbiculare* from the southwestern United States demonstrate significant niche expansion where their ranges do not overlap, but evolve divergent, specialized ecological roles in areas of sympatry (Montanucci 1981).

Our study is most similar to the interaction between Raccoons (*Procyon lotor*) and Green Iguanas (*Iguana iguana*) in Florida (Meshaka et al. 2007). Raccoons were removed from a Florida park to protect sea turtle nesting beaches. As Raccoon populations fell, exotic Green Iguana populations exploded. Raccoons controlled the Green Iguana populations by feeding on eggs and juveniles, and through harassment of adults. In our study, the invasive exotic Red Fire Ant served as the predator control for the Mediterranean Gecko population. Red Fire Ants readily feed on lizard eggs (Mount et al. 1981) and on juvenile Mediterranean Geckos (McCallum and McCallum 2006). They may also feed on lizards that are much larger than adult Mediterranean Geckos (Flowers and McCallum, 2012) making adult geckos reasonable fare. Without this aggressive predator, the Mediterranean Gecko population was released and able to grow.

Clearly, restoration activities involving non-native species must be done carefully to avoid compounding the problems associated with ecological release. As humans restore native habitats and convert native habitats into urban and agricultural uses, we must be concerned about the unintended results of our actions (Hails 2002; Meshaka et al. 2007). How environmental controls and interspecific interactions control populations of potentially nuisance species is difficult to predict (Soule et al. 2003). How our actions may alter this delicate balance; how to predict which species could become nuisances; and how to manage these possible outcomes are concepts that need attention from scientists and policy makers alike.

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