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Population Size, Trend, and Immigration in a Tennessee Population of Mediterranean Geckos (Hemidactylus turcicus)

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POPULATION SIZE, TREND, AND IMMIGRATION IN A TENNESSEE POPULATION OF MEDITERRANEAN GECKOS (*HEMIDACTYLUS TURCICUS*)

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Short Title.—Demography of Nonnative Geckos at the Invasion Front

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***Abstract.*— Biological invasions are a major problem for conservation of biodiversity. In the case of invasive reptiles, climate often restricts the extent of invasions. Exotic Mediterranean Geckos (*Hemidactylus turcicus*) are increasingly apparent in the southeastern United States, but their potential for establishment and spread in more temperate regions is unknown. Here we studied a population at the northern periphery of the known range of the species to assess the importance of overwinter survival, immigration, and *in situ* reproduction for population viability. We gathered data using capture-recapture methods and the unique dorsal patterns of individual geckos. Despite the more temperate climate at this site, geckos survived the winter and reproduced. Cormack-Jolly-Seber open population and robust design models indicated population growth over the course of the study. The ability of this species to successfully establish a population in this northerly location indicates potential for further invasion.**

Key Words.—capture-recapture; introduced species; pattern recognition; urban ecology

INTRODUCTION

The Mediterranean Gecko (*Hemidactylus turcicus*; Sauria, Gekkonidae) is native to the Mediterranean region of southern Europe, western Asia, and northern Africa. Mediterranean Geckos were first documented in the United States in Key West, Florida in 1910 (Locey and Stone 2006). This species has since established populations throughout much of the southern and western United States, as well as in more northern urban centers (Norden and Norden 1991; Locey and Stone 2006; Meshaka et al. 2006; Nordberg et al. 2013). Mediterranean Geckos often inhabit the walls of manmade structures in urban areas. Because of that habitat preference, humans often unintentionally transport them, which has been a major driver of their spread (Davis 1974; Meshaka et al. 2006). Climate likely is important in regulating the northward spread of this species, though geckos have been able to persist in relatively temperate areas, likely due to heat produced by manmade structures (Norden and Norden 1991).

Populations of this species were recently discovered in Knox County, Tennessee (Hively 2015). These populations are relatively far north in the introduced range of the species, so their fates are highly relevant to the future spread of this species. We therefore monitored one population to determine overwinter survival, population size and trend, and immigration.

MATERIALS AND METHODS

Recently, there have been confirmed sightings of what appear to be established populations of *Hemidactylus turcicus* at two widely separated localities in Knox County, Tennessee (Hively 2015; A.C. Echternacht, pers. comm.). In addition, at two other widely separated localities, there have been sightings of single lizards which, on the basis of description, may have been *H. turcicus* (B.M. Fitzpatrick and M. Ogle, pers. comm.). Our study site is that reported by Hively (2015) which is near a commercial product distribution center in Knoxville. There, the lizards inhabit concrete block retaining walls with abundant crevices.

We conducted surveys from September 2014 to November 2015. Differences in protocols among parties conducting surveys resulted in uneven sampling effort among sampling occasions. We surveyed geckos from dusk until no more new individuals were encountered. We searched for geckos using headlamps and captured them by hand. We then photographed the dorsal pattern of each individual and measured snout-vent length (SVL). We defined SVL at maturity as 4.2 cm (Punzo 2001). That value is also cited by Paulissen et al. (2014), Locey and Stone (2006), and Stabler et al. (2011)

We conducted pattern recognition on the photographs using I^3S Pattern version 4.0.2 (den Hartog and Reijns 2014). Before analyzing images, we cropped them and rotated them to the same orientation using Adobe Photoshop to more easily compare photos. We used the snout, left base of head, and right base of head as reference points to orient photos. To confirm identification results, we manually compared light and dark patterns of tubercles and skin. We conducted analyses only for the retaining wall with the most data since some survey parties did not visit both walls. Moreover, we did not record any individuals captured at both walls, suggesting that they are largely independent from a short-term demographic perspective.

We used the resulting encounter history to estimate population parameters over time via capture-recapture packages in R version 3.2.2 (R Core Team 2015). We compared estimates of population size over time to assess trends. Additionally, new individuals entering the population before reproduction occurs would indicate immigration, possibly from new introductions. We used package mra to run a Cormack-Jolly-Seber model with unequal time intervals and timevarying capture probabilities (McDonald 2015). Cormack-Jolly-Seber models are used to estimate population size at each sampling occasion when not assuming population closure. They allow immigration, birth, and mortality to occur. However, the population size at the first sampling occasion is not estimable using this model.

We used package Rcapture to run a robust design analysis (Rivest and Daigle 2004; Baillargeon and Rivest 2007; Rivest and Baillargeon 2014). The robust design is a model that blocks sampling occasions together into primary periods. Populations are assumed to be closed within primary periods but open between them. This model can estimate abundance for all primary periods and is thought to improve estimation of demographic parameters by pooling shorter-term studies together (Williams et al. 2002; Rivest and Daigle 2004). A downside of the robust design in our study was that our blocking was somewhat arbitrary because we had not designed sampling to have clear-cut primary periods. We were unable to include temporal effects in our robust design analysis because that function had excessive memory requirements when running on our data. This is a known issue with this function when working with datasets featuring many capture occasions (Baillargeon and Rivest 2007).

For the robust design analysis, we blocked sampling occasions into primary periods mainly by month, with occasions from the fall of 2014, March and April 2015, and October and November 2015 also blocked together to avoid having blocks with only single sampling occasions. Our blocking scheme is shown in Table 1. This scheme is arbitrary, as there is no objective way to group sampling occasions when we know the population was closed versus open. Adjusting the blocking scheme had negligible effects on parameter estimates.

RESULTS

Analysis of photos with pattern recognition software revealed that at least some geckos survived the winter. Fifteen individuals that were first captured in the fall of 2014 were recaptured at least once during the spring or summer of 2015. An example of such an individual is illustrated in Figure 1.

Successful *in situ* reproduction at the study site is indicated by three lines of evidence in addition to population size estimates. First, we found five communal nests in wall crevices, with intact nonviable eggs alongside broken shells, indicating that the broken eggs likely did successfully hatch. Second, there was a large increase in the number of geckos with small snout-vent lengths captured on the last few sampling occasions in October and November 2015 (Fig. 2). This is consistent with offspring entering the population. Third, we encountered gravid females from May through July 2015 (Fig. 3).

The population size estimates both indicate that population size remained relatively stable over the course of 2015, but show much growth toward the end of the study period (Tables 2-3; Fig. 4). The robust design model indicates a slight decline over early 2015, though this variation is within the range of the error bars (Table 3; Fig. 4). The final sampling occasions (October-November 2015), which have much larger population estimates, had very few recaptures (Fig. 5). As discussed above, smaller geckos were abundant in these periods (Fig. 2-3), many of a size consistent with their having hatched that year (Rose and Barbour (1968) found average hatchling SVL to be 2.59 cm; Selcer (1986) found mean size at hatching to be 2.4 cm).

Sample size, large on the first two occasions, was low for much of 2015, rising during the last two occasions (Fig. 3). Percent recaptures showed extensive variation over the study period but were very low on the last two sampling occasions (Fig. 5).

Pattern recognition worked well on Mediterranean Geckos. This method eliminates the need to employ more invasive markings such as visible implant elastomer or toe clipping. Pattern recognition was effective as long as well-lit photos of a straight dorsum from directly above were available. Differences in angle and poor lighting were the main factors that caused difficulties. Individuals retained their pattern for as long as 12 months. Figure 1 depicts one example of an individual's pattern remaining consistent. Use of pattern recognition software was much more efficient than manually cycling through all photos of individuals when there were many individuals.

DISCUSSION

We studied a population of introduced Mediterranean Geckos in Knoxville, Tennessee to address overwinter survival, population size and trend, and immigration. Monitoring the status of a northerly population of this nonnative reptile is relevant for predicting further spread. Geckos survived the winter and reproduced, and population modeling via capture-recapture software indicates population growth.

Successful overwinter survival of at least a portion of the population indicates that this species is able to survive winters in areas colder than most of its introduced range. At least some of the populations farther north are located in major cities, which likely have more significant heat island effects (e.g. Norden and Norden 1991). Overwinter survival was probably less than 50% from 2014 to 2015 (Tables 1-2, Fig. 4), suggesting that access to refugia during cold weather is a major determinant of population viability. New introductions also could potentially be important to maintain a viable population. The ability of this species to survive in this location means that it may continue to spread northward, at least in relatively urban environments.

Successful reproduction is indicated by the large numbers of small geckos encountered on the final two sampling occasions (Fig. 3), combined with the presence of nests and gravid females. The high abundances of juvenile geckos on these dates are similar to the pattern observed by Punzo (2001), in which the highest abundance of juveniles was observed in November. Increases in population size could possibly lead to expansion of this population through diffusion dispersal, although the lack of detected movement between walls in our study reinforces the low vagility seen in other studies (Rose and Barbour 1968; Trout and Schwaner 1994; Punzo 2001; Locey and Stone 2006).

We were unable to determine whether continued immigration or introduction events into the study site are occurring. The Cormack-Jolly-Seber model results show a rough pattern of increasing population size estimates over the early part of 2015 (Fig. 4), which could possibly be due to introductions or immigration. However, these could also be indicative of geckos becoming more active as temperatures became warmer. A more extensive investigation of this population and the surrounding areas, including the commercial distribution warehouse, might generate more definitive results on immigration.

Factors associated with sampling and uncertainty affect our data. Variation in sample size over the course of the study (Fig. 3) is likely due to a combination of geckos being less active in the colder months of the year and variation in sampling effort. One possibility regarding the low recapture rate seen in the final sampling periods is that adult geckos became more capture shy after having experienced sampling multiple times. This would mean that capture probability is different between individuals, which could possibly bias abundance estimates since we did not include individual covariates (Williams et al. 2002). Heterogeneity in survival probability among geckos could also affect our abundance estimates.

The very high population size estimates for the final period (Tables 2-3; Fig. 4) may be due to uncertainty in our data, since so few individuals were recaptured in those periods. In Figure 4, the standard error bars on the population size estimates for those periods are quite large, indicating that the estimates are uncertain. Large error bars over the course of the study mean that we cannot determine anything definitive about changes in population size. Additionally, the Cormack-Jolly-Seber estimate correlates well with sample size. It is uncertain whether this reflects some statistical bias or a legitimate biological relationship (e.g., we would expect to capture more individuals if there were more present in the population).

This population of geckos survived the winter, successfully reproduced, and likely grew in number, which indicates that this species is able to establish populations in locations more temperate than most of its introduced range. This means that further range expansion is likely. Indeed, this population could very well serve as a source of further introductions by jump dispersal since one retaining wall is located only a few meters from a lot where semi-trucks with open trailer doors are often parked. Future studies could further elucidate Mediterranean Gecko demographics in temperate areas and determine typical means of accidental transport to better halt spread of this nonnative species.

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TABLES

Table 1. Blocking scheme for robust design analysis.

Period	Date Range	Number of Sampling Occasions
1	Sept. 26, 2014 – Dec. 1, 2014	3
2	Mar. 16, 2015 – Apr. 22, 2015	6
3	May 2, 2015 – May 31, 2015	5
4	June 7, 2015 – June 27, 2015	4
5	July 11, 2015 – July 24, 2015	2
6	Oct. 13, 2015 – Nov. 4, 2015	2

Table 2. Population size estimates from Cormack-Jolly-Seber analysis.

Sampling Occasion	Population Size Estimate	Standard Error
1	NA	NA
2	88.0	28.9
3	46.7	34.3
4	22.0	30.6
5	21.2	29.5
6	40.9	49.1
7	41.4	27.6
8	45.7	38.2
9	96.8	106.5
10	36.0	19.3
11	80.8	92.0
12	56.0	47.2
13	56.5	28.8
14	39.9	25.4
15	63.4	53.7
16	81.1	66.5
17	60.0	36.0
18	35.9	19.4
19	41.9	27.0
20	50.9	23.1
21	808.3	826.7
22	1250.2	1273.4

Table 3. Population size estimates from robust design analysis.

Primary Period	Population Size Estimate	Standard Error
1	95.0	21.2
2	55.1	16.7
3	49.8	10.5
4	40.4	10.2
5	41.3	23.9
6	784.0	756.0

FIGURES

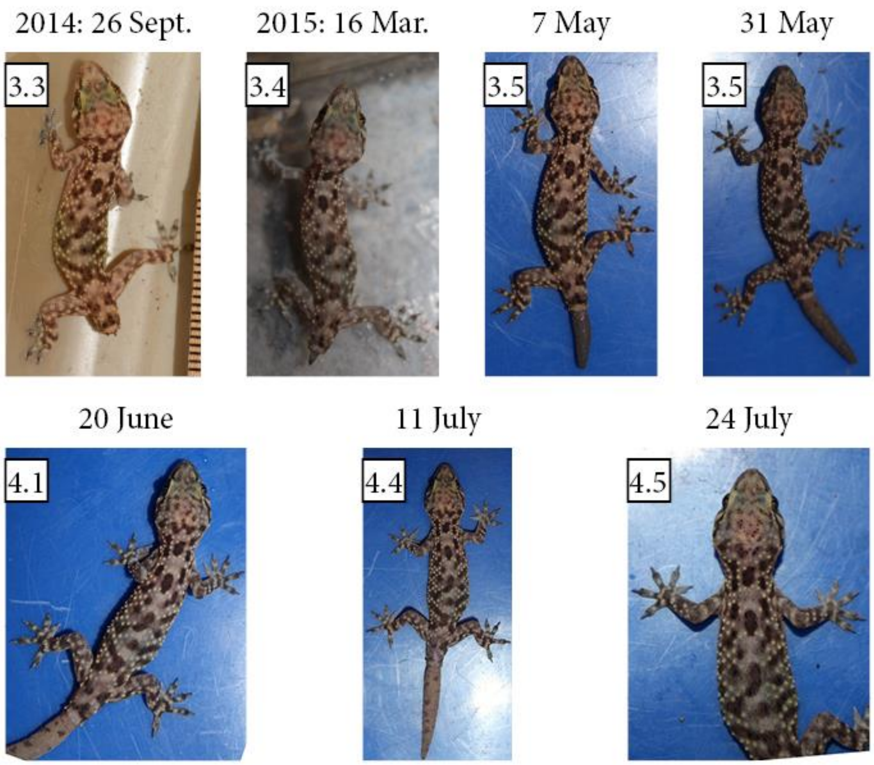

Figure 1. One individual recaptured over the course of the study with the date of each capture. SVL in cm is given in the inset in each photo. This individual evidently survived the 2014-2015 winter. (Photographed by Evin T. Carter and Chase L. Hively.)

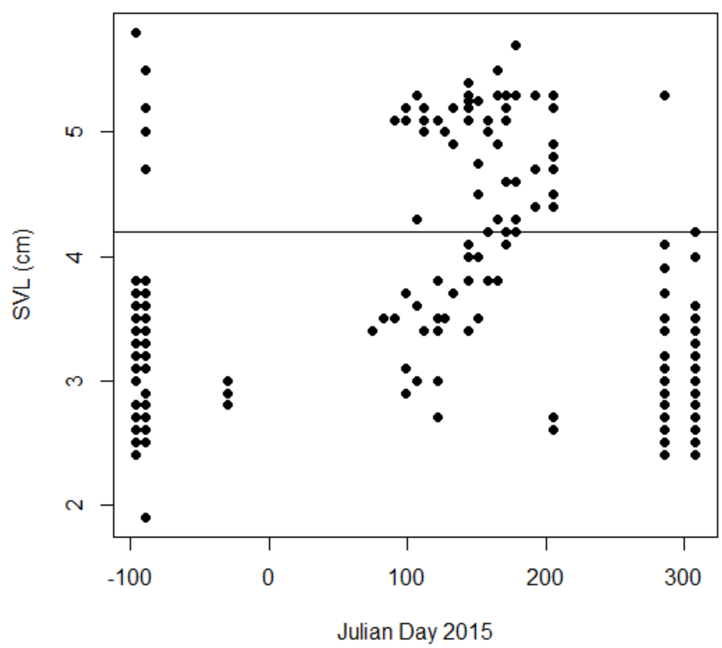

Figure 2. Snout-vent lengths of geckos over the study period. The horizontal line is at 4.2 cm, which we considered to be the size at maturity.

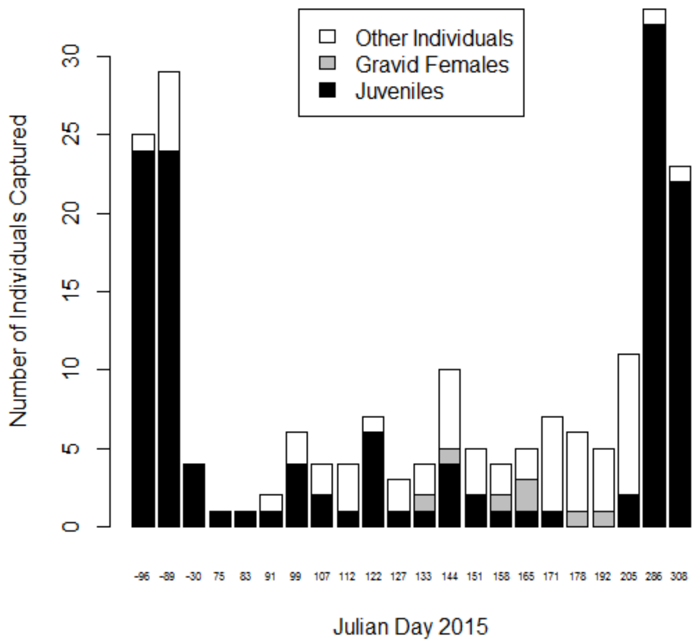

Figure 3. Numbers of juveniles, gravid females, and other adult geckos captured over the study period. All individuals per occasion add up to sample size.

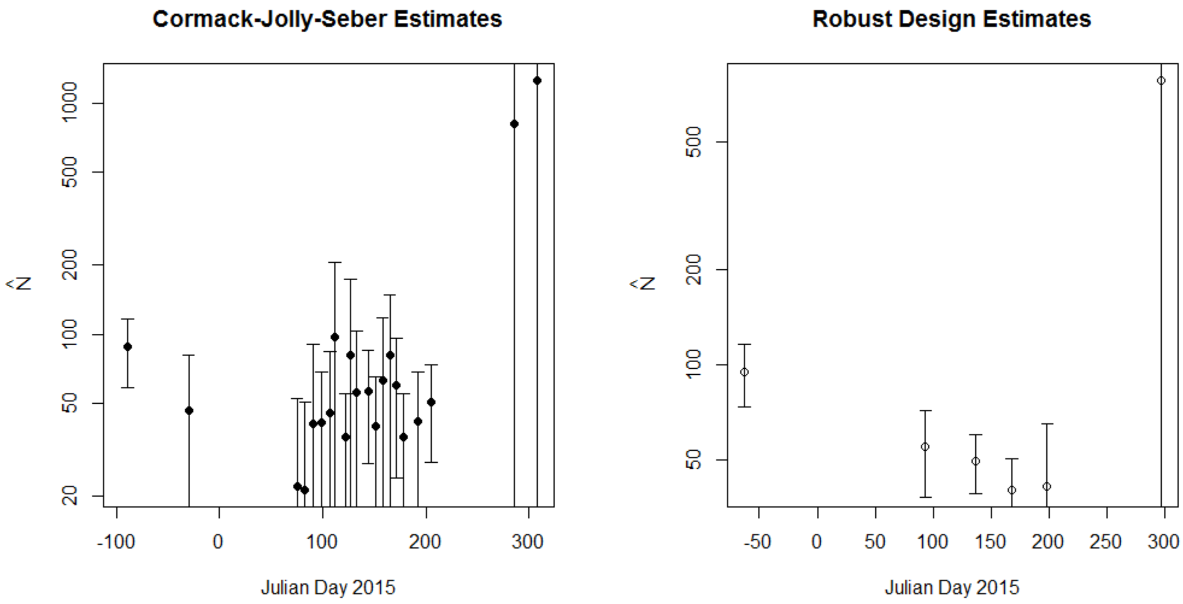

Figure 4. Population size estimates of Cormack-Jolly-Seber and robust design models with standard error bars. The y axes are on log scales.

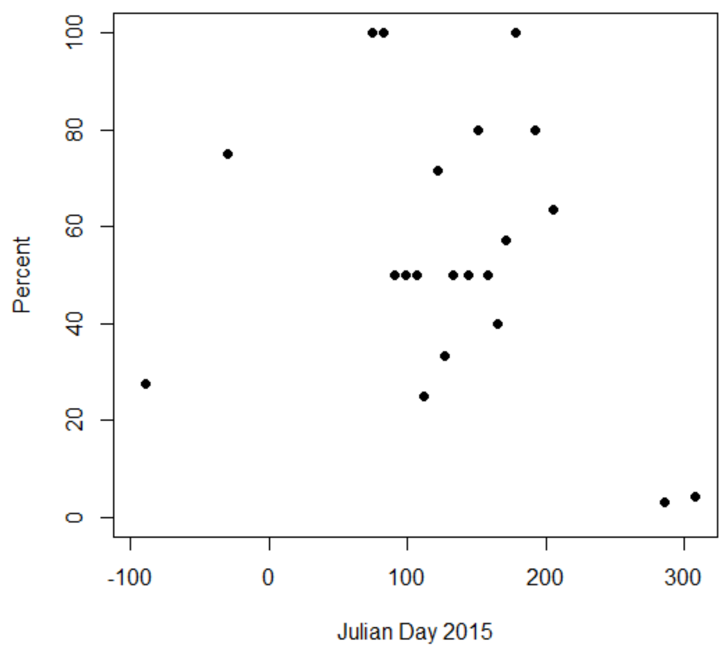

Figure 5. Percent recaptures over the study period.