Ecology, behavior and color variation of the green tree skink, *Lamprolepis smaragdina* (Lacertilia: Scincidae), in Micronesia

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Abstract—We studied populations of the green tree skink, *Lamprolepis smaragdina,* at three main sites in Micronesia: Pohnpei (Federated States of Micronesia, FSM) and Saipan and Tinian (Commonwealth of the Northern Mariana Islands, CNMI). We also surveyed Rota (CNMI), where the skink has not been recorded in previous surveys, to verify its absence. Our main goal was to describe some basic biology traits at these sites. Observations were carried out between 1993 and 1998. We used focal animal observations and visual surveys to describe the relative abundance, elevational distribution, behavior (perch choice, foraging behavior, activity time), and coloration of the species at each of the three sites. This information was then used to compare these populations in order to assess the origin of the CNMI populations.

As expected, we found no green tree skink on Rota. We found few differences among the three populations we did locate, Pohnpei, Tinian, and Saipan. Perch diameters and body orientations were similar between the three sites, as were population densities and foraging behaviors. However, Tinian's lizards perched lower than those of Pohnpei or Saipan, probably due to the smaller trees available to them. All CNMI lizards were green, whereas this morph typically comprises 40–60 percent of the population at FSM localities. These findings suggest isolation has allowed no differences in behavioral or ecological traits to evolve. We interpret the differences in color to indicate a small initial settling population in the CNMI (founder effect), consistent with an anthropogenic origin for the population and with low dispersal ability for the species.

Introduction

The green tree skink *Lamprolepis smaragdina* is widely distributed from Taiwan and the Philippines southward and eastward, through the Indo-Australian Archipelago, to northern Australia (Cape York), the Solomon Islands, Santa Cruz Islands, and to easternmost parts of Micronesia (Greer 1970, Manthey 1985). Throughout this wide geographical range it is diurnal and predominantly arboreal, only infrequently encountered on the ground (Reyes 1957, Brown & Alcala 1980, Buden 1995, 1996a,b). The diet is primarily composed of invertebrates. Lepidoptera and Hymenoptera accounted for nearly 50 percent of prey volume reported by Reyes (1957), and bees were reportedly eaten at a feral hive (Wiles & Conry 1990). Auffenberg & Auffenberg (1988) also found Coleoptera to be important in the diet. Ripe fruit is also sometimes taken, both in the Philippines (Auffenberg & Auffenberg 1988), in the Solomon Islands (McCoy, 1980), and in the Marianas (C. L. Raulerson, pers. com.). Vertebrates may also be taken at times, and at least one case of a small bird's nest being raided is known (T. Pratt, pers. com.). It is one of the larger skink species in the region, having a typical adult snout-vent length of 100 mm.

Although *L. smaragdina* can reach high densities in some locations (Buden 1996b), there have been few reports on the biology of this species. Buden (1995, 1996a,b) has briefly described some aspects of its ecology in the eastern Carolines, but little or nothing has been reported on reproduction, foraging behavior, or social structure. Even less is known about its biology in the Marianas, where it occurs on Saipan and Tinian (Rodda et al. 1991), reportedly the result of early introductions via canoe from the Caroline Islands (Eldredge 1988). An irresponsible attempt to establish a population on the campus of the University of Guam occurred in the late 1960s. Luckily, it was unsuccessful (Eldredge 1988, C. L. Raulerson, pers. com.). The failure to establish on Guam was presumably a result of predation by brown tree snakes (*Boiga irregularis;* Rodda et al. 1991) The reason why it had only been recorded from Rota once (Eldredge 1988) is unclear. Three possibilities are: 1) *L. smaragdina* never arrived there, and the one reported record is erroneous; 2) it arrived on Rota but failed to successfully establish itself; or 3) existing populations were not noticed during most previous surveys.

The goal of this study was to report on aspects of the behavior and ecology of *L. smaragdina* over a large part of its distribution. We therefore studied the populations of Pohnpei (Federated States of Micronesia, FSM) and the Commonwealth of the Northern Mariana Islands (CNMI), thereby covering widely separated areas within Micronesia.

Materials and Methods

SITES

Field work concentrated on Pohnpei, state of Pohnpei, FSM, and on Tinian and Saipan (CNMI). General descriptions of these islands are available elsewhere

(FSM: MacLean et al., 1986; Buden 1995, 1996a,b; Saipan: Wiles & Guerrero 1996; Tinian: Wiles et al. 1989; see also Mueller-Dombois & Fosberg 1997). Briefly, Pohnpei (approximately 7° N) has an area of about 350 km². Saipan (approximately 15° N) has an area of 123 km², Tinian (also approximately 15° N) of 102 km², and Rota (approximately 14° N) of 84 km². The atolls mentioned (but not surveyed in this study) have an area <2 km². Maximum elevation on the atolls is 3–4 m, on Tinian it is 178 m, and on Rota, Saipan, and Pohnpei over 450 m. Saipan and Pohnpei have population in excess of 30,000 people, Tinian of about 2,500, Rota of about 1,500, and the atolls all have 500 or fewer residents. CNMI sites were typically covered with tangantangan (*Leucaena leucocephala*), a ubiquitous introduced disordered tree normally reaching 5–10 m (Raulerson & Rinehart 1991). Pohnpei sites were generally more pristine, with tree cover that was both taller and much more diverse. *Cocos* forest predominated on the atolls, often with *Scaevola* and *Tournefortia* coastal scrub areas. Average annual rainfall for the CNMI is around 202 cm, for Pohnpei over 480 cm.

DATA COLLECTION

We conducted our study between 1993 and 1998. Our own observations were augmented by data from the literature and discussions with various local biologists. Lizards were observed in different habitats, at various hours of the day and (in the CNMI) during both the dry and wet seasons. In Pohnpei we conducted a systematic survey of major habitat types (Table 1). We visited Rota five times in 1997 and 1998. Foot and vehicular surveys of much of the island, as well as discussions with local biologists, were used to seek green tree skinks. Special attention was given to the area immediately around the port and airport, where such an arrival, if recent, would presumably have originated. Less comprehensive surveys were carried out in the rest of the CNMI. Relative abundance was

Table 1. Observation rates of *Lamprolepis smaragdina* on Pohnpei.

Habitat	Elevation zone (m)	Lizards/ hr	Search time h	Search time %	% of total Observations
Mangroves	0	2.5	4.0	6	11
Atoll forest[a]	1- 4	3.5	6.8	10	26
Marsh	1- 10	0.0	2.9	4	0
Road-side	1-100	1.3	7.1	10	10
Dw/Sv[b]	1-200	1.4	13.3	20	19
Agroforest[c]	1-200	1.8	13.1	19	24
Grass/fernbrake	1-600	2.4	3.8	6	10
Rainforest	150-600	0.0	13.3	20	0
Dwarf forest	600-800	0.0	3.3	5	0

[a] Atoll forest occurs mainly on low, flat, lagoon islands, It is comprised of *Cocos* and broadleaf trees with varying amounts of coastal shrub.

[b] Disturbed woodland/secondary vegetation.

[c] Agroforest is native forest modified to accommodate crops such as banana (*Musa*), breadfruit (*Artocarpus*), coconut (*Cocos*), taro (*Calocasia* and *Cyrtosperma*) and tapioca (*Manihot*). Many native trees are left standing.

estimated using linear visual transects. Counts of all specimens visible from the path of the single observer were conducted during daylight hours, both in the forest interior and at forest-edge along the strand line. Survey distances (Tables 1, 2) were estimated from USGS maps of each location. We noted the elevation at each of our transects, and used that information to assess the effect of elevation on *L. smaragdina* presence.

Behavioral observations were conducted during walking surveys of appropriate habitats. Foraging behavior observations were conducted using the methods of Huey & Pianka (1981) and Perry et al. (1990). We calculated the two most commonly used indices of foraging behavior, number of moves per minute and percent of time spent moving (Perry 1995). Care was taken to observe only animals that were primarily foraging, avoid eliciting a flight response in focal animals, and record observations for each animal only once. For studies of relative abundance, perch choice, and color variation we similarly recorded each animal only once by only using each transect once.

Lamprolepis smaragdina is known to be active during the day. To test for the possibility of nocturnal activity around human habitations, we surveyed thirteen mahogany trees (*Swietenia macrophylla*), in Kolonia, Pohnpei. Most trees exceeded 1 m in diameter at breast height. Trees flanked a walkway that traverses the Pohnpei state campus of the College of Micronesia. Two of them had exposed, incandescent light bulbs, mounted on 15 x 30 cm pieces of wood set about 3–4 m high on the trunk. A sloping, wooden rain guard was attached above the bulb. We did not conduct similar work in the CNMI. Clearly such situations are artefactual,

Table 2. Estimates of *Lamprolepis smaragdina* relative abundances obtained from visual surveys in Pohnpei State, Federated States of Micronesia, and Rota, Tinian and Saipan, Commonwealth of the Northern Mariana Islands. Data for atoll islands are from Buden (1995, 1996a, 1996b)

Locality	Survey distance (km)	Relative abundance (lizards/km)
Ant Atoll	10.2	5.9
Pohnpei		
urban[a]	6.5	2.5
rural[b]	8.6	6.5
Mokil Atoll	5.5	4.6
Pakin Atoll	10.5	4.5
Pingelap Atoll	6.0	3.0
Rota	>15	0.0
Saipan	4.3	7.3
Tinian	1.0	2.0

[a] In yards, vacant lots, and along tree-lined paved roads in Kolonia.

[b] On the edges of disturbed habitats along gravel roads and foot trails in Madolenihmw Municipality.

and we were interested in demonstrating that such activity can occur, not in comparing its frequency between the FSM and CNMI.

Results

Despite considerable effort, we did not find the green tree skink on Rota, nor did we talk to any local biologists who have ever seen it. In Pohnpei, *L. smaragdina* was common throughout the lowlands. It is apparently scarce or absent in upper montane forest, and all recorded observations during the island-wide herpetological survey conducted in the summer of 1995 were below about 200 m. Failed attempts to locate green tree skinks at one higher location on Saipan (Suicide Cliff, 250 m) corroborated these findings. Relative indices of abundance obtained from visual surveys ranged from 2.0 lizards/km on Tinian to 7.3/km on Saipan (Table 2). In many cases, several (up to seven) individuals were encountered on a single tree, with larger trees typically hosting more lizards; *Leucaena* forest was typically poor in skinks at all study sites.

Lamprolepis smaragdina were active during the daylight hours in all locations. At non-lighted sites, and at ones where only diffuse lighting was available at night, we observed no nocturnal behavior. However, up to three skinks were frequently observed at night on the brightly lit trees on the Kolonia campus of the College of Micronesia, Pohnpei. This is the first documented examples of opportunistic night-light feeding in this species. Animals were actively feeding on small insects (mainly microlepidoptera) drawn to the light. Most of these sightings were within two hours after sunset, but at least two of the observations were at about midnight, and several just at dawn. No skinks were observed on any of the adjacent (unlighted) trees at these times, although as many as four were observed together on these same trees during the day.

During the day, *L. smaragdina* were typically seen perched about 1–5 m high on tree trunks in open, sun-exposed areas (Table 3). On Pohnpei, 9 percent of skinks were observed on low perches (0–0.9 m above ground), 69 percent on mid-level perches (1–6.9 m) and 22 percent on high perches (7 m and above). Similar values were obtained on Saipan (16, 70, and 14 percent at low, medium and high perches, respectively), but Tinian values were lower (62, 38, and 0 percent at low, medium and high perches, respectively). Perch heights were significantly different between the sites (F = 6.845, df = 2,92, 2-sided p = 0.002, ANOVA). A post-hoc Student-Newman-Keuls test showed no difference between Pohnpei and

Table 3. Perch heights and diameters of *Lamprolepis smaragdina* observed at three study sites in Micronesia.

Locality	Perch height (m)			Perch diameter (cm)		
	Average	SD	N	Average	SD	N
Pohnpei	3.78	2.93	32	37.4	35.34	35
Saipan	2.72	2.26	50	29.4	21.78	42
Tinian	0.89	0.95	13	37.0	26.12	19

Table 4. Dorsal color variation in three populations of *Lamprolepis smaragdina* from Pohnpei State, Federated States of Micronesia, and from Tinian and Saipan, Commonwealth of the Northern Mariana Islands. "Intermediate" individuals were brownish green, greenish brown, or yellowish brown.

Locality	Green		Brown		Intermediate	
	Number	Percent	Number	Percent	Number	Percent
Ant	32	41	19	24	28	35
Pakin	69	63	18	16	23	31
Pohnpei	52	61	7	8	26	31
Saipan	84	100	0	0	0	0
Tinian	21	100	0	0	0	0

Saipan perch heights, but both differed significantly from Tinian's. Perch diameters were similar at the three sites. Small perches (up to 9 cm diameter) comprised 16 percent on Tinian, 5 percent on Saipan, and 11 percent of perches used on Pohnpei. Medium perches (10–39 cm) comprised 63, 52, and 69 percent, respectively, at these sites, and thick perches (over 40 cm) comprising 20, 43, and 20 percent of all perches at the three sites, respectively. Average perch diameter did not differ among the three sites (Table 3; $F = 0.598$, df = 2,92, 2-sided p = 0.55, ANOVA). Of the 33 individuals for which body orientation was recorded on Pohnpei, 23 (70%) were facing down the trunk and the 10 others were facing up. Results for the CNMI were similar, with 60% of Saipan and 67% of Tinian lizards facing down. Orientations were not significantly different among the three sites ($x^2 = 2.53$, df = 4, 2-sided p = 0.64).

Green was the most common dorsal coloration at all study sites (Table 4). It accounted for 56% of 274 animals observed in the FSM and for all 105 animals observed on Tinian and Saipan. No other color has ever been observed in the Marianas (E. W. Campbell III, T. H. Fritts, G. H. Rodda, S. R. Vogt, pers. com.). The difference between FSM and CNMI was highly significant ($x^2 = 68.12$, df = 2, 2-tailed p<0.0001).

We observed a total of 76 *L. smaragdina* foraging (Table 5). Without exception, all feeding events involved arthropods. Most prey items were small, but one lizard was seen eating a praying mantis almost as long as its own body; it took over eight minutes to consume this item. Statistical comparisons were not carried out with Tinian lizards because of the small sample size and the intermediate values between those of Saipan and Pohnpei lizards. There were no significant

Table 5. Foraging indices of *Lamprolepis smaragdina* observed on Pohnpei, Federated States of Micronesia, and on Saipan and Tinian, Commonwealth of the Northern Marianas. MPM: moves per minute, PTM: percent of the time spent moving.

Locality	MPM		PTM		N
	Average	SD	Average	SD	
Pohnpei	1.67	1.57	12.93	15.68	33
Saipan	1.34	1.56	10.55	13.18	38
Tinian	1.60	2.39	11.40	16.40	5

differences between the FSM and CNMI populations in number of moves per minute (t = 0.886, df = 69, p = 0.39) or in the percent of the observation time spent moving (t = 0.695, df = 69, p = 0.50; 2-tailed t-tests).

Intraspecific interactions observed included courtship and, most commonly, short chases of one individual by another. The cause for these bouts of aggression was not clear, though they were usually initiated by a larger individual approaching and displacing a sedentary smaller one. Few interspecific interactions were seen.

Discussion

As expected from previous reports (Brown & Alcala 1980, Manthey 1985, Auffenberg & Auffenberg 1988, Reyes 1957), we found *L. smaragdina* to be primarily a diurnal tree-dwelling species. Like our experience at all but one location, Reyes (1957) observed no night feeding during his year-long study of the feeding habits of this species in the Philippines. The term "night-light niche" was coined by Schwartz & Henderson (1991) for the nocturnal feeding activities at artificial lights by typically diurnal lizard species. McCoid & Hensley (1993) listed eight species in this category, seven of which are anoles (genus *Anolis*), the other a skink (*Cryptoblepharus poeciliopleurus*) collected under porch lights on Cocos Island, off Guam, Mariana Islands. The green tree skink is the latest addition to this list, which we expect will continue to grow. Whether the same lizards were active throughout a 24-hour period or specializing in night-feeding remains unknown, and worthy of further study.

Also as predicted (Brown & Alcala 1980, Auffenberg & Auffenberg 1988), we found these lizards exclusively at lower elevations throughout the range we covered. However, the one high-elevation site we inspected on Saipan may have been lizard-free primarily due to habitat considerations (see below), and green tree skinks may be found at other higher sites in the CNMI. Like McCoy (1980), Wiles & Conry (1990), and Wiles & Guerrero (1996), we found the skink mostly on large tree trunks and rarely on smaller trees or on the smaller branches of large trees. *Lamprolepis smaragdina* perch heights were similar between Saipan and Pohnpei, perch diameters were the same at all sites, and we found no differences in lizard orientation between the three sites. The lower perch height observed on Tinian we attribute to the lower forest height there, rather than to any active choice on the part of the lizards.

Relative lizard abundances obtained in visual transects on Pohnpei and in the CNMI were broadly similar, and matched those reported from atolls associated with Pohnpei (Buden 1995, 1996a, 1996b). However, these summaries may be somewhat misleading, as they mask large variations within a locality. For example, Buden (1996b) counted 22 *L. smaragdina* on a 300m transect (73.3 skinks/km) through a *Pisonia* and *Terminalia* forest on Temwena, Pakin Atoll, and 33 individuals in an 800m transect (41.3/km) in *Cocos* forest on Nikelap. A much higher value was recently obtained by Buden (1999), who observed 170 individ-

uals of *L. smaragdina* for each one km stretch on Oroluk Atoll, state of Pohnpei, FSM. In the CNMI, *Leucaena* transects typically contained few or no green tree skinks, similar to the observation of Wiles & Guerrero (1996). Rodda & Fritts (1998) calculated a density estimate on Saipan, based on four 10x10 plots where the vegetation was completely removed and all resident lizards were counted. They found plots covered with *Leucaena* averaged 50 green tree skinks (0.66 kg biomass) per hectare, compared to zero for native forest. However, one of the two *Leucaena* plots had no *Lamprolepis,* and the native forest plots included few large trees (Rodda & Fritts 1998). At the same time, survey rows of larger ornamental trees planted for beautification purposes in the CNMI resulted in densities as high as 11 individuals/100 m. Visual surveys are known to be highly sensitive to a large number of factors, including observer experience, forest structure, and seasonal effects on lizard activity (G. H. Rodda, pers. com.) This makes statistical comparisons between these sites pointless, but still allows rough generalizations to be made. In our case, relative densities in native forest at Pohnpei State locations were higher than those at non-ornamental forest habitat in the CNMI. This is consistent with previous observations that these skinks prefer larger trees (Wiles & Conry 1990; Wiles & Guerrero 1996). Unfortunately, our data could not be compared to those of Wiles & Conry (1990) for Palau, because we used a different index of abundance than theirs.

On Chuuk (also in the FSM), Kepler (1994) reported at least 13 color morphs of *L. smaragdina;* About 66 percent of color-noted individuals were green. McCoy (1980) listed bright green and olive green as the colors commonly observed in various parts of the Solomon Islands. We suspect color is genetically determined in this species, and interpret the absence of color polymorphism in the CNMI population as resulting from a small founder population and low genetic variation. Alternatively, CNMI populations may have originated from an all-green population elsewhere, but we are not aware of any such location.

Foragers are often divided into two artificial categories, active (or widely foraging) and sedentary (or sit-and-wait) (Perry & Pianka 1997). Foraging indices (moves per minute, percent time moving) obtained at all locations placed the green tree skink into the widely foraging category typical of other members of the family Scincidae. This supports the claim such behaviors have a large phylogenetic component (Perry 1995).

Our observations show little variation in most of the attributes we studied between FSM and CNMI populations. The one exception is color, which suggests low levels of genetic variance within CNMI populations. How this should be interpreted depends on when *L. smaragdina* arrived in the CNMI. All sources agree the presumptive origin of the CNMI populations was anthropogenic. Presumably, people only brought a small number of the lizards with them, making for low genetic diversity and potentially explaining the lack of color diversity. The skink never reached Guam naturally, even before the brown tree snake arrived there. On Tinian it is still limited to the center of the island, near the port (Wiles et al. 1989; Perry, unpublished). Eldredge (1988) reports *L. smaragdina* on

Rota, citing no specimens or previous records. However, Wiles et al. (1990) did not record it there, nor could we find any specimens or local biologists who have ever encountered it, leading us to suspect the skink may never have been found on Rota either. This pattern supports the notion *L. smaragdina* is a poor natural disperser. Under this scenario, a small (green) founder group arrived on Saipan, probably only once. Thus, the CNMI population is likely to be highly genetically homogenous.

If CNMI and FSM populations have been separated for hundreds of generations, as Eldredge (1988) thought, then we would have expected isolation to cause genetic divergence between the two groups. Since many behaviors are genetically controlled, this could result in differences between behaviors observed in the FSM and CNMI. Wiles et al. (1989) and Wiles and Guerrero (1996), on the other hand, suggested a much later arrival date on Saipan and Tinian, probably in the 1970s. The lack of behaviorial differences between skinks in the CNMI and Pohnpei is consistent with this suggestion. If the origin of *L. smaragdina* in the CNMI is relatively recent, the time was too short for behaviorial differences to evolve due to genetic isolation alone.

Acknowledgements

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