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Distribution and habitat of the endangered Mariana skink, *Emoia slevini*, on Islan Dåno′, Guam[1]

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Abstract— The Mariana skink (*Emoia slevini*) is a federally endangered lizard whose ecology is poorly known. It was considered extirpated on Islan Dåno′, Guam, but was rediscovered there in 2012. Here, we delineate its distribution as of 2017-2018, describe its habitat use, and evaluate density of the more common Pacific blue-tailed skink (*Emoia caeruleocauda*) as an indicator of habitat suitable for *E. slevini*. We conducted visual encounter surveys across Dåno′ followed by intense surveys for *E. slevini* throughout all areas of the forest type where it was first detected. Geospatial analysis showed a limited distribution of individuals in area constituting 6.2–12.8% of the island's total area. Overlay of *E. slevini* locations (n = 199) on a digital vegetation/land cover layer revealed that, under conditions of complete spatial randomness, it was over-represented in Coconut Forest, followed by Mixed Introduced Forest, and underrepresented in three other vegetation classifications. This analysis, when conducted for *E. caeruleocauda* (n = 296), revealed a similar pattern. An investigation into the association of *E. slevini* locations with individual coconut palms digitized from aerial imagery revealed a positive clustering of individual *E. slevini* at the 99% confidence level nested within the 90-99% level for palms, indicating the importance of this tree species on a landscape scale. Analysis of perch types showed downed palm debris (dead fronds and coconuts) were the most frequently used perch types, demonstrating the importance of this tree at the microhabitat scale. Although widespread on Dåno′ in the 1950's, Coconut Forest is presently the most limited forest type constituting only 1.2% of the island's total area. A comparison of hot spot clustering for the two lizard species revealed that clustering for *E. slevini* was nested within the 90-99% level for *E. caeruleocauda*, further supporting the feasibility of using density of *E. caeruleocauda* as an indicator of habitat favorable for *E. slevini*.

Introduction

The Mariana skink, *Emoia slevini*, is one of two reptile species endemic to the Mariana Islands (Brown 1991, Weijola et al. 2020). Brown & Falanruw (1972) described *E. slevini* from the holotype and paratypes collected on Islan Dåno′ (Cocos Island; hereafter Dåno′), a 37-hectare island 1.6 km off the southwestern coast of Guam, and additional paratypes collected on Guam proper (one individual), Rota (two individuals), and Tinian (one individual) in 1945, 1945, and 1946, respectively. Subsequent herpetological surveys on Guam, Rota, and Tinian have failed to detect *E.*

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slevini and it is now considered extirpated on those islands (Rodda et al. 1991). Since its original first description, *E. slevini* has been recorded from the islands of Alamagan, Asuncion, Pagan, and Sarigan in the Northern Mariana Islands. Reports of *E. slevini* from Maug and Guguan apparently stemming from Fritts et al. (unpublished) have been propagated in the literature despite there being no known museum vouchers or reports from either island. The apparent extirpation of *E. slevini* on Guam, Rota, and Tinian is enigmatic, considering the findings of Pregill (1998) and Steadman (1999). They determined, through examination of fossil remains, that *E. slevini* was once the most abundant skink species present at sites they examined on Rota, Tinian, and Aguiguan. Surveys for lizards conducted on Aguiguan in 2002 and 2008 did not detect *E. slevini* (Esselstyn et al. 2003, U.S. Fish and Wildlife Service 2008). Due of the extirpation of *E. slevini* on the larger islands where it formerly occurred and the uncertain status of populations on the more northern islands where it has been documented more recently, the United States Fish and Wildlife Service listed *E. slevini* as endangered in 2015 (U.S. Fish and Wildlife Service 2015). The U.S. Fish and Wildlife Service has not yet designated critical habitat for *E. slevini,* but a Species Report (Richardson & Amidon 2020) and Recovery Plan have been completed (U.S. Fish and Wildlife Service 2022). A Recovery Implementation Strategy is in preparation (T. Willsey, pers comm).

Brown & Falanruw (1972) made no mention of the geographic extent or abundance of *E. slevini* on Dåno′ in their original description of the species. Similarly, McCoid et al. (1995) did not report where they encountered *E. slevini* on Dåno′, reporting only that capture rates for *E. slevini* in sticky traps were much lower on Dåno′ than on Alamagan and Asuncion (9 individuals in 1988-1993, one individual 1988, and 21 individuals in 1988, respectively). McCoid (1996) determined that *E. slevini* was the least common skink species on Dåno′ and it has not been reported there since then. The skink had been presumed extirpated there by the early 2000’s (see U.S. Fish and Wildlife Service. 2015).

It was a surprise then when *E. slevini* was observed on Dåno′ in 2012 at one location in closed canopy forest (Lardner, in litt.), offering a new opportunity to collect information on this species and an isolated population. Genetic analyses confirmed that these recently observed “*E. slevini”* are *E. slevini* and not a hitherto unknown species (Richmond et al. 2021). The objectives of the present study were to: 1) delimit the current geographical extent of *E. slevini* on Dåno′, 2) describe its habitat use with respect to recognized vegetation and land cover classifications and microhabitat features, and 3) assess the suitability of using density of a more common forest skink, *E. caeruleocauda*, as an indicator of suitable habitat for *E. slevini* that could then inform reintroduction efforts on islands where *E. slevini* is extinct.

Materials and Methods

Observations on *E. slevini* were conducted on Dåno′ (Fig. 1) during daylight hours every 1-2 weeks from May 2017 to May 2018 under fair weather conditions when lizards were active. All work was based on visual encounters. Determining sex of individuals from a distance was not possible because sexual dimorphism, though presumably apparent in adults, was not discernable to us at any body size. Initial work consisted of searching visually for *E. slevini* at the forested location where it had recently been rediscovered (Lardner, in litt.) to develop a search image and ability to reliably distinguish it from other sympatric skink species. Two other terrestrial skink species are common in the same habit as *E. slevini* and can be of comparable size and coloration depending on age. The dorsal ground color of *E. slevini* is medium to dark brown. A patternless form of the *E. caeruleocauda* is common on Dåno′ and dorsal coloration of adults may also be medium to dark brown with no blue on the tail, particularly in adult males. The non-native curious skink, *Carlia ailanpalai*, is now the most abundant and widespread skink species on the island. This species also has a uniform dorsal color of medium to deep brown. All three species are diurnal, occur in the same habitat, and are primarily surface active. Visual differentiation among species was made using a suite of morphological characters unique to *E. slevini* that, with practice, could be discerned from a distance. These characters included dark flecks and light yellow-orange flecks scattered over the dorsum (all juveniles and some adults), a relatively small head, and eyes that appear dark-colored throughout. Adult *E. slevini* could be differentiated from all other species based on their relatively large body size.

To determine distribution of *E. slevini* and *E. caeruleocauda* on Dåno′, we conducted visual searches along transects spaced approximately 30 m apart, oriented North-South across the entire island exclusive of habitats where these species are unlikely to be found or those where vegetation was impassable (Fig. 2A,B). Because transects were not pre-established, distance between transects and their direction often varied considerably due to vegetative obstructions. When a surveyor approached shore as indicated by presence of strand vegetation (south side of island) or sandy beach (north side of island), the survey track was continued east or west to where the next north-south transect would begin. Habitats that do not support *E. slevini* that were not surveyed include the maintained grounds of the resort, beach, and strand vegetation. There were three areas on the island covered in dense and impassable thickets of *Colubrina asiatica* that may support *E. slevini,* but they were not surveyed because accessing would have required cutting and clearing transects resulting in novel edge habitat. The geographic location of each *E. slevini* and *E. caeruleocauda* was recorded in Universal Transverse Mercator coordinates (North American Datum of 1983) at an accuracy of ± 3 m using a hand-held global positioning system (GPS) unit (Model GPSmap 60CS, Garmin International Inc., Olathe, KS). Lizard transects were surveyed once and their completion required three visits to the island, conducted between March 24 and April 8, 2018.

Upon completion of these surveys, we characterized the general forest type where *E. slevini* was encountered. This forest type consisted of closed canopy dominated by *Cocos nucifera*, *Hernandia sonora*, *Thespesia populnea*, *Morinda citrifolia* and *Carica papaya* with an occasional large *Casuarina equisetifolia*. The understory was sparse and the forest floor mid-morning to late afternoon was always dappled with patches of sunlight, cloud cover permitting. We then conducted intensive visual searches throughout all such areas of forest on the island recording the location of each *E. slevini* observed with the GPS. A conservative bounding polygon for the point distribution of all individual *E. slevini* observed was constructed using the minimum concave hull tool in the Data East XTools Pro extension (12.0.1745) for ArcGIS 10.7.1. (ArcGIS 10.7.1, ESRI 2019). A less restrictive bounding polygon was fitted to the points using the minimum convex hull tool in ArcGIS.

To identify vegetation and land cover classifications where *E. slevini* and *E. caeruleocauda* were observed we used ArcGIS to overlay locations of individual lizards on a vegetation and land cover map developed for the Mariana Islands (Amidon et al. 2017). Vegetation classification descriptions and accuracy assessments from Amidon et al. (2017) are provided in Table 1. Classifications used herein are only those where lizards were observed or surveyed. The three large patches of *C. asiatica* thicket on the island were not captured in the classification and were therefore mapped with the GPS, converted to polygons, and used to clip the other vegetation and land cover polygons to their revised boundaries. The Feature Vertices to Points tool in ArcToolbox was used to extract lizard location points by species from the polygons. Polygon areas and point counts within polygons were then summed by species by vegetation and land cover category. Vegetation and land cover categories where we did not survey for lizards either because habitat was known to be unsuitable for these species, was physically impassable during surveys, or where no lizards were encountered, were not included in the analysis. An exception was a narrow polygonal area of Developed Vegetation on the windward side of island that was judged suitable for forest skinks and therefore surveyed ("Developed Vegetation Survey"). These data allowed us to calculate lizard point counts that could be expected within each vegetation and land cover under complete spatial randomness. The expected count number for a vegetation and land cover category is computed as the total number of lizard observation points in a category multiplied by the proportion of area covered by a habit category. Chi-square goodness of fit tests were performed by species to examine the association between vegetation and land cover category and lizard point count. Following a statistically significant omnibus test for the chi-square statistic, multiple comparison tests were conducted to determine which land cover categories contributed to the global statistical significance using the ‘chisq.theo.multcomp ‘ test in the R package ‘RVAideMemoire’. This test performs pairwise comparisons for the specified probabilities (observed and expected) and adjusts *p*-values for false discovery rate (Hervé & Hervé 2020). To illustrate how *E. slevini* and *E. caeruleocauda* points are over- or underrepresented in different land cover categories, a relative count index was calculated as follows:

$$c(O,E) = \left\{ \begin{array}{ll} \underline{\quad 0 \quad} & ,\text{if } O + E = 0 \\ \dfrac{o - E}{o + E} & ,\text{if } O + E > 0 \end{array} \right\}$$

Where *c* is the relative count index; *O* is the number of observed points falling in a land cover category; *E* is the expected number of points falling in that land cover category. The relative count index values range between +1 and −1 (exclusive) where a positive *c* means over-representation (i.e., more observed points than expected under CSR) and a negative *c* means the opposite.

During fieldwork we noted that both lizard species were often associated with downed vegetative debris from *C. nucifera* trees. To investigate a potential association between individual lizards of both species and palms, we used ArcGIS to heads-up digitize the location of each palm visible on a high-resolution (0.1 m) true color (R, G, B) 2013 aerial image in the SID/MrSID (Multi-Resolution Seamless Image Database) format georeferenced to WGS 84/UTM zone 55N obtained from Naval Facilities Engineering Command Marianas. Coconut palms may live up to 100 years of age (Chan & Elevitch 2006), thus most of the mature trees present when this imagery was taken were likely still present at the time of our surveys.

We then conducted separate hotspot analyses for both lizard species and palms using the “Optimized Hot Spot Analysis” tool in ArcGIS to assess potential clustering. All lizard location data were used in these analyses. This tool, using the Getis-Ord Gi* statistic, identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots) of lizard and palm presence. To determine whether locations of individual *E. slevini* and palms cluster similarly we compared the overlap in their hot spots. To evaluate the suitability of using distribution and density of *E. caeruleocauda* as an indicator of suitable habitat for *E. slevini* we compared the overlap in their hot spots.

For a large subset of the *E. slevini* observed, we recorded the perch type where an individual was first observed. Perch type has been used as one component of lizard microhabitat (Ribeiro & Sá-Sousa 2018.). Perch type was classified as either downed palm frond, downed coconut, downed dead wood, coral rubble, bare ground, or tree trunk, which collectively constituted the full range of perch types available where lizards were observed. All perches where *E. slevini* were observed were situated at or near ground level. We tested for differences in perch type usage frequency using a chi-square goodness of fit test (‘chisq.test’) in the ‘stats’ package for R. Following a statistically significant omnibus test for the chi-square statistic, multiple comparison tests were conducted using the ‘chisq.multcomp’ test in the package ‘RVAideMemoire’ (Hervé & Hervé 2020).

Because most areas on the island where we surveyed for *E. slevini* had to be surveyed repeatedly to register sufficient observations, and because lizards were not marked to permit reidentification, counts reported here almost certainly contain repeat observations on some of the same individuals. The resultant spatial distribution of observations should nonetheless give a good approximation of the current geographic extent of the population. Any bias in the other features analyzed were absorbed into the variance. All statistical analyses were conducted using R version 4.0.3 (R Core Team 2020).

We hypothesized that *E. caeruleocauda* presence should be a reasonable proxy suitable habitat for *E. slevini* because it is also a forest species that is most common in well shaded habitat (Buden & Taboroši 2016). On Dåno′ it was always present at sites where *E. slevini* was observed, although it also occurred in somewhat more open areas and oftentimes higher up in vegetation. All islands in the Mariana archipelago where *E. slevini* occurs, or once occurred, have extant native populations *E. caeruleocauda*.

Results and Discussion

A total of 12 *E. slevini* and 296 *E. caeruleocauda* were encountered during the initial whole island survey. This disparity in numbers was not due to a relative inactivity of *E. slevini* or our ability to detect them where present. The relative abundance calculable from these two totals is similar to those obtained using time constrained visual surveys for these species in the core area of *E. slevini* at the time of the present study (Mathies and Sablan, unpublished data). The spatial distributions of the *E. slevini* and *E. caeruleocauda* observed are shown in Fig. 2A and B, respectively. Locations for all *E. slevini* observed during this study (n = 199) are shown in Fig. 3A. The *E. slevini* were observed within an area approximately 646 m long immediately west of the resort and to the leeward side of the island. Minimum convex and concave polygons bounding locations of these individuals circumscribed areas of 4.3 ha and 2.1 ha, respectively (Fig. 3A). For jurisdictional purposes, the areas of minimum convex polygon on the government and privately owned sides of the island are 1.1, and 3.1 ha, respectively. The area of minimum concave polygon on the government and privately owned sides are 1.0 and 1.1 ha, respectively.

Locations of all *E. slevini* and *E. caeruleocauda* overlaid on the vegetation and land cover classifications of Amidon et al. (2017) are shown in Fig. 3B. Vegetation and land cover classifications where *E. slevini* were observed were Coconut Forest, Mixed Introduced Forest, Casuarina Forest, Developed Vegetation, and Scrub/Shrub. Those for *E. caeruleocauda* were the same as those for *E. slevini* except for observations registered in Scrub Forest, but not Scrub/Shrub. It should be noted that the Coconut Forest classification of Amidon et al. (2017) generally represents former coconut plantations, but their methods do not distinguish plantations from large natural stands, as is apparent from their maps of some of the Northern Mariana Islands at locations where plantations have never existed. The irregular spacing of trees within the area classified as Coconut Forest and throughout the rest of the island indicates that if any areas were once coconut plantation (see Fosberg 1960), the species has since reverted to a natural distribution.

Percent coverages for whole island vegetation and land cover classifications (10 classifications total) are provided in Table 2. Table 3 juxtaposes observed and expected lizard point counts for each species for the five vegetation and land cover classifications in which these species were observed. Overall, point counts differed significantly from expected counts across different land cover categories for both *E. slevini* and *E. caeruleocauda*, and except for *E. caeruleocauda* (Developed Vegetation, $p = 0.055$), all comparisons of expected versus observed counts contributed to the observed statistical significance of omnibus tests (Table 4). Fig. 4 shows the relative count indices for *E. slevini* and *E. caeruleocauda* for the five aggregated land cover categories. Both species were overrepresented in Coconut Forest followed by Mixed Introduced Forest but underrepresented in all other land cover categories. The pattern of over-/under-representation across land cover classifications was similar for both species, but over-/under magnitudes are more pronounced for *E. slevini*. That is, *E. slevini* tended to be more closely associated with Coconut Forest and Mixed Introduced Forest and less associated with the other landcover categories than *E. caeruleocauda*.

Visual representations for the results of the hotspot analyses for *E. slevini*, *E. caeruleocauda*, and palms are presented Fig. 5 A-C, respectively. Individuals of *E. slevini* exhibited a positive and significant positive clustering at the 99% level in one area just west of the resort grounds. Individuals were clustered to the extent that no cold spots were identified. Individuals of *E. caeruleocauda* presented a positive significant clustering at the 99% level in one large and one small area and four distinct cold spots, the largest of which were located on the eastern end of the island where large stands of *Casuarina* are prevalent. Palms presented a positive significant clustering at the 99% level in a large area on the leeward side of the island and clustering throughout the remainder of the islands was largely negative at the 99% level or insignificant in the band surrounding the positive clustering. Positive clustering of *E. slevini* at the 99% confidence level was largely contained within the positive clustering of palms at the 90-99% level (Fig. 6A). Like *E. slevini*, positive clustering of *E. caeruleocauda* at the 99% confidence level was largely contained within the positive clustering of palms at the 90-99% level (Fig. 6B). Last, with regards to the degree of spatial association between *E. caeruleocauda* and *E. slevini*, positive clustering of *E. slevini* at the 99% confidence level was almost entirely contained within the positive clustering of *E. caeruleocauda* at the 90-99% level (Fig. 6C).

Count data for perch type for *E. slevini* are shown in Fig. 7. The three most common perch types in decreasing order of frequency were palm fronds, coconuts, and dead wood. Representative photos of these perch types utilized by *E. slevini* and are shown in Fig. 8A-C. The omnibus test for the chi-square statistic for perch type was significant, as were the majority of post-hoc multiple comparison tests including that for palm fronds vs. coconuts (Table 5). Although we defined perch types based upon the immediate substrate where a lizard was resting, these perches typically constituted part of a larger deposition of downed vegetative or coral material that are likely of greater importance to an individual or group of individuals than "perch type" per se. The structural complexity of such depositions, however, would have been challenging to characterize. Representative examples of the types of debris depositions where *E. slevini* was typically observed are shown in Fig. 8A-C.

DISCUSSION

POPULATION DELINEATION

Visual surveys conducted along transects allowed us to quickly locate the primary area on Dåno′ where *E. slevini* occurs and characterize the forest type there. Subsequent surveys conducted in that forest type and its peripheral areas allowed us to more finely map the distribution of the species but were labor intensive given the low numbers of individuals observed on any given day. The fraction of *E. slevini* observed to *E. caeruleocauda* observed during the initial survey (12/296 = 0.041) provides a relative index of the scarcity of *E. slevini* which we believe is representative on Dåno′ at the time of our study. One of the main findings of our study is that the distribution of *E. slevini* on Dåno′ is presently quite limited with individuals observed only in relatively small area of forest (2.1 ha, minimum concave polygon or 4.3 ha, minimum convex polygon) located about midpoint of the length of the island and to the leeward (western) side. The area of land inhabited by *E. slevini* on the privately-owned side is approximately twice that on the government of Guam-administered side. Only habitat on the government-owned side of the island offers reliable protection from development or other disturbances and the most restrictive measure of habitat area there is only 1.0 ha (minimum concave polygon). Because historical reports of *E. slevini* do not specify where individuals were observed on Dåno′, it is unknown whether the area inhabited in the past was greater than the present, only that up until recently, the species was at low enough levels as to be undetectable. The geospatial information provided by this study will provide a baseline to evaluate changes in distribution of this isolated population in the future. Our survey/delineation methodology may also be of use for studies aiming to estimate population size or vital rates.

HABITAT USE

This is the first study to examine habitat use by *E. slevini*. Despite the limited range of *E. slevini* on Dåno′, it nevertheless occurred in five of the six vegetation classifications on Dåno′ used by

Amidon et al. (2017), indicating that it is not a habitat specialist, at least at the level of those broad classifications. Our more detailed analysis, however, showed that *E. slevini* was most over-represented in Coconut Forest followed by Mixed Introduced Forest. In congruence, hot spot spatial analyses showed positive clustering of *E. slevini* at the 99% confidence level almost entirely within the area of positive clustering for palms. In contrast, *E. slevini* was underrepresented in Casuarina Forest, Developed Vegetation, and Scrub/Shrub, indicating these may be more marginal habitat types for the species. It is important to note that Coconut Forest is the most limited forest habitat on Dåno′ covering only 2.9% of the total forested area. The coconut palm, whose evolutionary origins were once unclear, is now known to be native to the Pacific (Gunn et al. 2011). Wetland sedimentary cores taken on Guam from which samples were extracted for pollen analyses showed that the coconut palm was among the native plants existing on Guam when the first human colonists arrived (Athens & Ward 2004). The skink and the palm therefore share a lengthy historical association.

Our finding that dead fallen palm fronds and coconuts were the two most common perch types used by *E. slevini* further implicates the potential importance of this tree species to *E. slevini*. We recognize that a shortcoming of our study is that we did not measure the frequency of perch types selected relative to those available. We therefore cannot state whether *E. slevini* exhibits preferences in perch type per se. Fallen palm fronds were the most abundant type of structural debris on the forest floor in most areas where *E. slevini* occurred and the observed frequency of use as perches is presumably related to their relative abundance. Regardless, the behavior of *E. slevini* when disturbed further leads us to believe that palm frond and coconut accumulations provide important refugia for this species. Shed palm fronds, as they accumulate over time beneath a palm tree, form mounds with a three-dimensional latticework that offers numerous passageways down into a mound. Similarly, coconuts, as they pile up naturally beneath their parent tree, provide a labyrinth of passages down into the pile (Fig. 6A). This tendency to persist and accumulate in a wet tropical biome where vegetative decomposition is typically rapid is due to the highly recalcitrant nature of palm material to decomposition (Gopal et al. 2020). Accumulations of large coral rubble deposited far inland by typhoons, although relatively uncommon *E. slevini* habitat on Dåno′, form a labyrinth structure not unlike that formed by fallen coconuts (Fig. 6B). The behavior of *E. slevini* when disturbed is to move quickly from view downwards into the accumulation of vegetative or coral debris beneath their perch. Brown & Falanruw (1972) noted similar behavior. We rarely observed *E. slevini* more than a few movements from an entrance into such refugia. Although Bare Ground designation was the most common "perch type" available within *E. slevini* habitat, we only observed individuals "in the open" in this way on nine occasions. The behavior of *E. caeruleocauda* and *C. ailanpalai* when disturbed from perches on the same underlying accumulations of vegetative debris as *E. slevini* was to move away, staying in view of the observer initially, and then climbing higher in vegetation or eventually seeking refuge under cover, respectively. These observations, though anecdotal, lead us to believe that *E. slevini* is more dependent upon suitable debris accumulations on the forest floor for refugia than the sympatric skink species.

Previous accounts of *E. slevini* habitat use on Dåno′ are meager. McCoid et al. (1995) encountered *E. slevini* only in forested areas, noting at the time, that forest constituted only 24% of island's area. In apparent contrast to our findings, Brown & Falanruw (1972) reported that *E. slevini* inhabited forested areas on Dåno′ consisting of primarily *Casuarina* trees with some scattered coconut trees, other broadleaf trees, and a sparse understory. Most lizards they observed were active on the forest floor although a few were observed low on the trunks of trees and where forest met shrubbery adjacent to beach. They noted that most specimens took refuge under material on the forest floor when disturbed. We found that *E. slevini* was underrepresented in the Casuarina Forest classification, though like the coconut palm, *C. equisetifolia* is native to the Mariana Islands (Jarzen & Dilcher 2009). It should be noted that the Casuarina Forest classification is typically applied to any forested area where *C. equisetifolia* occurs with no differentiation made from areas where it may form pure stands. Beyond its native range *C. equisetifolia* can be invasive (Tetsuto et al. 2011) in part because most parts of the plant produce chemicals that exert allelopathic effects on understory plant species (Xu et al. 2015). This species is the dominant tree species east and south of the resort area on Dåno′ and notably, these areas were statistical cold spots for *E. caeruleocauda* (Fig. 3B. Where densities of *C. equisetifolia* are high, a homogeneous mat of dead needles is formed on the forest floor resulting in an environment completely devoid of other live vegetation. Currently, Casuarina Forest constitutes 78% of all forested area on Dåno′. It seems unlikely that *E. slevini* or other skink species could ever inhabit such areas in any great numbers unless remediation understory vegetation can be effected.

Dåno′ is the smallest area of land inhabited by *E. slevini* throughout its global range. Consequently, the diversity of forest types there are limited compared to that of the larger islands in the Mariana Archipelago. Information on the types of forest inhabited by *E. slevini* on the large islands of Guam, Rota, and Tinian, however, are also sparse because the skink was extirpated on these islands shortly after their first discoveries. Under the vegetation classification employed by Amidon et al. (2017), the one specimen from Guam was collected at Ritidian Point in 1945 in what would have been Coconut Forest backed by higher elevation Native Limestone Forest. The two specimens from Rota were collected in 1945 at "isthmus Sosan" which is the present-day location of Songsong village on the coast which may have been Coconut Forest (see Wiles et al. 1990). The one specimen from Tinian collected in 1946 inland at "Mt. Lasso" would have been from Native Limestone Forest. Fossil remains of *E. slevini* have been excavated at the "Railhunter Rockshelter" and "Seabird Crevice" sites on Tinian that were once thought to have been covered in Native Limestone Forest (sensu Fosberg 1960), and at "Payapai Cave", "Crevice N of Paypai Cave", and "Matamoros Cliffside Cave" on Rota, all located within Native Limestone Forest (Pregill 1998). On the smaller island of Aguiguan south of Tinian, fossil remains of *E. slevini* were found at Pisonia Rockshelter site in Native Limestone Forest (Pregill 1998).

Of the four smaller islands in the Commonwealth of the Northern Mariana Islands where *E. slevini* has been documented in recent years, all four have acreages of Coconut Forest (Sarigan, 273 ha; Alamagan, 508 ha; Pagan, 1,163 ha; Asuncion, 156 ha; see Table 3 in Amidon et al. 2017). Native Limestone Forest, however, is absent from all four, and Native Volcanic Forest is present only on two (Sarigan, 100 ha; Asuncion, 480 ha; Table 3, in Amidon et al. 2017). Most general surveys for lizard species have been conducted on Sarigan where at least six studies (1997-2006) have documented limited numbers of *E. slevini*. All these Sarigan surveys were conducted within two habitat types, "coconut forest" and "native forest", with the exception of one transect placed in "grassland" (Martin et al. 2008). Sample sizes of *E. slevini* in all studies were low (<10 per vegetation type per study) and overall, *E. slevini* was just slightly more prevalent in coconut forest than native forest. On Asuncion, Falanruw (1989) observed three *E. slevini* "…near a pile of coconuts in a western ravine (type C)." where type C refers to her vegetation classification "Coconut groves and areas of human influence". Lizard surveys on Asuncion conducted in native forest, but not coconut forest, yielded three *E. slevini* (Williams et al. 2009). McCoid et al. 1995 reported for Asuncion that "…many specimens have been collected or observed in forested ravines." Three lizard surveys have been conducted on Alamagan (McCoid et al. 1995, Cruz et al. (2000), and Murray et al. (2018) all of which documented presence of *E. slevini*. On that island, McCoid et al. (1995) again mentioned only that *E. slevini* was collected or observed in forested ravines. Cruz et al. (2000) registered 23 *E. slevini* in "mixed coconut forest' (Coconut Forest interspersed with patches of Hibiscus Thicket, sensu Amidon et al. 2017) and *E. slevini* in "mixed secondary forest' (Coconut Forest, Mixed Introduced Forest, Scrub/Shrub, Mixed Grass/Herbaceous, sensu Amidon et al. 2017). Murray et al. (2018) registered only one *E. slevini* in "mixed forest" (Coconut Forest interspersed with patches of Hibiscus Thicket, sensu Amidon et al. (2017). The only existing specimen from Pagan (USNM 529972) was collected in 1999 at "South end of island, saddle between two southern-most peaks" (a second individual was seen) Vogt et al. (2001) and S. Vogt (in litt.), which is a patchwork area of Coconut Forest, and Mixed Introduced Forest, sensu Amidon et al. (2017).

In conclusion, there is strong evidence that *E. slevini* inhabits, or formerly inhabited on some islands, a diversity of native forest types, and on some of the northern islands it may also inhabit the edges of introduced grasslands (*Chrysopogon aciculatus* and *Miscanthus floridulus*, Kessler 2011). Coconut Forest, whether naturally occurring or as former copra plantation, is but one forest type used by *E. slevini*, and its apparent preference for this type of forest on Dåno′ is likely due to the absence of other suitable forest types that occur on some of the larger islands. Finer scale characterizations of *E. slevini* habitat, microhabitat, and types of refugia used are needed in the other forest types it inhabits, particularly Native Limestone Forest, from which it has been documented frequently.

DENSITY OF *EMOIA CAERULEOCAUDA* AS AN INDICATOR OF FAVORABLE HABITAT FOR *EMOIA SLEVINI*

The use of *E. caeruleocauda* density an indicator of habitat suitability for *E. slevini* implicitly assumes that its density is driven by resource availability and that *E. slevini* is largely dependent on those same resources. Although density-based assessment of habitat quality can be accurate (Bock & Jones 2004), simply assuming a direct relationship between consumer density and resource abundance or habitat quality can be misleading because species occurrence and density can be disconnected from static measures of habitat quality when resources are highly seasonal, unpredictable over time, and patchy (Van Horne 1983, Johnson 2007). Cases of mismatching between density and resources been documented for mammalian and avian species where individuals are able to move among different areas in response to seasonal fluctuations in resource availability (Mosser et al. 2009) or where younger age classes are excluded from higher quality habitat through competition with mature individuals (Van Horne 1983). Such delinkages, however, have not been reported for small species of lizards in tropical environments where reproduction can be continuous, or nearly so (e.g., *E. caeruleocauda*; Goldberg & Kraus (2010), and references therein).

Of the six land cover categories where *E. caeruleocauda* and *E. slevini* were collectively observed on Dåno′, four were shared (Fig. 7). Both skink species were overrepresented in Coconut Forest and Mixed Forest and underrepresented in Casuarina Forest and Developed Vegetation. *E. caeruleocauda* occurred in greater numbers in Casuarina Forest than *E. slevini* suggesting that it is more of a generalist in the types of habitats it uses than *E. slevini*. Comparisons of overlap in positive clustering for *E. caeruleocauda* and *E. slevini* showed that the area of positive clustering for *E. caeruleocauda* largely contained that of *E. slevini*. However, the area of positive clustering for *E. caeruleocauda* was substantially larger than that of *E. slevini* indicating that there are either finer scale difference in habitat used by these two species than we were able to discern or that *E. slevini* is still expanding its range on the island. Recent work on Dåno′ leads us to believe that it is the latter (Fisher & Mathies, unpub. survey data). Comparisons of forest types and clustering overlap for *E. slevini* and *E. caeruleocauda* support our hypothesis that areas of high densities of *E. caeruleocauda* are the areas most likely to support *E. slevini*. Whether this finding holds for other islands and habitats where both skink species are present remains to be determined. On Sarigan, *E. caeruleocauda* was always encountered with *E. slevini*, but always in much greater abundance (Martin et al. 2008) making this island a good location to conduct further evaluations. Because distribution and density of *E. caeruleocauda* is relatively easy to assess, we recommend that these metrics be used as an initial tool for selecting areas of habitat suitable for reintroduction of *E. slevini*. Although the best methods of assessing habitat quality are considerably more labor intensive, in part because they do not involve a proxy, final site selections for *E. slevini* should ideally be guided by studies that directly assess demographic and habitat-specific measures such as reproduction, growth, body condition, and survival as these have been shown to provide some of the best measures of habitat quality (Beerens et al. 2015, Johnson 2007, Wheatley et al. 2002).

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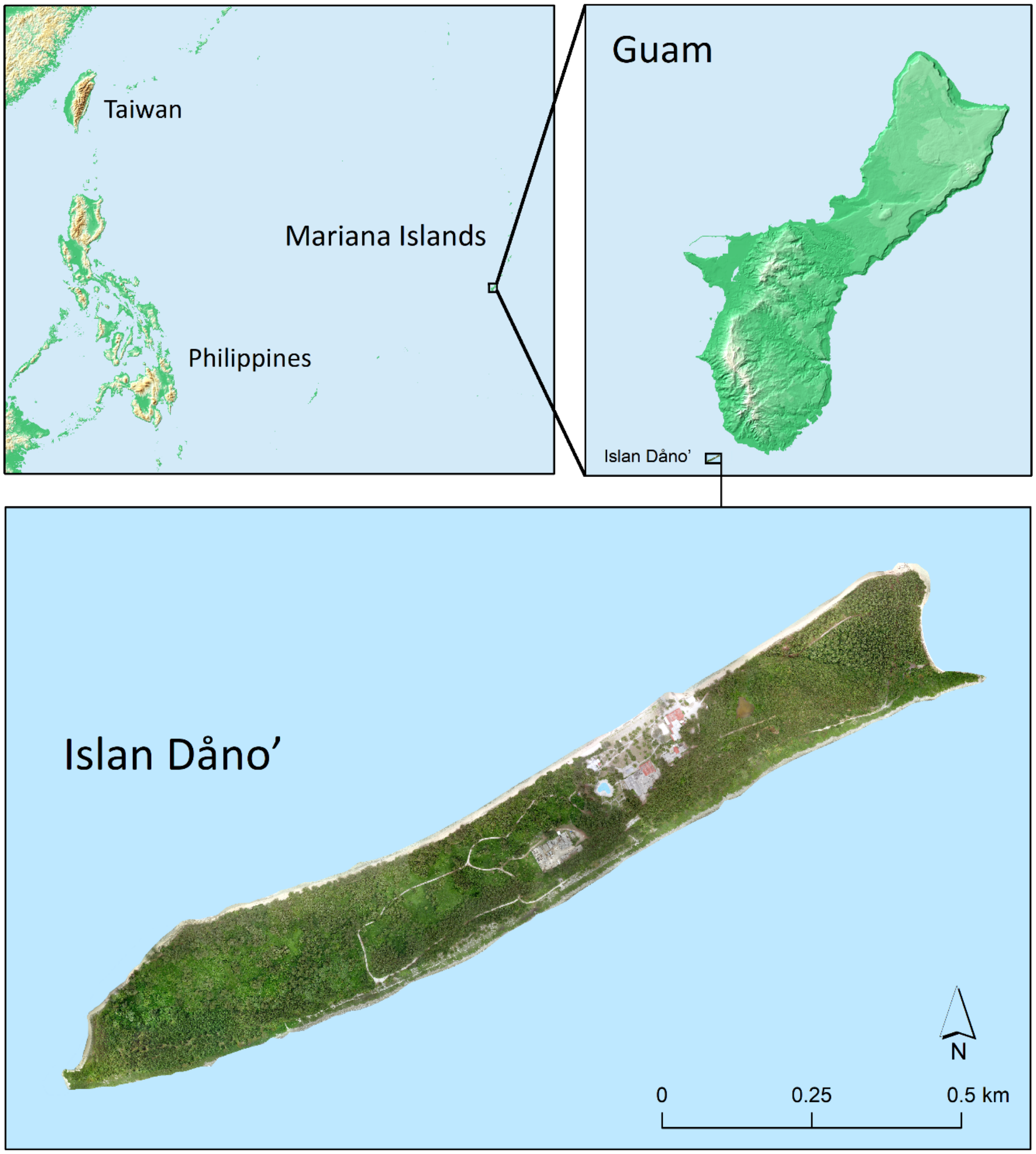

Figure 1. Location of Islan Dåno′ (Cocos Island) and study area for *Emoia slevini* in the western Pacific Ocean. Imagery in top two panels was extracted from the ESRI World Terrain Elevation Tinted Hillshade Layer (ESRI 2025). Aerial imagery used in lower panel was provided by Naval Facilities Engineering Command Marianas.

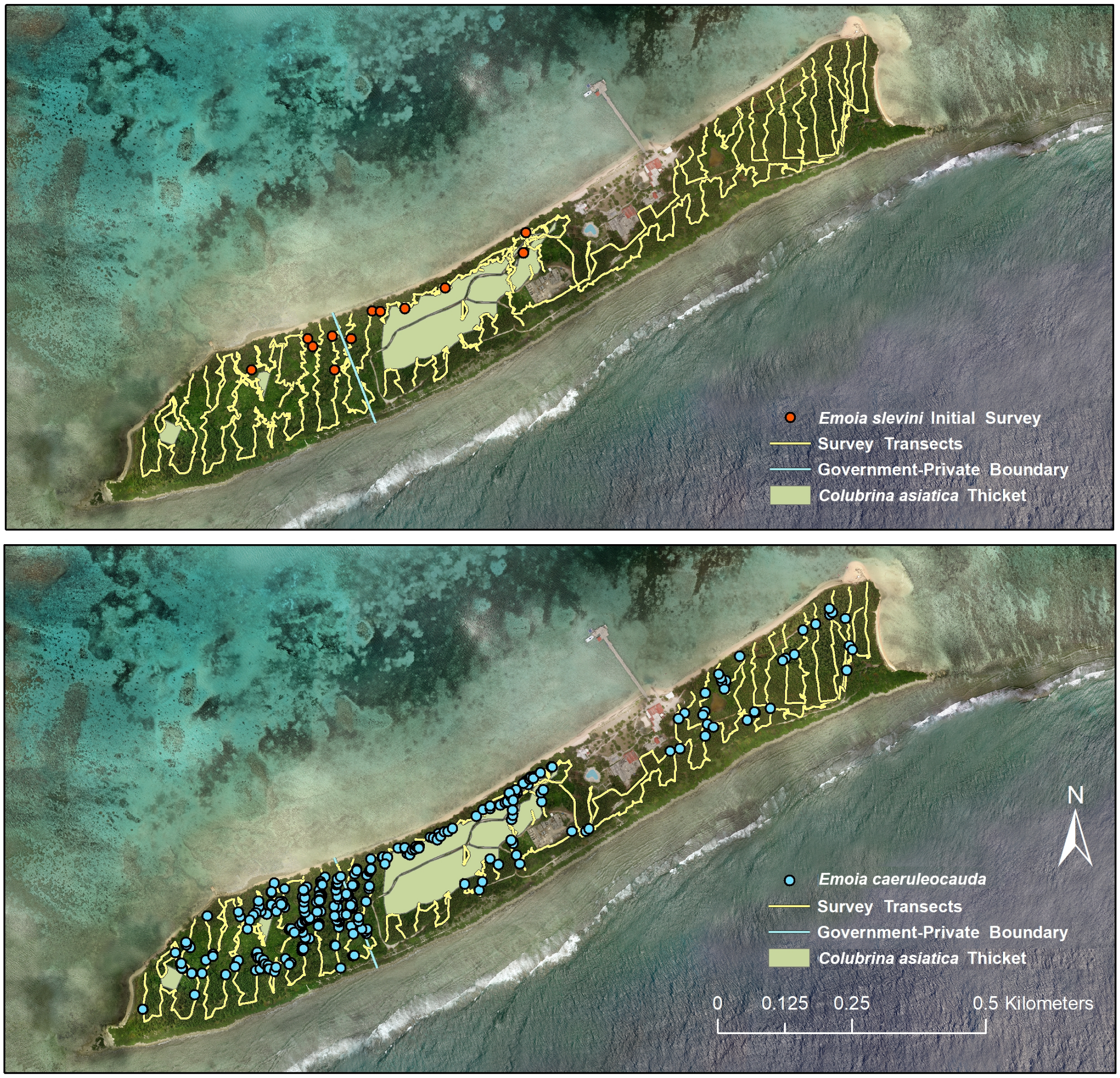

Figure 2. A) Survey transects and locations for individual lizards observed during whole island survey for *Emoia slevini* and B) *Emoia caeruleocauda* on Islan Dåno′, Guam. The number of individuals observed for each species are given in parentheses in map legends. Aerial imagery used in panels A and B was provided by Naval Facilities Engineering Command Marianas.

Figure 3. A) Minimum convex and concave hulls on distribution of *Emoia slevini* on Islan Dåno′, Guam. Note that population occurs on both government-owned side of island (western) and privately owned "resort" side of island (eastern), B) All observations of *Emoia slevini* and *Emoia caeruleocauda* on all the vegetation and land cover classification coverages for the island (sensu Amidon et al. 2017). Areas of *Colubrina asiatica* thicket were mapped manually and areas of overlap with vegetation and land cover polygons subtracted (see Methods). Number of individuals of each species observed are given in parentheses in map legends. Aerial imagery used in panel A was provided by Naval Facilities Engineering Command Marianas.

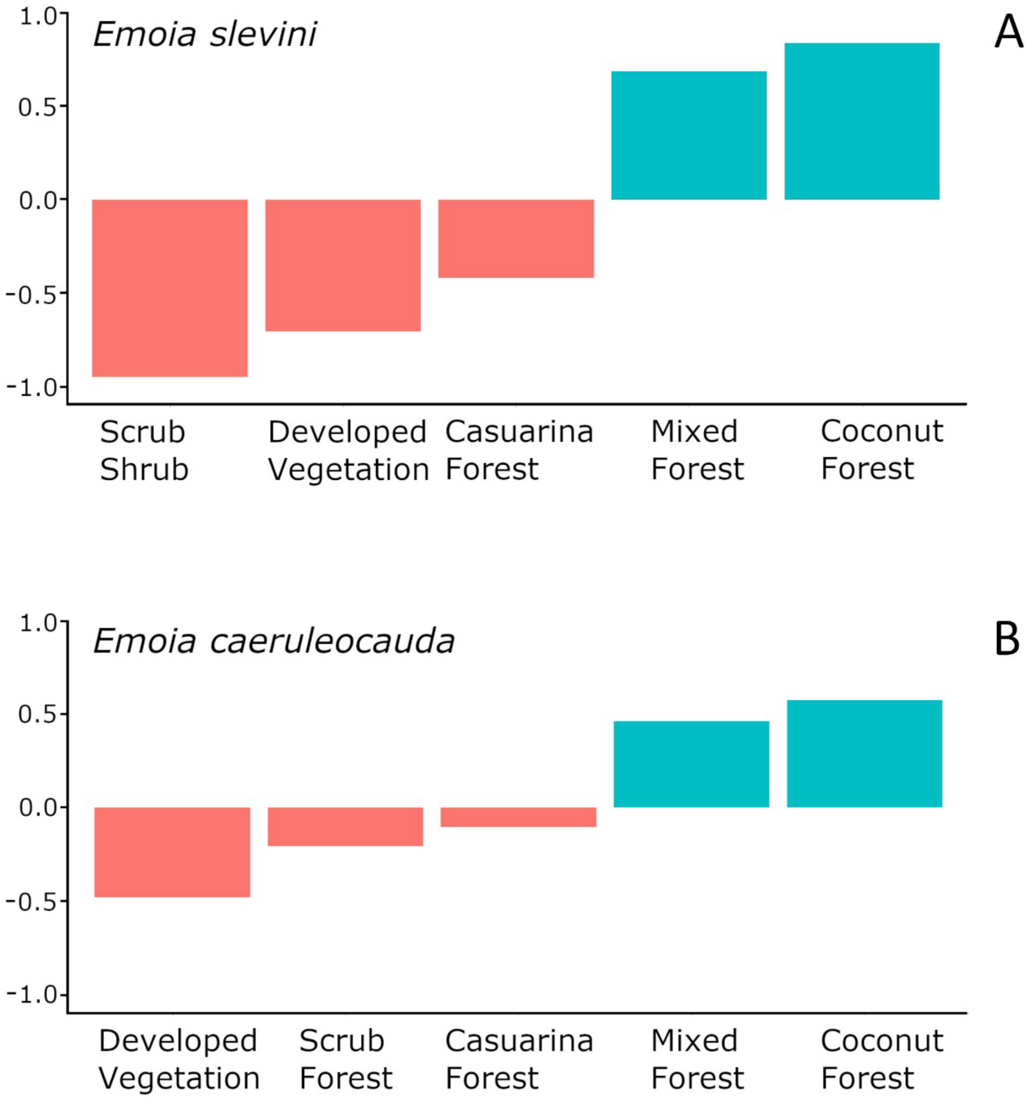

Figure 4. Relative count indices for A) *Emoia slevini* and B) *Emoia caeruleocauda* for five aggregated land cover categories where these species occurred on Islan Dåno′ (Cocos Island), Guam. Positive values indicate over-representation (i.e., more observed points than expected under complete spatial randomness) while negative values indicate the opposite.

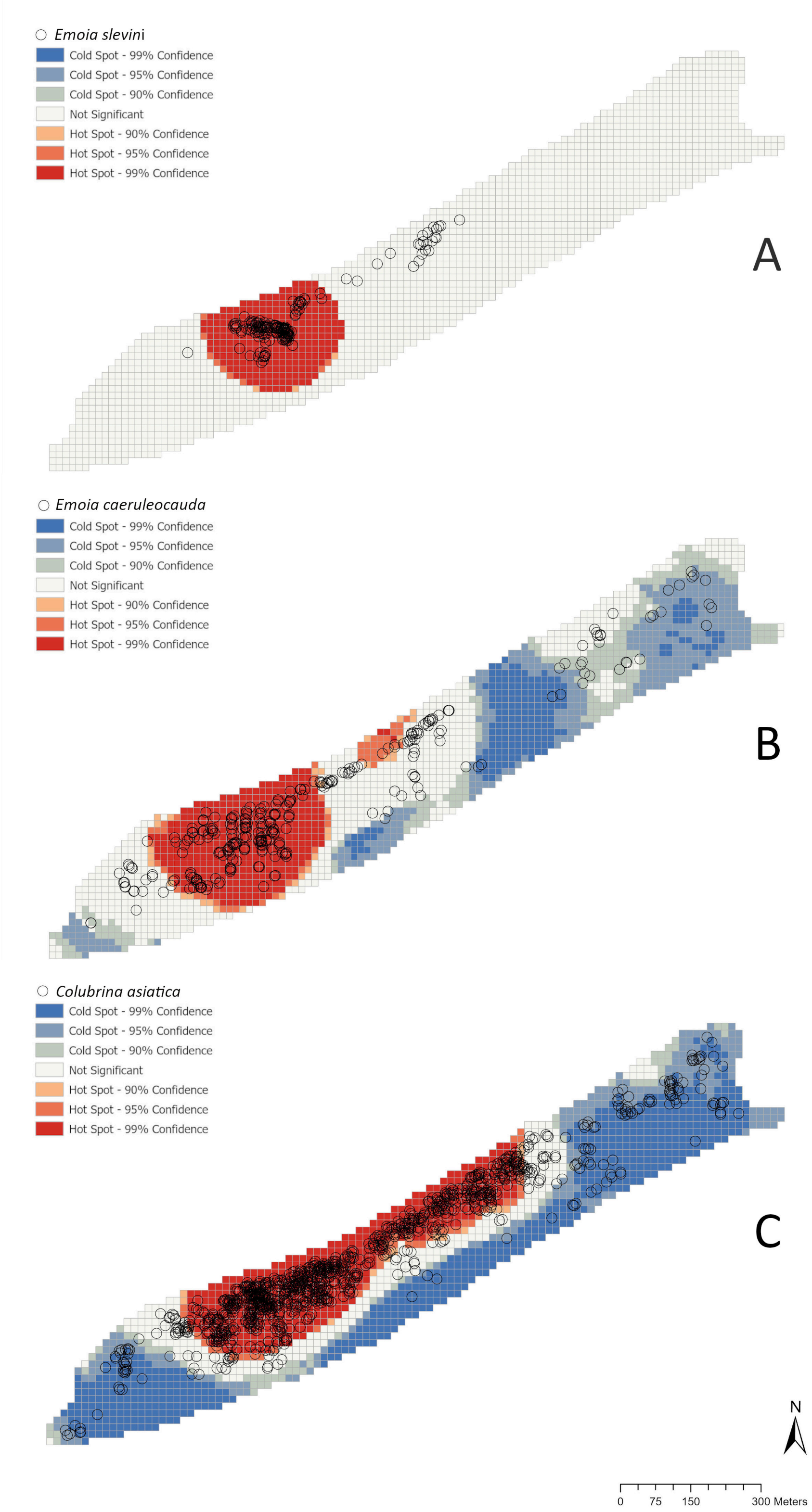

Figure 5. Lizard and palm locations (hollow circles) and hotspots on Islan Dåno′ (Cocos Island): A) *Emoia slevini*. B) *Emoia caeruleocauda*. C) *Cocos nucifera*.

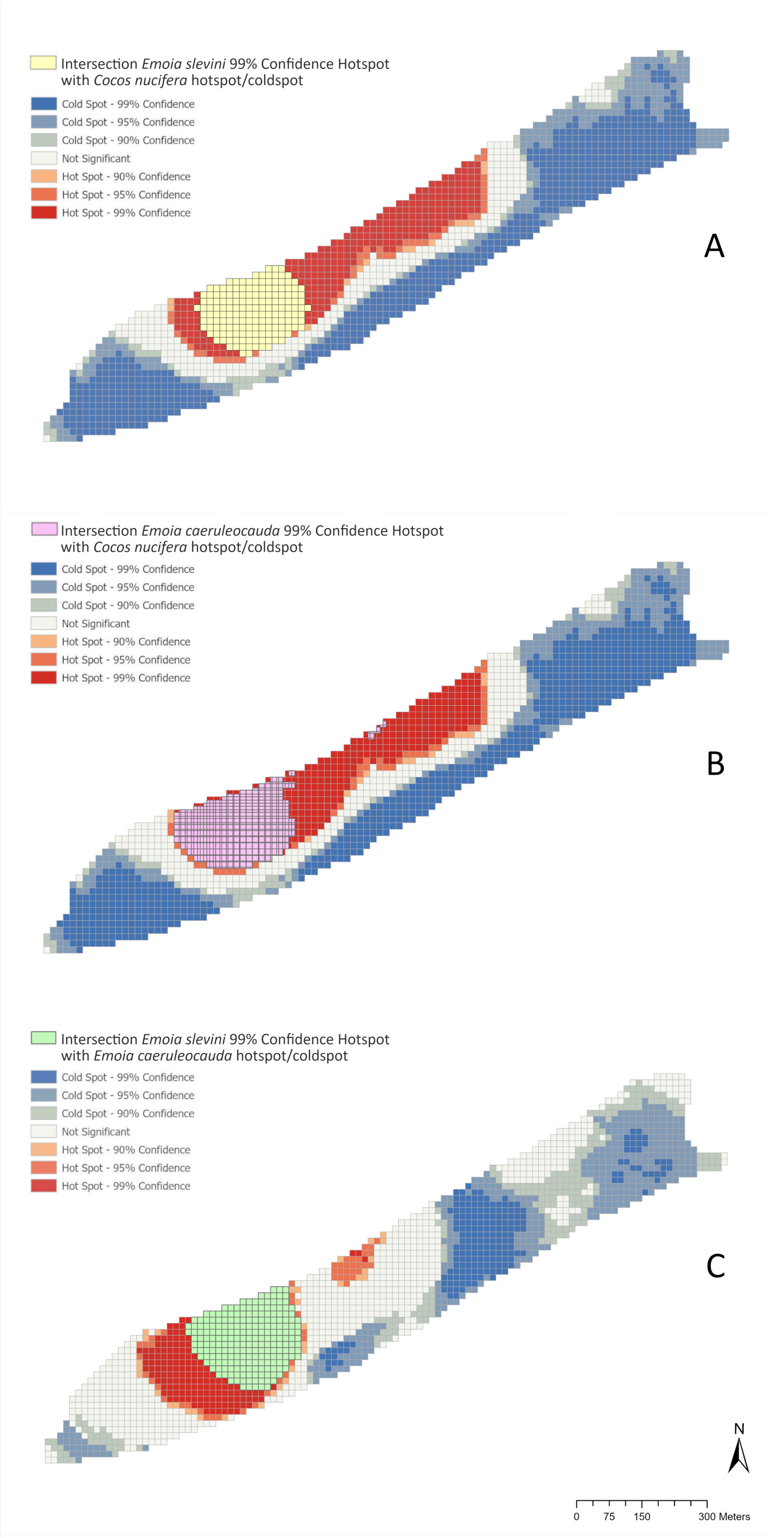

Figure 6. Hotspot intersection of lizards and palms on Islan Dåno′ (Cocos Island): A) *Emoia slevini* and *Cocos nucifera*. B) *Emoia caeruleocauda* and *Cocos nucifera*. C) *Emoia slevini* and *Emoia caeruleocauda*.

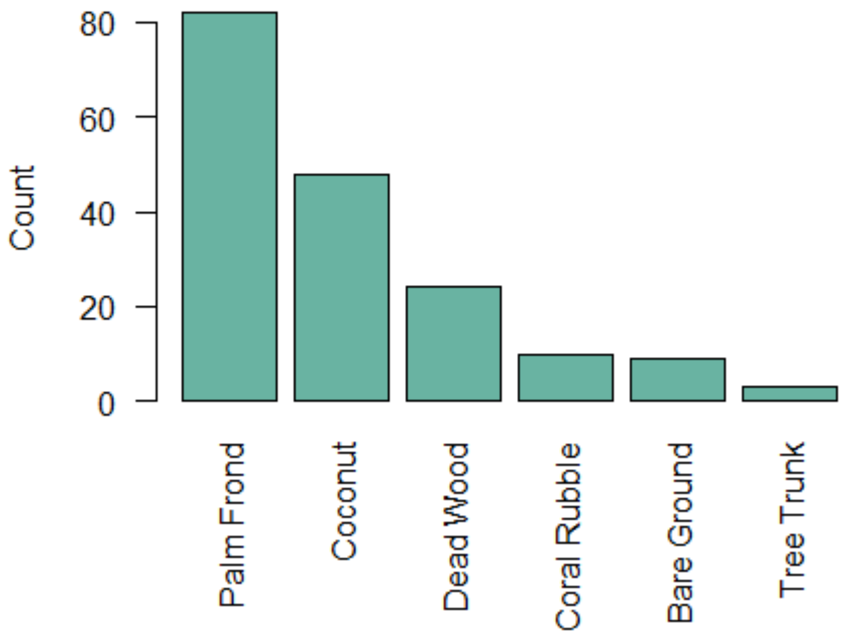

Figure 7. Perch type frequencies for *Emoia slevini* on Islan Dåno′ (Cocos Island), Guam.

Figure 8. Representative photos of the three most common perch types used by *Emoia slevini* on Islan Dåno′ (Cocos Island), Guam by decreasing frequency of use: A) downed coconut palm fronds (*Cocos nucifera*), B) downed coconuts, and C) downed dead wood. Photo credit, panels A and C: G. Curt Fiedler.

Figure 9. Representative photos of types of vegetative and coral debris accumulations frequented by *Emoia slevini* in forest habitat on Islan Dåno′ (Cocos Island), Guam. A) naturally occurring deposition of fallen coconut fronds and coconuts in Coconut Forest, B) inland typhoon-deposited coral rubble in Mixed Introduced Forest, C) longstanding area for resort-deposited green waste and garbage alongside road in Mixed Introduced Forest (site of recent "rediscovery" for *E. slevini*, see Introduction).

Table 1. Vegetation classification descriptions and accuracy assessments for Islan Dåno′, Guam from Amidon et al. (2017). Classifications given here are only those where lizards were observed or surveyed (see Methods). Producer accuracy is a measure of the error associated with not including (omission) an area within a land cover/vegetation type. User accuracy is a measure of other land cover/vegetation types that were incorrectly included (commission) in a land cover/vegetation type (see Amidon et al. 2017). The *Colubrina asiatica* Thicket classification was mapped in the field (see Methods).

VegClass	**Description**	**Accuracy (Producer/User)(%)**
Casuarina Forest	Stands or individual *Casuarina equisetifolia* (ironwood).	(100/97)
Coconut Forest	Stands of *Cocos nucifera* (coconut), generally representing former coconut plantation.	(100/92)
Mixed Introduced Forest	Dominated by non-native species. Canopy species may include combinations of coconut, ironwood, and other native or non-native species.	(82/90)
Scrub/Shrub	Interior areas dominated by scrub or shrub species, generally non-native species. Does not include coastal scrub species (e.g., *Pemphis acidula*).	(73/90)
Developed Vegetation	Parks and residential open spaces with ornamental and shade trees and shrubs.	(87/94)
Colubrina asiatica Thicket	*Colubrina asiatica* thicket physically impassable to surveyors.	n/a

Table 2. All vegetation and land cover classification coverages for Islan Dåno′, Guam from Amidon et al. (2017). Areas of *Colubrina asiatica* thicket were mapped manually and areas of overlap with vegetation and land cover polygons subtracted (see Methods).

VegClass	**Hectares**	**% Coverage**
Casuarina Forest	11.26	33.5
Scrub/Shrub	9.63	28.7
Unconsolidated Shore	2.93	8.7
Colubrina asiatica Thicket	2.79	8.3
Mixed Introduced Forest	2.76	8.2
Developed	1.91	5.7
Developed Vegetation	1.60	4.8
Coconut Forest	0.41	1.2
Mixed Grass/Herbaceous	0.23	0.7
Bare Soil/Gravel	0.09	0.3

Table 3. Number of expected versus observed lizard occurrences in vegetation and land cover classification coverages (sensu Amidon et al. 2017) under complete spatial randomness on Islan Dåno′, Guam. Vegetation and land cover classifications presented are only those where lizards occurred and were surveyed (see Methods).

		Emoia slevini		*Emoia caeruleocauda*	
Vegetation and Land Cover Classification	**Total Hectares**	Expected	Observed	Expected	Observed
Coconut Forest	**0.41**	3.27	38	4.85	18
Mixed Introduced Forest	**2.76**	22.08	120	32.67	89
Casuarina Forest	**11.25**	89.91	37	133.04	108
Scrub/Shrub	**9.63**	76.98	2	113.92	75
Developed Vegetation	**0.72**	5.76	1	8.53	3

Table 4. Statistics for omnibus chi-square goodness of fit tests examining the association between vegetation and land cover category and lizard point count on Islan Dåno′, Guam, and pairwise comparisons for the observed and expected probabilities. P-values for pairwise comparisons adjusted for false discovery rate.

	Emoia slevini			*Emoia caeruleocauda*		
Omnibus chi-square test	$\chi2$	*df*	*p*-value	$\chi2$	*df*	*p*-value
	911.2	4	<0.0001	154.5	4	<0.0001
Vegetation & Land Cover Classification	**Pairwise Comparisons**					
Coconut Forest	375.0	1	<0.0001	36.4	1	<0.0001
Mixed Introduced Forest	488.8	1	<0.0001	109.3	1	<0.0001
Casuarina Forest	57.0	1	<0.0001	8.6	1	0.004
Scrub/Shrub	119.5	1	<0.0001	21.8	1	<0.0001
Developed Vegetation	4.1	1	0.04	3.7	1	0.055

Table 5. Results of omnibus goodness of fit chi-square test for perch type use by *Emoia slevini* and multiple comparisons adjusted for false discovery rate.

Omnibus Chi-Square		***p*-values for multiple comparisons**						
Perch Type	Observed		Palm frond	Coconut	Log	Coral Rubble	Bare Ground	Tree Trunk
Palm frond	82	Palm frond	-	-	-	-	-	-
Coconut	48	Coconut	0.0048	-	-	-	-	-
Log	24	Log	<0.0001	<0.0001	-	-	-	-
Coral Rubble	10	Coral Rubble	<0.0001	<0.0001	0.0204	-	-	-
Bare ground	9	Bare Ground	<0.0001	<0.0001	0.0123	0.0123	-	-
Tree trunk	3	Tree Trunk	<0.0001	<0.0001	<0.0001	0.0602	0.0892	-
χ^2	**157.9**							
df	**5**							
***p*-value**	**<0.0001**							

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