Short Communication

# Madagascan Day Geckos (*Phelsuma* spp.) Exhibit Differing Responses Along a Gradient of Land-Use Change

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**Abstract**

Madagascar is a key priority for global conservation efforts, as much of its diverse and highly endemic biota is threatened by deforestation. Despite this threat, there are limited data on the responses and tolerances of herpetofaunal species to landscape change. This study investigated the response of Madagascan day geckos (*Phelsuma* spp.) to deforestation in Nosy Be, Madagascar. We selected six sites along a gradient of land-use change: two in Sambirano rainforest ("Forest"), two in secondary, fragmented forest ("Fragment"), and two in agricultural plantations ("Orchard" and "Cropland"). We conducted a series of time-constrained searches at each site. The mean encounter rate of *Phelsuma* geckos (geckos detected per person/hour) was greater in agricultural sites than Forest sites, but no difference was detected between Forest and Fragment or Fragment and agricultural areas. Three species were encountered more frequently in agricultural land than forested sites, but this was not true for *Phelsuma seippi*, an endangered species on the IUCN Red List. These results suggest that adaptive, generalist species may benefit from anthropogenic land-use change, whereas specialist species will suffer. Our study emphasizes the importance of extending research beyond the borders of protected forests to include anthropogenically disturbed areas.

**Keywords**

land-use change, deforestation, habitat disturbance, gecko, conservation

## Introduction

Deforestation for agriculture is a key driver of species extinctions worldwide (de Almeida-Rocha, Peres, & Oliveira, 2017; Harper, Steininger, Tucker, Juhn, & Hawkins, 2007). It has negative impacts on biodiversity via direct habitat loss and fragmentation (de Almeida-Rocha et al., 2017; Smith, Horning, & Moore, 1997). Such change is particularly concerning in tropical rainforests, which provide habitat for a significant proportion of terrestrial species (Harper et al., 2007).

Madagascar is a key priority for global conservation efforts due to its diverse and highly endemic biota, coupled with the ongoing threat of habitat loss (Goodman & Benstead, 2005; Harper et al., 2007; Jenkins et al., 2014; van Heygen, 2004; White, 1983). Native vegetation in Madagascar is removed via slash and burn techniques, which destroy all above-ground foliage, resulting in the transition of primary rainforest to secondary bamboo forest (van Heygen, 2004). As such, slash and burn agriculture is regarded as the country's main driver of deforestation and habitat disturbance (Irwin et al., 2010; Waeber, Wilme, Mercier, Camara, & Lowry, 2016).

It is estimated that 90% of Madagascan endemic species rely solely on forest habitats (Dufils, 2003). Previous studies indicate that Malagasy fauna exhibit a negative response to land clearing and burning; however, this response is poorly understood (Gardner, 2009; Irwin et al., 2010). This issue is particularly pressing for

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Madagascar's unique herpetofauna which, despite their high diversity, have received little attention (D'Cruze, Henson, Olsson, & Emmett, 2009; Jenkins et al., 2014; Lehtinen & Ramanamanjato, 2006; Raxworthy & Nussbaum, 2000).

The gecko genus *Phelsuma* (Gray, 1825) has the highest diversity of any Malagasy lizard genus, and is estimated to contain 44 species (D'Cruze, Sabel, Dawson, & Kumar, 2009; Ikeuchi, Mori, & Hasegawa, 2005; Rocha, Posada, Carretero, & Harris, 2007; Rocha et al., 2010). Many species have successfully colonized Madagascar's neighboring islands, including the Comoros, Mascarenes, and Seychelles, as well as more distant locations (Rocha et al., 2007, 2010). Relatively, little is known of the current distribution of *Phelsuma* spp. or the impact of land-use change on their patterns of occurrence (Ikeuchi et al., 2005); but they are believed to be more tolerant of habitat modification than other related genera (Raxworthy & Nussbaum, 2000; van Heygen, 2004). *Phelsuma* spp. have been recorded in a range of habitats, including human-modified areas such as agricultural plantations and infrastructure (Augros, Fabulet, & Hawlitschek, 2017a; Augros et al., 2017; Bauer, 2003; D'Cruze, Sabel, et al., 2009; Gardner & Jasper, 2009; Glaw & Vences, 2007). Several *Phelsuma* species are recognized on the IUCN Red List, including *Phelsuma seippi* (Meier, 1987) which is currently classified as Endangered (IUCN, 2017; Ratsoavina, Glaw, Rabibisoa, & Rakotondrazafy, 2011).

The majority of herpetological research in Madagascar has occurred in primary habitats within protected area networks (D'Cruze, Henson, et al., 2009; Gardner & Jasper, 2009). As such, there is limited knowledge of the distributions, responses, and tolerances of species in anthropogenically disturbed areas (Gardner & Jasper, 2009). As deforestation continues throughout Madagascar, this information will be crucial for future conservation efforts. The aim of this study was to assess and quantify the response of *Phelsuma* geckos to land-use change in Nosy Be, Madagascar.

## Methods

### Study Area

This study was undertaken on Nosy Be (13.317°S, 48.259°E; Figure 1), the largest offshore-island in Madagascar, located 12 km from the northwest coast. Measuring 25,200 ha, Nosy Be is situated within the Sambirano Domain, a transitional zone between the dry, deciduous forest of the west and the wet rainforest of the east (Andreone et al., 2003; van Heygen, 2004). It is characterized by a humid, tropical climate and vegetation similar to the lowland rainforests of the mainland (Andreone, Guarino, & Randrianirina, 2005; Goodman & Benstead, 2003). Sambirano rainforests have a closed canopy 25 to 30 m in height, with few emergent trees (White, 1983). These forests are highly diverse and dominated by species of palms, bamboo, and epiphytes (White, 1983). The island has a mean annual rainfall of 2,000 to 2,250 mm and a mean annual temperature of 26°C (Battistini, 1960). This study was conducted during the wet season, throughout January and February, to coincide with peak levels of herpetofaunal activity (Glaw & Vences, 2007).

Much of the primary rainforest on Nosy Be has been cleared for agricultural crops (including rice, sugar cane, coffee, ylang-ylang, and fruits), timber harvesting, zebu grazing, roads, and tourism infrastructure (Andreone et al., 2003, 2005). Patches of remnant forest still persist along creek lines and roadsides (Andreone et al., 2005). Most of the primary forest (862 ha) is now included within the Strict Nature Reserve: La Réserve Naturelle Intégrale de Lokobe (Madagascar National Parks, 2015; United Nations Environment World Conservation Monitoring Centre, 2017).

### Study Sites

Six sites were chosen around the village of Ambalahonko, Nosy Be (Figure 1). Sites were selected to represent a temporal gradient of forest recovery following clearance for agriculture (Table 1). Two sites were sampled in each of the following land-use categories: Sambirano rainforest, free from any recent human-disturbance (''Forest''); and fragmented, secondary forest frequently visited by humans (''Fragment''). In addition, one site was sampled in a banana and ylang-ylang plantation (''Orchard'') and another in a pineapple plantation (''Cropland''; Table 1). The Forest category consisted of a primary rainforest site at the border of La Réserve Naturelle Intégrale de Lokobe and a 30-year-old forest site recovering from past clearance. Only interior forested areas were selected to avoid any edge effects. Fragment sites were located in the Ministere des Eaux et Forests managed buffer zone and consisted of a 20-year-old site and a 10-year-old site, both of which were still utilized for timber extraction and stock grazing. These sites were adjacent to cleared areas and fragmented by walking tracks. Finally, both the Orchard and Cropland sites were located in degraded, cleared agricultural areas. It was necessary to separate these two sites due to differences in vegetation structure and the presence of remnant native vegetation. All sites were located within 1,500 m of the center of Ambalahonko village. Sites were separated by a mean distance of 300 m and a minimum of 130 m (Figure 1).

### Survey Methods

A series of time-constrained searches (Corn & Bury, 1990), also known as active searches or visual encounter

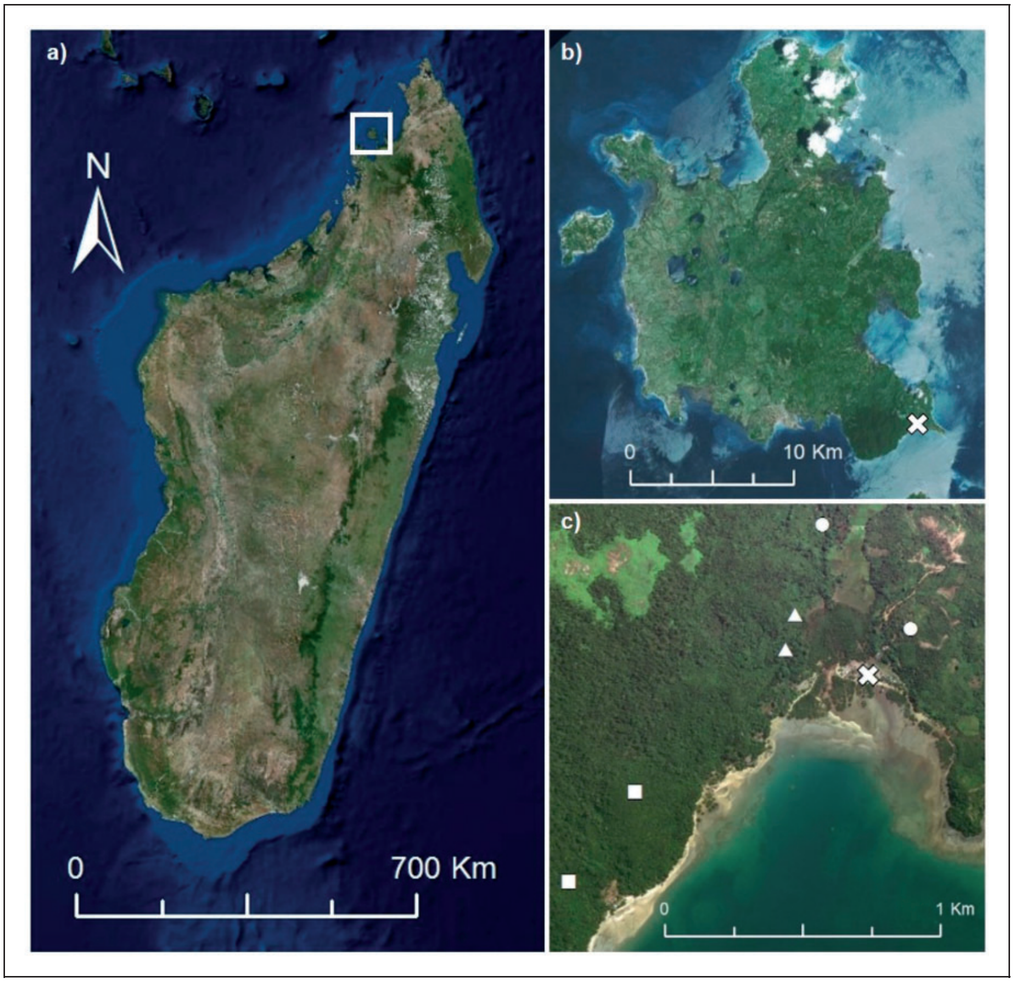


**Figure 1.** (a) A satellite image of Madagascar indicating the island of Nosy Be off the northwest coast. (b) The white cross indicates the village of Ambalahonko (13.405° S, 48.345° E). (c) Squares indicate Forest sites, triangles indicate Fragment sites, and circles indicate Orchard and Cropland sites.

**Table 1.** Summary of Land-Use Information for Each of the Six Study Sites.

| Site no. | Land cover | Current human land-use | Forest extent | Time since clearance | Category |
|---|---|---|---|---|---|
| 1 | Primary rainforest | None | Continuous | Never cleared | Forest |
| 2 | Recovering rainforest | None | Continuous | 30 years | Forest |
| 3 | Secondary forest | Travel between villages and timber extraction | Fragmented | 20 years | Fragment |
| 4 | Secondary forest | Abandoned farm land and zebu grazing | Fragmented | 10 years | Fragment |
| 5 | Agriculture | Ylang-ylang and banana plantation | Cleared | 0 years | Orchard |
| 6 | Agriculture | Pineapple plantation | Cleared | 0 years | Cropland |

*Note*. Time since clearance was estimated from local knowledge.

surveys, were undertaken at each site. Each search was conducted by a team of four to seven trained volunteers and at least one experienced researcher. Wherever possible, the same volunteers and researcher assisted with every search. Each search represented 180 observer minutes of opportunistic searching for herpetofauna within a defined site area of $50 \times 50$ m. Survey duration was calculated by dividing 180 minutes by the number of surveyors present. During each search, the team spread out across the survey area and moved through the site at a steady pace, searching all appropriate microhabitat sites to a height of approximately 4 m above the ground.

Due to logistical, timing, and funding constraints, surveyors could not cover the forest strata above 4 m in height. Surveyors remained separated throughout the entire search to avoid double counting individuals. All *Phelsuma* species encountered during surveys were visually identified in the field to limit disturbance. Three searches, equating to 540 observer minutes, were conducted at each of the six sites. All active searches took place between 0900 and 1100 hours and 1400 and 1600 hours, from 2 January to 5 February 2012.

### Data Analysis

We collated all occurrences of *Phelsuma* geckos and calculated the relative abundance and species richness for each land-use type (Forest, Fragment, Orchard, and Cropland). A Kruskal–Wallis test and a post hoc Dunn's test (with the Bonferroni adjustment method) were undertaken in RStudio (R version 3.3.1; R Core Team, 2016) to compare the mean encounter rate (geckos detected per person/hour) and mean species richness of *Phelsuma* geckos between Forest, Fragment, Orchard, and Cropland sites.

## Results

Time-constrained searches detected a total of 97 *Phelsuma* geckos from five species (Figure 2). The giant Madagascar day gecko (*Phelsuma grandis*; Gray, 1870) was the most frequently detected species, while Seipp's day gecko (*Phelsuma seippi*; Meier, 1987) and the Zanzibar day gecko (*Phelsuma dubia*; Boettger, 1881) were the two rarest encountered species (Table 2). The Orchard and Cropland sites had the greatest relative abundance of *Phelsuma* geckos, while the Forest sites had the lowest relative abundance (Table 2).

Species richness of *Phelsuma* geckos varied from one to five species per site. The Orchard had the highest richness with all five *Phelsuma* species recorded. The primary forest adjacent to La Réserve Naturelle Intégrale de Lokobe had the lowest species richness, with only one species encountered (*Phelsuma laticauda*; Boettger, 1880).

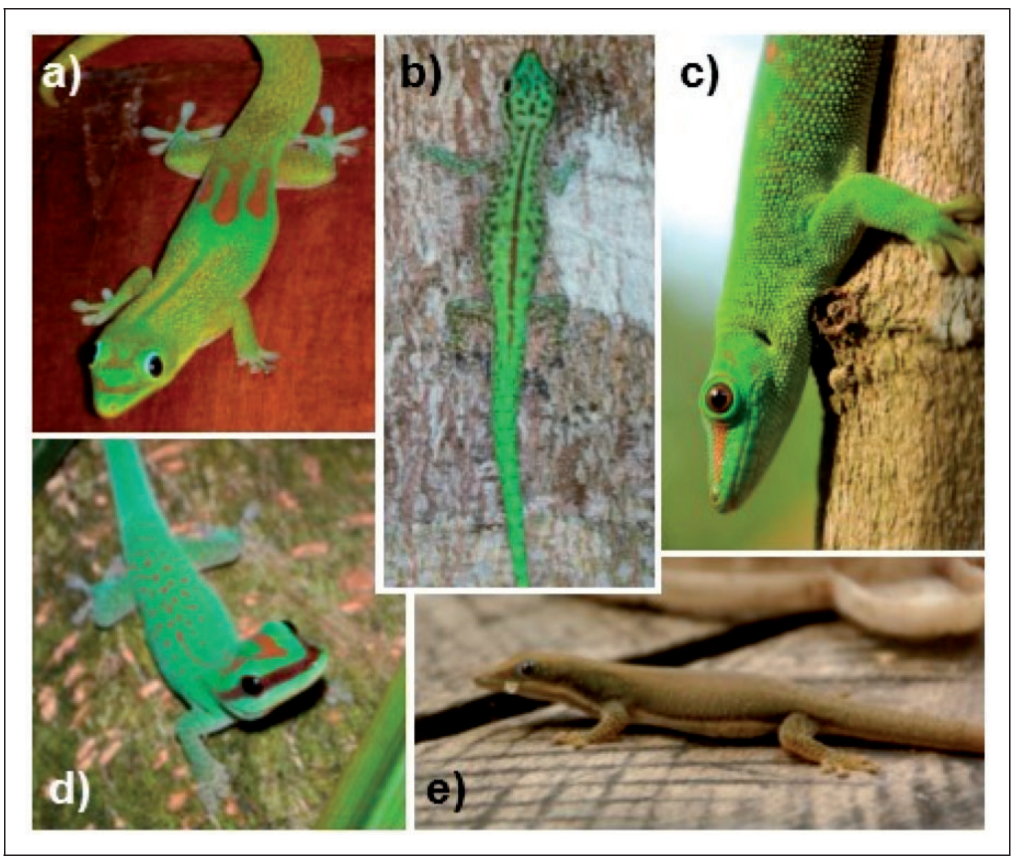


**Figure 2.** Examples of all five *Phelsuma* gecko species detected in this study. (a) Broad-tailed day gecko (*Phelsuma laticauda*; Boettger, 1880), (b) Abbott's day gecko (*Phelsuma abbotti*; Steineger, 1893), (c) Giant Madagascar day gecko (*Phelsuma grandis*; Gray, 1870), (d) Seipp's day gecko (*Phelsuma seippi*; Meier, 1987), and (e) Zanzibar day gecko (*Phelsuma dubia*; Boettger, 1881). All photographs by Jacinta Humphrey, January 2012.

**Table 2.** A Summary of the Relative Abundance of *Phelsuma* Species Detected in Forest, Fragment, Orchard, and Cropland Sites on Nosy Be, Madagascar.

| Common name | Scientific name | Forest | Fragment | Orchard | Cropland | Total |
|---|---|---|---|---|---|---|
| Abbott's day gecko | *Phelsuma abbotti* (Stejneger, 1893) | 0 | 2 | 6 | 12 | 20 |
| Zanzibar day gecko | *Phelsuma dubia* (Boettger, 1881) | 0 | 0 | 3 | 0 | 3 |
| Giant Madagascar day gecko | *Phelsuma grandis* (Gray, 1870) | 1 | 14 | 20 | 15 | 50 |
| Broad-tailed day gecko | *Phelsuma laticauda* (Boettger, 1880) | 2 | 0 | 8 | 6 | 16 |
| Seipp's day gecko | *Phelsuma seippi* (Meier, 1987) | 3 | 4 | 1 | 0 | 8 |
| Total | | 6 | 20 | 38 | 33 | 97 |

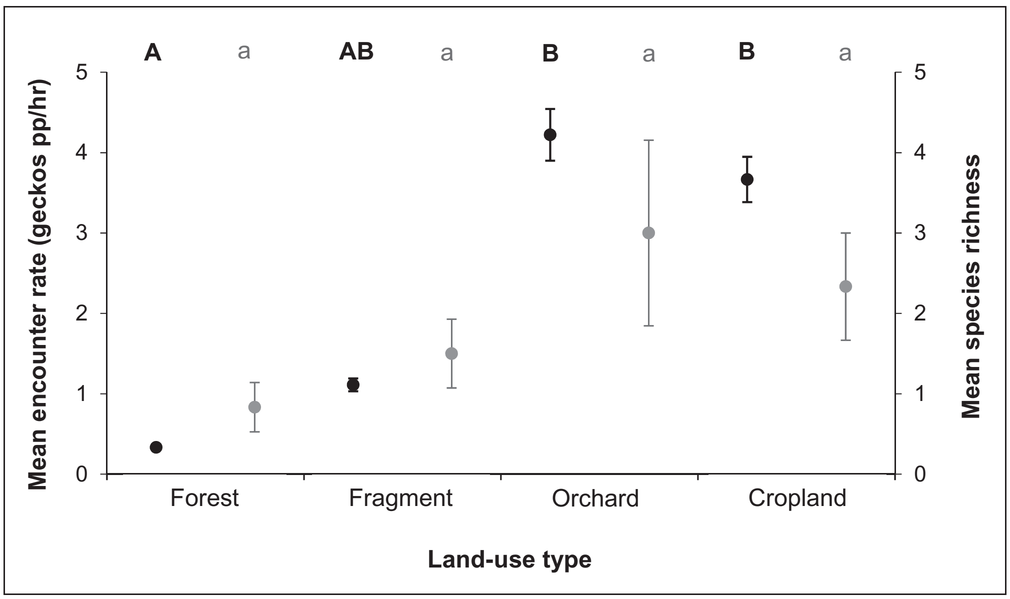


**Figure 3.** Mean encounter rate (detections per person/hour; black) and species richness (gray) of *Phelsuma* geckos recorded for each land-use type in Nosy Be, Madagascar. Error bars denote standard error of the mean. Encounter rates for Forest sites (A) were significanlty different to Orchard (B) and Cropland sites (B). Fragment sites (AB) did not differ from Forest, Orchard, or Cropland sites. There was no significant difference in species richness between the four land-use types (a).

## *Comparison of Land-Use Types*

There was a significant difference in the relative abundance of *Phelsuma* species recorded at sites in different land-use types ($H = 10.37$, $df = 3$, $p < .05$; Figure 3). This difference was found between Forest and Orchard sites (Dunn's test, $Z = -2.51$, $p < .05$) and Forest and Cropland sites (Dunn's test, $Z = -2.68$, $p < .05$). There was no discernable difference between the other remaining sites surveyed (Table 3). The species richness of *Phelsuma* geckos also differed between land-use types; however, this difference was not significant ($H = 6.59$, $df = 3$, $p > .05$; Figure 3; Table 3).

**Table 3.** Summary Data of the Dunn's Test With Bonferroni Adjustment Method for Both the Relative Abundance and Species Richness of *Phelsuma* Geckos.

| | Forest | Fragment | Orchard |
|---|---|---|---|
| Relative abundance | | | |
| Fragment | −1.52 ($p > .1$) | | |
| Orchard | −2.51 ($p < .05$)* | −1.25 ($p > .5$) | |
| Cropland | −2.68 ($p < .05$)* | −1.42 ($p > .1$) | −0.15 ($p > .5$) |
| Species richness | | | |
| Fragment | −1.26 ($p > .5$) | | |
| Orchard | −2.17 ($p > .05$) | −1.13 ($p > .5$) | |
| Cropland | −1.95 ($p > .1$) | −0.91 ($0 > .5$) | 0.19 ($p > .5$) |

### Species-Specific Responses

*Phelsuma* species responded differently to the gradient of land-use change (Figure 4). The mean encounter rate for the giant Madagascar day gecko (*P. grandis*), the broad-tailed day gecko (*Phelsuma laticauda*; Boettger, 1880), and Abbott's day gecko (*Phelsuma abbotti*; Stejneger, 1893) increased in more recently disturbed sites (Figure 4). In contrast, the mean encounter rate for Seipp's day gecko (*P. seippi*) declined with recent human disturbance (Figure 4). No conclusions could be drawn about the Zanzibar day gecko (*P. dubia*) as this species was only detected at one site (Figure 4).

## Discussion

There was a significant difference in the relative abundance of Madagascan day geckos (*Phelsuma* spp.) between Forest and Orchard and Forest and Cropland sites. Surveys recorded a greater mean encounter rate and species richness in disturbed, agricultural land than in primary rainforest. These results indicate that agricultural land can provide habitat for Malagasy species; hence, future research should extend beyond the borders of protected forests into anthropogenically disturbed areas.

### Trends of Individual Species

*Phelsuma* geckos are likely attracted to areas with a greater number of arboreal perch sites, egg laying sites, and higher food availability (Augros et al., 2017; D'Cruze, Sabel, et al., 2009; Ineich, 2010), such as agricultural plantations and human settlements. These species may also favor human-modified habitats because they offer increased cover and protection from predators (D'Cruze, Sabel, et al., 2009). Our results indicated three species of *Phelsuma* geckos were more readily encountered in human-modified habitats than forested

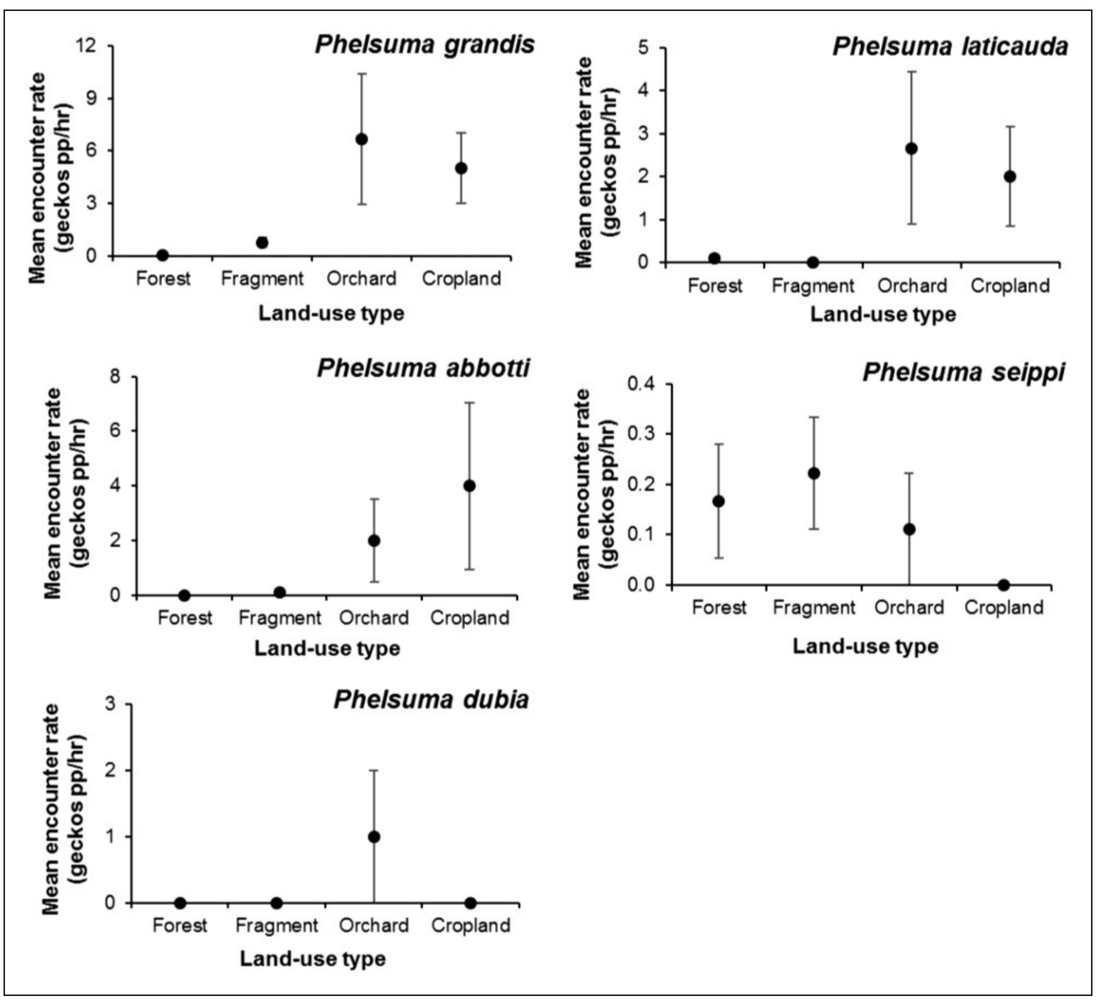


**Figure 4.** Species-specific responses to a gradient of land-use change. Each figure represents the mean encounter rate (detections per person/hour) for a single *Phelsuma* species across the four land-use types. Error bars denote standard error of the mean.

sites: the giant Madagascar day gecko (*Phelsuma grandis*; Gray, 1870), the broad-tailed day gecko (*Phelsuma laticauda*; Boettger, 1880), and Abbott's day gecko (*Phelsuma abbotti*; Stejneger, 1893). Previous studies in Madagascar have identified *P. grandis* and *P. laticauda* as adaptive generalists, as they are often recorded in disturbed areas (D'Cruze, Sabel, et al., 2009; Roberts & Daly, 2014). Further studies on neighboring islands have indicated similar distributions (Hawlitschek, Bruckmann, Berger, Green, & Glaw, 2011), with urban or agricultural areas found to provide habitat for up to five coexisting species (Augros, Fabulet, & Hawlitschek, 2017b). Some authors have proposed that *Phelsuma* geckos may benefit from ongoing deforestation in Madagascar (Glaw & Vences, 2007; van Heygen, 2004), as they are able to use open, cultivated areas and are often more abundant in such sites compared with their natural forested habitats (Bauer, 2003). Overall, our results support existing evidence that *P. grandis*, *P. laticauda*, and *P.abbotti* may be less vulnerable to habitat destruction than other Malagasy reptiles due to their ability to utilize disturbed forests and agricultural plantations.

In contrast, Seipp's day gecko (*Phelsuma seippi*; Meier, 1987) is classified as Endangered by the IUCN (2017) due to its restricted range within a fragmented habitat, which is undergoing continued conversion into agricultural land (Ratsoavina et al., 2011; Roberts & Daly, 2014). Current research suggests that *P. seippi* may depend on bamboo forest, as it is often detected on the fringes of rainforest in stands of bamboo (van Heygen, 2004). *Phelsuma seippi* is likely a habitat specialist, and therefore it is more sensitive to forest degradation, loss, and fragmentation than other congeners (Irwin et al., 2010; Raxworthy & Nussbaum, 2000). Our results, with most records in Forest and Fragment sites, support the view that this species is less tolerant to land-use change than the other *Phelsuma* geckos detected in our study. Further research is needed on the habitat requirements of this species to aid future conservation planning (Ratsoavina et al., 2011).

The Zanzibar day gecko (*Phelsuma dubia*) was only detected in the banana plantation ("Orchard"). As such, no conclusions could be drawn regarding its response to land-use change on Nosy Be. *Phelsuma dubia* is believed to be a highly adaptable species and is often found in anthropogenically modified habitats including fruit plantations (Hawlitschek et al., 2011; van Heygen, 2004). Previous studies have suggested that *P.dubia* may be rare in the region (van Heygen, 2004), which could account for our sparse detections. Conversely, recent research has indicated that *P. dubia* is likely to be underestimated in surveys as it favors high perches which are difficult to detect from ground level (Augros et al., 2018).

### Methodological Considerations

The detectability of reptiles is highly variable and depends on the degree of species crypsis (both in appearance and behavior) (Hampton, 2007; Marzerolle et al., 2007), survey technique used (Ribeiro-Junior, Gardner, & Avila-Pires, 2008), sampling effort (Garden, McAlpine, Jones, & Possingham, 2007), weather conditions (Crosswhite, Fox, & Thill, 1999), and the habitat type (Ribeiro-Junior et al., 2008). Large, brightly colored species, such as the giant Madagascar day gecko (*P. grandis*), are often easier to detect than dull, cryptic species in forested habitats (D'Cruze, Sabel, et al., 2009). In addition, previous studies in tropical regions have indicated that the detectability of wildlife is heavily influenced by forest structural complexity (Jenkins, Brady, Bisoa, Rabearivony, & Griffiths, 2003; Smith et al., 1997). Secondary forest is comparatively more open, enabling researchers to detect target species at a greater distance or encounter cryptic species more frequently (Smith et al., 1997). These factors, habitat structure and vegetation density, may have influenced our ability to detect geckos in primary rainforest habitats.

Furthermore, due to logistical, timing, and funding constraints, we were unable to survey for *Phelsuma* geckos above a height of 4 m during this study. The detection success of small arboreal species from the ground, especially in tall-canopy forest, is likely to be low (Imlay, Dale, Buckland, Jones, & Cole, 2012). It is therefore important to note that agricultural sites, especially those devoid of tall trees such as the pineapple plantation, would have been surveyed more thoroughly in this study when compared with forested sites. For future surveys, we recommend conducting stationary vantage point surveys with binoculars (Augros et al., in press), or if possible, following the method outlined by Imlay et al. (2012): elevated point count surveys with distance sampling.

Collection of data in this study was largely undertaken by volunteers. Individuals may vary in their level of commitment, experience, and skill, and there is a risk that volunteers may introduce bias by recording false absences or via uneven sampling effort within or between sites (Bird et al., 2014; Crall et al., 2011). Recent research, however, suggests that volunteer data is often just as accurate as data collected by experienced professionals (Lewandowski & Specht, 2015). To reduce the potential for bias in our study, volunteers were trained in species identification and were required to pass a short test prior to participating in surveys. In addition, all volunteers in this study were current research assistants with the Society of Environmental Exploration and possessed fauna surveying experience and a relevant tertiary qualification. We therefore consider it unlikely that volunteer bias would have affected our findings.

The authors wish to acknowledge that this is only a small pilot study. Our understanding of the response of

*Phelsuma* geckos to land-use change would benefit from more in-depth research, particularly with the addition of a greater number of replicate sites and a broader range of survey methods to cover all forest strata, such as elevated point count surveys with distance sampling.

### Conclusions

Madagascan day geckos (*Phelsuma* spp.) display differing responses to landscape change. Several adaptive, generalist species are tolerant of land clearing as they are capable of using cleared agricultural areas and human infrastructure (Glaw & Vences, 2007; van Heygen, 2004); but others are sensitive to anthropogenic disturbance (Irwin et al., 2010). *Phelsuma seippi*, the only species detected in this study that is currently recognized on the IUCN Red List (2017), appears to be sensitive to land-use change (Irwin et al., 2010; Raxworthy & Nussbaum, 2000). Further research is required to broaden the understanding of the responses of these species, and common native fauna, to landscape change in order to face the ongoing threat of deforestation.

## Implications for Conservation

Knowledge of the distributions, responses, and tolerances of species to anthropogenic land-use change will be crucial for future conservation efforts in Madagascar (Gardner & Jasper, 2009; Raxworthy & Nussbaum, 2000). Our understanding of the conservation value of secondary forest and agricultural land is limited, although unprotected forests and disturbed habitats are known to possess considerable biodiversity (Andreone et al., 2003; Gardner, 2009; Ingram & Dawson, 2006). Furthermore, as evidenced in this study, modified habitats can support populations of some adaptive, generalist species. We therefore recommend that future research extends beyond the borders of protected areas to include anthropogenically disturbed areas such as secondary regenerating forest and agricultural landscapes.


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