Home range, habitat use and social behaviour of the endangered Mauritian gecko

*Phelsuma guentheri*

Master’s Thesis

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Zurich, 31st January 2008

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Abstract

Use of space and social organisation in the field is still little known among nocturnal gecko species (Gekkonidae). Their nocturnal habits make observation difficult. Modern techniques of radio-tagging with miniaturization of tags allow advances in this field. The present study addressed questions of home-range size, habitat use and social behaviour in Guenther's gecko (*Phelsuma guentheri*). As the only extant member of the Day gecko genus *Phelsuma* it is assumed to be predominantly nocturnal. This large and inconspicuous species is endangered and only occurs on a single island off the Mauritian north-east coast. Translocation within its former range has been proposed as a measure to minimise the risk of extinction. The data on the basic ecology of *P. guentheri* will facilitate decisions in the context of translocation. To document the spatial ecology and social behaviour of this species I tracked 12 adult geckos in their preferred habitat, palm forest, on Round Island. All radio-tracked geckos had discrete ranges that varied considerably within both sexes, however. Average home-range size with the minimum-convex-polygon estimate of males and females was 73 m$^2$ and 31 m$^2$, respectively. The fixed kernel estimator determined mean areas of 132 m$^2$ and 48 m$^2$ for males and females, respectively. Home ranges of males and females were not significantly different. Body size, too, did not correlate with the home-range area. Males and females did not differ in either snout-vent length or body weight, but overall males grew larger. All tracked geckos preferably used the dominating fan palm *Latania loddigesii* during both day and night. Groups of animals lived together in the home ranges of tagged animals. Males and females had overlapping areas and were sighted together on several occasions. In none of the cases, there were any social interactions however. Polygamy is the likely mating system of *P. guentheri* based on the evaluation of home-range overlap of male and female geckos. Radio tagging proved a valid technique for the study of such a secretive gecko and qualified for future use if certain considerations are followed. Radio tagging is also recommended for monitoring after translocation. Recommendation for any receiving island is that vegetation should be forest-like and offer a combination of refugia and feeding sites.
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1. Introduction

Detailed studies on spacing pattern and social behaviour in animals date from the early 1920s, with first accounts from birds (e.g. Howard, 1920). While other taxa, particularly mammals and birds, have been extensively studied, research on reptiles lagged behind for a long time (Stamps, 1977). Even within the reptile taxon there has been a bias with a focus on terrestrial lizards in temperate latitudes (e.g. Simms, 1970) or arid and desert areas (e.g. Parker, 1974; Satrawaha & Bull, 1981). Within the reptile family of the geckos (Gekkonidae), particularly diurnal geckos with their often bright colours and aggressive territorial displays have caught the attention of herpetologists. Several studies have looked at territorial behaviour of diurnal geckos in captivity, but also in the field (e.g. Kästle, 1964; Osadnik, 1987; Ikeuchi et al., 2005). Confirmation of territoriality of nocturnal geckos in the field has been difficult owing to the secretive lifestyle of many nocturnal geckos. Therefore, most accounts on territoriality in nocturnal geckos report fighting in captivity, or exclusive occupancy of shelter sites in the field (Stamps, 1977). However, data from captive studies can vary considerably from field observations because, for instance, males in crowded captive conditions cannot form territories but dominance hierarchies develop instead (Hagdorn, 1973). Correlations between home-range size, degree of polygyny, and sexual size dimorphism that were found in other territorial lizards still need to be investigated in nocturnal geckos.

1.1. Animal space use and sociality

Animals extract the resources they need for survival and reproduction from their environment. These resources are limited in space and time and therefore shape communities dependent on them. The outcome of interactions between individuals and their environment are population dynamics and, more statically, patterns of distribution and abundance. To look at these patterns and their causes is a fundamental issue in ecology (Krebs, 1978). As Pianka (1973) pointed out, ‘exactly where in the environmental mosaic a lizard forages, as well as its mode of foraging in that space, is perhaps its most important ecological attribute’. A useful approach to study the relevant interactions is to look at animal movement in relation to social and ecological factors (Hebblewhite et al., 2005).

Animals usually do not wander around aimlessly, but stick to areas that they traverse in their ‘normal activities of food gathering, mating and caring for young’, known as their home range (Burt, 1943). This definition points out two important dimensions of this specific area, supply of trophic resources and social interaction. The home range is a link between the landscape and the population dynamics, and is the most commonly used estimator of animal space use (Börger et al., 2006a). The concept was alternatively formulated by Kenward (2001) as ‘an area repeatedly traversed by an animal’. This definition allows an objective delineation of an animal’s home range based on excursions where the movement is there and back. Thereby it enables us to separate a home range from unidirectional dispersal excursions (Kenward, 2001).
Across animal species, studies have shown a connection between the ecology and the mating system of a species. Environmental factors influence male and female reproductive success. Females tend to follow the distribution of resources because their reproductive rate is limited by them (Krebs & Davies, 1995). For males, reproductive success is limited by access to females. Males can usually benefit more than females by maximising their number of matings. Therefore they compete and monopolize as many females as they can in their territories (Krebs & Davies, 1995). The distribution of females in space and time determines the ability of a male to gain access to them. Thus, for example, polygamy is more probable in the case of aggregated food resources, where it often is easier for males to defend areas around several females. With even distribution of resources there is less potential of polygamy (Krebs & Davies, 1981). A diverse range of social structures has been documented in reptiles (especially lizards), most of them being simple and based on territoriality and dominance hierarchies (Stamps, 1983). The most frequent mating system in reptiles is promiscuity, when individuals of both sexes pair with various individuals of the other sex during the reproductive season (Stamps, 1977; Pough et al., 2001). Monogamy, as characteristic in many birds and mammals, is the exception, and long-term pair bond has only been observed in few species (Cuadrado, 2002). A well-known example is *Phelsuma standingi* in Madagascar. Pairs of males and females live together on trees, and the pair bond is so strong that they do not accept new partners even if one is removed or dies (Henkel & Schmidt, 1991).

Morphological appearance and behaviour allow conclusions about the social system and space use of a species. For instance, most lizard species with strong differences in home-range size are taxa in which males grow larger than females and compete aggressively for mating opportunities (Stamps, 1977). An increase of sexual dimorphism in size or ornamentation with the degree of polygyny exists in many taxa (e.g. primates, Clutton-Brock et al., 1977; mammals, Alexander et al., 1979; amphibians, Shine, 1979; birds, Björklund, 1990). A major reason for this is probably that the sex roles are more similar in monogamous species with biparental care for offspring (Andersson, 1994). The correlation between home range defence in general, the size of the defended area, sexual dimorphism and the mating system led Stamps (1983) to propose home range ratios as a quantification method of polygyny in territorial lizards. The larger the home ranges of males are compared to those of females of a species, the more likely is polygyny. In the diurnal gecko *Phelsuma madagascariensis kochii* Ikeuchi et al. (2005) confirmed this with their findings of conspicuous male biased dimorphism, territorial displays and larger home ranges of males.
1.2. Conservation of island populations of endemic species

Understanding the spacing pattern and social behaviour is an essential prerequisite for successful conservation management of endangered species. A major part of such conservation work has taken place on oceanic islands, which have been disproportionately affected by human-caused extinction of species (Smith et al., 1993). Two traits of island ecosystems have contributed to the 'extinction crisis': their high levels of endemism and their relative simplicity with fewer species and interactions than in comparable areas of mainland ecosystems (Whittaker, 1998). The latter can be interpreted as islands being less competitive environments that allow introduced species to take over.

Species in which small population size and restriction of the range coincide are highly vulnerable to extinction (Terborgh & Winter, 1980). Stochastic variation of the local environment (e.g. from a cyclone) can cause the size of such small populations to fluctuate ('small population paradigm', Caughley, 1994). In an extreme case, the number of reproductive animals decreases below a certain threshold level without any opportunity for recovery. Conservation management aims at preventing and reversing such declines. One such management tool is translocation of (parts of) populations of endangered species within their former range of distribution. This method has indeed become an important management tool, but in many cases the reintroduction attempts have failed (Dickinson et al., 2001). Successful translocations rely heavily on detailed knowledge on the life history and biological demands of the target species: e.g. habitat preferences, adaptation to local ecological conditions, social behaviour, home-range size, and food requirements (IUCN, 1995). Monitoring after translocation is essential as well, and obviously, meaningful interpretation of this is dependent on reference values from the original habitat. Important information prior to reintroduction is the distribution of sexes and closely related animals to get maximum genetic diversity for the founder population. On release, it is similarly important to establish an appropriate way of distributing the animals, which meets their specific requirements spatially and socially. For instance, any recipient site for the reintroduction of a species must be large enough to contain a sufficient number of animals to maintain at least mid-term population viability.
1.3. Round Island as a case study

Mauritius once had a rich reptile diversity and belongs to the biodiversity hotspot of Madagascar and the Indian Ocean islands (Myers et al., 2000). Since colonisation by humans in the 16th century, extensive habitat degradation and clearance and high rates of extinction have devastated Mauritius and its offshore islets. Cats, pigs, mongooses, and particularly rats are examples of predators that were introduced, and together with direct human habitat destruction, probably caused the extinction of all larger lizard species on mainland Mauritius (Cheke, 1987). Several species survived on offshore islands. Therefore these islands, despite their often small size, have gained importance for the conservation of endemic, threatened species (Jones, 1993). Among these islands, Round Island is of particular importance. Cats and rats never made it to Round Island, and it became a refuge for several plant and reptile species that went extinct elsewhere. For instance, it has the largest remaining area of palm forest that once dominated the lowlands of north and west Mauritius (the so-called ‘palm savannah’; Vaughan & Wiehe, 1937). This is astonishing in view of the habitat destruction Round Island nevertheless. Goats (Capra hircus) and rabbits (Oryctolagus cuniculus) were introduced in the 19th century and have had a strong negative influence on the ecosystem (Cheke, 1987; Bullock, 1986). After the eradication of goats in 1978 and rabbits in 1986 (Merton, 1987), recruitment of young palm trees has increased markedly (Bullock et al., 2002). Furthermore, together with natural recovery, a programme for the reintroduction of hardwood tree species run by the Mauritian Wildlife Foundation (MWF) aims at the restoration of the island. Bullock et al. (2002) called it an ‘experiment’ that allows measuring ecological processes in the long term.

The reptile community of Round Island is the least modified of any Mascarene island (Bullock, 1986). Eight reptile species, including six lizards, were present on Round Island until recently. One of the two snakes however, the burrowing boa (Bolyeria multocarinata), is considered extinct because it has not been seen since 1975 (Bullock, 1977). Of the seven remaining species, four were restricted to Round Island until 2006: Guenther’s gecko (Phelsuma guentheri), Durrell’s night gecko (Nactus durrelli), Telfair’s skink (Leiolopisma telfairii) and the keel-scaled boa (Casarea dussumieri). In 2006, Telfair’s skink and Durrell’s night gecko were reintroduced to other predator-free islets (Cole et al., 2007).

However, reptile species on Round Island remain vulnerable because of stochastic and anthropogenic events (North et al., 1994). Cyclones have had large negative impacts, particularly on tree vegetation (e.g. cyclone Gervaise 1975). Beside such a natural disaster, accidental introduction of predatory or competitive species (such as rats or house geckos) is the main risk (Bullock, 1986). Especially now with the recent establishment of a permanent field station and frequent change-overs of management staff and researchers. Already in the first management plan for Round Island (Merton et al., 1989), translocation of the three species keel-scaled boa, Guenther’s gecko and Telfair’s skink was proposed to ‘spread the risk’ of possible extinction. At the same time, it was emphasized that more detailed data on the ecology of these reptiles would be essential to plan such conservation action.
1.4. Study background

Beside conservation, *Phelsuma guentheri* is also of ecological interest because it is the only extant *Phelsuma* species that is assumed to be predominantly nocturnal (Bullock, 1986). A study on *P. guentheri* would thus be valuable to elucidate potentially convergent development of ecological traits between nocturnal geckos from several typically nocturnal clades. Its secretive lifestyle has not only been pointed out in the field but also for captive animals. Wheeler & Fa (1995) found in their study in Jersey Zoo that the geckos favoured areas with hiding places, particularly during day-time. Besides information from captive studies (Wheeler & Fa, 1995; Flynn, 1986; Langebaek, 1979), a field study (Carpenter, 2003) provided more insight into macro- and microhabitat use and activity patterns. Arboreality and association with the palm forest had long been suggested and evidence was found in a field study (Carpenter, 2003). Data from the wild population exist on population size (Bullock et al., 2002), egg laying sites (Carpenter, 2003), habitat use (Carpenter, 2003), and diet (Bullock, 1986).

Yet, many uncertainties remain, particularly in the field of behavioural ecology. Their secretive nature has limited observation by eye. For instance, Bullock (1986) compared encounter rate of geckos from the ground to direct counts in the palm crowns. He found that 70% of the *P. guentheri* geckos were missed when only counting from the ground. A good way to overcome such observation bias is radio tracking. My study is the first field-based investigation of movement patterns and social biology of the gecko *P. guentheri*. The advantage of modern techniques of radio tracking is that animals can be located at any time, regardless of where they are and whether they are active or not (Kenward, 2001). Thereby, observation bias due to visibility in certain habitats can be minimized. Another important point is the ease of individual identification, which does not require any further recapture or disturbance during the time of data collection.
1.5. Study aims and questions

The aims of the present study are to investigate the home range, habitat use and social behaviour of *P. guentheri*. The acquired knowledge will allow assessment of the spatial requirements of this gecko species. To achieve these aims I established a technique of radio tagging this elusive species to allow less biased observations. Specifically, my study aims are:

1) **Home-range size.** Establishing the size of the home ranges male and female *P. guentheri* during the breeding season. I investigate factors that might influence home-range size, such as sex and body size. As an additional indicator of the size of home range of males and females relative to each other, I aim at comparing body size of males and females.

2) **Habitat use.** Carpenter (2003) established habitat use of *P. guentheri*. In this study I attempt to verify his findings based on observations by radio tracking. I aim at determining any temporal pattern in the vertical movement, i.e. any rhythm of using the available height levels in their habitat.

3) **Social behaviour.** I study overlap of home ranges within and between sexes to acquire more knowledge on the social structure of *P. guentheri*. Beside static interaction, investigated as overlap of home ranges, I also aim at observing dynamic social interactions, i.e. social behaviour among conspecifics. A further aim is to identify any interactions with other reptile species in the habitat.

4) **Radio tagging method.** When a complex technique such as radio tagging is used on a species for the first time, particular care is essential. I aim at closely monitoring the animals and how they cope with the tags on their backs. Apart from investigating potential adverse tag effects that might influence the validity of the collected data, I also aim at evaluating the technique for future use on *P. guentheri*. 
2. Material and Methods

2.1. Study site

The field work was carried out on Round Island (57°47'03” E, 19°54'03” S), 22.5 km off the north-east coast of Mauritius (figure 1). The island, a remnant of a basaltic volcanic cone, has an age between 25'000 and 100'000 years (Merton et al., 1989) and was connected to mainland Mauritius during the last Ice Age (Arnold, 1980). It covers 219 ha and rises 280 m above sea level (Johansson, 2003). Climatically, Round Island is semi-arid with an average annual rainfall of 880 mm and an annual mean temperature of 24°C. Temperatures are highest in January (average 27.3°C) and lowest in July (average 20.7°C) (all records by the Round Island wardens; MWF, 2007). June, July, and August are the cold and dry Mauritian winter months.

Round Island can be divided into seven distinct habitat types according to vegetation and substrate (Johansson, 2003): (1) palm forest, (2) mixed weed & herb-rich community, (3) helipad, (4) rock slab, (5) summit, (6) coastline, (7) crater (see Round Island map in appendix 1). The palm-rich forest covers about 65 ha (N. Zuël, pers. comm.), and today covers mainly the more sheltered western and northern slopes. It was once more widespread on Round Island, and consisted of at least four palm species: fan palm (Latania loddigesii), bottle palm (Hyophorbe lagenicaulis), screwpine (Pandanus vandermeerschii), and hurricane palm (Dictyosperma album var. conjugatum). Today, Latania is the dominating species (Johansson, 2003).
2.2. Study species

*Phelsuma guentheri* is probably the largest living *Phelsuma* species with a snout-vent length of 140 mm maximum in males (Vinson & Vinson, 1969; Bullock, 1986). Day geckos of the genus *Phelsuma* are distributed across the Indian Ocean (Loveridge, 1942). About 40 species are currently recognised (Austin et al., 2004). More than half of them occur on Madagascar and nearby islands (Hallmann et al., 1997). In the Mascarene Archipelago an insular radiation led to seven currently recognised species, four of which occur on and around Mauritius (Austin et al., 2004). Three of these species are small, diurnal and occur on the main island. The fourth is the large *P. guentheri*, which is substantially nocturnal (Austin et al., 2004). A recent phylogenetical study suggested that *P. guentheri* is secondarily nocturnal and basal to all extant Mascarene forms (Austin et al., 2004). However, accounts of activity pattern have disagreed considerably: Vinson & Vinson (1969) reported it to be diurnal. Bullock (1986) considered *P. guentheri* to be nocturnal while Carpenter (2003) found no distinct pattern of activity. *P. guentheri* feeds on insects, fruit, nectar, and also on other geckos (Vinson & Vinson, 1969; Bullock, 1986; Carpenter, 2003).

Typical of *P. guentheri* is its inconspicuous colour that varies from bark-like grey to brown and bright grey (Vinson & Vinson, 1969). Only few other *Phelsuma* species are similar in their drab colours of simply brown tones (e.g. *P. mutabilis, P. modesta* (Henkel & Schmidt, 1991)). Another characteristic feature which may reflect its partially nocturnal nature, is the vertically elliptical pupil (Vinson & Vinson, 1969).

The breeding season is mainly in July and August, but can extend to October (N. Zuël, pers. comm.). The population is estimated in the low thousands (i.e. <5'000 animals), and therefore the species remains vulnerable to extinction (Bullock et al., 2002).

2.3. Data collection

2.3.1. Catching and tagging individuals

With the help of several volunteers, I caught 21 animals during daytime between 28th May and 6th July 2007. The geckos were caught by hand, some of them with the additional help of a rubber-band noose at the end of a stick. I avoided the common use of other loop materials (e.g. waxed dental floss; Bennett, 1999), because of the delicate skin of *P. guentheri*. After catching the animals, they were checked for recent scars and any signs of malnourishment such as a protruding backbone or pelvis (N. Cole, pers. comm.).
I also determined their sex, distinguishing males from females by their preanofemoral pores (figure 2 and 3). For transport and further handling in the field station, the geckos were kept in white cloth bags. The trees the geckos were caught on were marked with tape and a GPS coordinate was recorded (Garmin model GPSMAP 76; record in decimal degrees with the map datum WGS 84).

In the field station, the animals were weighed with a pesola scale (600 g, 5 g accuracy) while in their bags. I placed the animals belly-down in a transparent plastic box to measure the snout-vent length (SVL) and tail length (TL), preventing them from moving with a piece of soft rubber foam pressed down in the box. Two lines were then drawn onto the bottom of the box following the central body line along the ventral side: the first one from the tip of the snout to the vent, and the second from the vent to the tip of the tail. All animals caught were identified as adult or juvenile according to their size (SVL (snout-vent length) ≤ 100 mm = juveniles (North et al., 1994). An additional measure was the width of the base of the tail, which was measured 10 mm below the vent with a dial calliper three times (Wiha, dialMax®, accuracy 0.1 mm). An average was calculated from the three measurements to account for measurement error. In a next step, the body condition of the animals was assessed with several traits. Number and location of scars on the head, body, and tail was recorded together with an account if any toe had been lost. The tail was assessed as well as being original complete, complete regenerated, or broken. In the case of a complete regenerated tail, the length of this piece was measured once with a dial calliper, too. These records served not only for an assessment of body condition but also for unanimous identification of a gecko, for instance, if it lost the tag.

The backpack harnesses I used were constructed for the specific anatomy and dimensions of *P. guentheri*, based on designs described by Fisher & Muth (1995), Richmond (1998), and Warner et al. (2006). Additional input for the design came from Dylan van Winkel who has been radio tagging a similar-sized nocturnal gecko, *Hoplodactylus duvaucelii*, in New Zealand. The skin of *P. guentheri* is very soft and particularly prone to damage, even compared to other species of the genus *Phelsuma* (N. Zuël, pers. comm.). Therefore we used soft veterinary latex stretch bandages on rolls of 4.5 m x 15 cm (Gospel CoPoly cohesive flexible bandage).
First, a piece of 40 cm was cut from the role and folded over to get a double-layer sheet of 20 x 15 cm. A paper template was clipped to the stretch bandage to cut out the backpack harness with a pair of scissors. The harness consisted of a central part where the transmitter was attached, an additional piece for padding, two shorter straps to fasten the transmitter, and the shoulder straps of 100 mm length and 6 mm width (figure 4). A single size fitted all adult animals (which ranged from 102 - 138 mm snout-vent-length). Two types of transmitters were used (Sirtrack Ltd., Havelock North, New Zealand; single stage transmitter type 1, battery life = 4.5 months, weight = 3.5 g, and single stage transmitter type 2, battery life = 2.5 months, weight = 3 g). The transmitter was glued onto the harness with super glue gel (UHU Schweiz AG). Transmitters were chosen for the geckos so that the weight of the complete tag, i.e. transmitter and harness, did not exceed 8% of the animal’s weight (within the recommendations by Beaupre et al., 2004).

Figure 4. Harness with the additional piece for padding (top left), tag ready for mounting (top right), and close-up of the transmitter on the harness (bottom left).

1 In this thesis, I always refer to the transmitter as the ready-to-use device made up from electric circuitry, power supply, and whip antenna. Tag or backpack is used to refer to the combination of transmitter and harness which was mounted on the animals.
The active nature of *P. guentheri* made mounting the tag easiest when one person held the gecko, while a second person attached the backpack. Depending on the exact attachment strategy (glue used or not, belly strap Y/N) the following steps were adapted. In the case of super glue gel being used to partially glue the tag to the animal’s back, two or six droplets of glue were placed on the bottom side of the centre piece of the tag. Using gel glue was favourable to avoid pungent vapours that could be harmful to the animals. The tag was placed on the back of the gecko right behind the neck with the shoulder straps pointing forward along each side of the head. This placed the antenna dorsally and caudally along the axis of the body. Next, the person holding the animal firmly pressed the tag against the gecko’s back while the other person pulled each shoulder strap down along the shoulder, crossed the straps on the gecko’s chest and pulled them back up behind the opposite foreleg (figure 5). To check the fit of the straps on the chest and in the axilla the animal was turned to its back. After the check, the straps were attached dorsally to the centre piece of the tag using two drops of glue on each side. Excess material from one of the straps was cut off, while the other strap was glued over the back of the transmitter for additional stability (figure 6). On the chest the two crossing straps were glued together for more rigidity. In each case, the straps were held in position for about 30 s until the glue had dried. For the backpack design with a belly strap, one end of a strap of 8 mm width was glued on the left side at the very back of the centre piece. The other end of the strap was pulled under the belly and up on the other side, and then glued to the right side of the centre piece. One casualty in the first week of tagging and the overall body condition of juvenile *P. guentheri* found in the field, led us to a decision against further tagging of juveniles. Therefore only adult male and female *P. guentheri* geckos were tagged and studied.
Tagging usually took place in the evening in the field station and the animals were released the next morning, which allowed a check of the animals after one night with the tag on. The tags stayed on the animals between 3 and 58 days (mean tagging duration 18 ± 14 days). Animals that got out of their tags were caught again, identified with the help of the morphometric measurements and the records on body condition, and re-tagged once. Re-tagging was avoided if an animal had bruised skin anywhere the new tag would be situated.

2.3.2. Adverse effects of tagging

Because tagging had never been tried on this gecko species, and because it has a very sensitive skin that sheds easily, special attention was paid to prevent adverse effects. Important potential effects on survival, physiology, and behaviour of the animals were monitored. Table 1 shows the factors that were considered. The focus was on direct observation of adverse effects rather than an experimental comparison of tagged and untagged animals, which was logistically not feasible. To complete the observations during the tagging period, tagged geckos were also monitored for up to four weeks after removal or loss of the tag. Particularly in cases where scars resulted from tagging, it was important to see how the animals dealt with it. I used permanent colour to mark these animals in order to be able to identify them also from a distance or when they were partly hidden (non-toxic enamel paint, Revell AG, Germany; and Plakat-Tempera Gouache Winsor & Newton, England).

Table 1. Categories and observations that were taken to account for potential adverse tag effects.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Questions asked</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival</td>
<td>Casualties</td>
<td>Report of any casualty</td>
</tr>
<tr>
<td>Physiology</td>
<td>Effect on tissue Scars or wounds</td>
<td>Body assessment after tagging, photos of scars</td>
</tr>
<tr>
<td></td>
<td>Body weight</td>
<td>Potential weight loss Weighing before/after tagging</td>
</tr>
<tr>
<td>Behaviour</td>
<td>Movement</td>
<td>Is walking, climbing, or jumping impaired? Observation of the first three animals in a plastic box before release, observation in the field</td>
</tr>
<tr>
<td></td>
<td>Entanglement</td>
<td>Does the animal get entangled (e.g. in vegetation)? Observation in the field</td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td>Are interactions with other individuals inhibited? Observation in the field</td>
</tr>
</tbody>
</table>

2.3.3. Radio tracking

After release, locating and observing the geckos started on the following day. I decided for this strategy, against several acclimatization days before collecting data (Withey et al., 2001), because of several reasons. Firstly, this method allowed closely surveying tag fit and body condition of the animals from the very start of their time back in the wild. Secondly, tags started to come off much earlier than expected even when the tag had an apparent optimum fit.
This required an immediate start of data collection to efficiently use the period an animal was tagged. A systematic sampling scheme was created to equally cover all 24 h of a day. I subdivided a day into six four-hour intervals, starting with 06:00-10:00 h, and onwards. This subdivision was based on temperature and light conditions, which are rather constant during each of these intervals (N. Zuël, pers. comm.). I attempted to collect an equal number of locations for each animal in all intervals. The blocks were arranged so that two locations of an animal were separated by a minimum time period of 4.5 hours, satisfying the usual criteria for statistical independence in such studies (i.e. sufficient time between observations for the study species to traverse its home-range diameter; White & Garrott, 1990). Due to logistical reasons, the schedule for locating the animals was not completely randomised. Instead, animals were located in a sequence so that neighbours were located successively, rather than having successive locations at opposite ends of the study area. Additionally, I thus avoided disturbance of animals in the centre of the study area by frequently passing their areas. To prevent effects of the overall order of locations on the collected data I started with another animal each time (Kenward, 2001).

The tagged geckos were located with a telemetry receiver R-1000 (Communications Specialists Inc., California, USA) and a three-element Yagi antenna (Sirtrack Ltd, Havelock North, New Zealand). After getting an approximate location of an animal with triangulation, I homed in with the aim to spot the animal for a quick check of its body and backpack before taking further records (see table 2).

Table 2. Records for each location of a Guenther’s gecko that were used for analysis. The full monitoring protocol is available in the appendix.

<table>
<thead>
<tr>
<th>Record category</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal</td>
<td>Record of the exact geographic position, e.g. measured to an absolute reference tree with a measure tape and a compass (Recta DS 40, 2° accuracy). Northing and easting were calculated in the data table.</td>
</tr>
<tr>
<td>Date</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>GPS coordinate</td>
<td>Latania sp., Pandanus sp., rock, ground, other</td>
</tr>
<tr>
<td>Substrate</td>
<td>Measured at an accuracy of 0.1m from 0 to 3m and estimated at an accuracy of 0.5m at a height of &gt; 3m</td>
</tr>
<tr>
<td>Height above ground of spotting</td>
<td>Record: number; species; interactions, e.g. for P. ornata differentiate between juvenile and adult and for L. telfairii juv., subadult, adult</td>
</tr>
<tr>
<td>Presence of other reptiles (within a distance of 1m)</td>
<td>General: assessment of general body condition to see whether animal is well nourished (signs of malnourishment: backbone, pelvis or neck bones visible) Colouration (in 2 categories grey, brown plus account whether pattern is visible or not) Remarks (e.g. not available, shedding)</td>
</tr>
<tr>
<td>Body condition assessment</td>
<td>Fit on the animal and if there were any bruises from the backpack, condition in terms of straps and glue</td>
</tr>
<tr>
<td>Backpack condition</td>
<td></td>
</tr>
</tbody>
</table>
2.3.4. **Habitat mapping**

In order to get exact coordinates of the trees that the geckos inhabited, I mapped all trees in the respective clumps relative to a reference tree by using a measure tape and a compass. The reference trees were geo-referenced with a GPS. In the areas I mapped there were no other palms than *Latania loddigesii*. I mapped all *Latania* palms with a trunk and palms without a trunk that had a minimum total height (i.e. at the highest leaf point) of 2 m. For *Latania* palms with a trunk, the trunk height was measured at an accuracy of 0.1 m up to a height of 3 m or estimated at an accuracy of 0.5 m for palms with taller trunks. For the ones which had not yet developed a trunk, total height was recorded. Additional records were the diameter at breast height, sex of the tree, and the availability of fruit or pollen. The coordinates of the reference trees were converted from decimal degrees to UTM coordinates on the same WGS 84 ellipsoid (Universal Transverse Mercator; Snyder, 1987). All conversions were done with the ‘Labonde’ online applet (ottmarlabonde.de/L1/UTM-1.htm, 19/10/2007). I used a trigonometric formula to calculate the geographic coordinates for all mapped trees and created a map in ArcView 3.3 GIS (ESRI, Redlands, California (USA)).

2.4. **Data analysis**

Each animal was located telemetrically between 1 and 40 times during the period from 4\textsuperscript{th} June to 12\textsuperscript{th} August 2007. I excluded 9 of the 21 tagged animals totally from the home-range analysis because there were less than ten locations for each of these animals. The twelve animals for which home-range size was determined were radio tracked for a period ranging from 15 to 68 days (mean tracking duration 30 days). A total of 282 locations were recorded for these twelve geckos, with an average of 24 locations (standard deviation ± 8) per gecko.

2.4.1. **Home range analysis**

I used two estimators for the calculation of the home ranges of males and females. The minimum convex polygon, a linkage estimator, and the kernel estimate, a density estimator.

The minimum convex polygon (MCP) is the smallest possible convex polygon that encompasses all the known locations of a tracked individual (Hayne, 1949). It is a widely used and simple method of calculating home-range area and allows comparison with other studies (Harris et al., 1990). It is particularly recommended for the study of herpetofauna because reptiles tend to use the same location several times. Such behaviour leads to highly autocorrelated data that can in turn cause underestimation of home ranges, for example, with the least-squares cross-validation (LSCV) used in kernel estimates (Row & Blouin-Demers, 2006). One hundred percent MCP was used because eliminating the outermost locations with a 95% MCP has been shown to lack any biological basis (White & Garrott, 1990).
The second calculation method I used, the kernel estimator, produces a distribution estimating the likelihood of finding the animal at any particular location within its home range (Worton, 1989). It is considered the most sophisticated method of home-range analysis and also allows quantifying intensity of use (Worton, 1989). It has been shown to be robust even with small sample size of only 10 locations (Börger et al., 2006a). The method requires the user to set numerous parameters specifically for the study species and its characteristics of space use. I used fixed kernels, which are rated as preferable to adaptive kernels (Seaman & Powell, 1996). I calculated the 95% kernel which is the one most often used to estimate the total home-range area of an individual because a probability of 100% is extremely unlikely (Powell, 2000). Moreover, the 100% kernel would extremely overestimate the home range because it includes areas where animals have never been located. Choosing the smoothing parameter h of the kernel is the most important and difficult aspect of using kernel estimation (Worton, 1989). Two methods of calculating h have been evaluated in ecological studies: the reference method (h_{ref}) and the least-squares cross-validation method (h_{lscv}). In this study, the smoothing parameter h was calculated as the mean between h_{ref} and h_{lscv} for each animal. I decided for this standardized and intermediate method because it was animal-specific and resulted in areas that were biologically relevant. Biological relevance was assessed visually for the arboreal *P. guentheri* as the fit between the 95% kernel with the respective h and the available trees in the habitat. The resulting kernel outlines were appropriate intermediates between the h_{ref} kernels with large areas that were never used and the other extreme of ‘rings around locations’ with h_{lscv} (i.e. severe underestimation of home-range area). Home ranges were calculated and analysed with the Home Range Extension (Rodgers & Carr, 1998) and the extension XTools (DeLaune, 2003) in ArcView 3.3 GIS. All output maps were created in ArcGIS 9.2 (ESRI, Redlands, California (USA)).

### 2.4.2. Analysis of social behaviour

For a record of social behaviour, all tagged or untagged animals that were spotted on the same trees or trees adjacent to the ones the tagged focus animal used were recorded. In the analysis, only geckos that were located in the area delineated by the MCP 100% of a focus animal were termed ‘co-occurring’. This estimator better reflected where the focus animal was actually sighted and was therefore more accurate for determining which animals used the same areas compared to the kernel estimate.

### 2.4.3. Statistical analysis

I used R version 2.4.0 to conduct all statistical analyses and accepted P < 0.05 as level of significance. Mean values are shown either with the standard deviation (SD) or the standard error (SE). The standard deviation was used to display the variation in a sample. Standard error, the ‘standard deviation of the mean’, was used as a measure of accuracy for estimating the mean of the population (Storrer, 1995). In the analysis of vertical height above ground, multiple mean comparisons were done using Tukey’s Range Tests to control for Type I experimentwise error rate.
### 3. Results

#### 3.1. Home-range size during the breeding season

##### 3.1.1. Home-range size

Home range sizes of *P. guentheri* were determined using between 16 and 40 locations for each of the five male and seven female radio-tracked animals (table 3). The average minimum convex polygon size was 73 m² (SE ± 20) for males and 31 m² (SE ± 13) for females (table 3, figure 7). Using the fixed kernel estimator, mean home range size was 132 m² (SE ± 40) and 48 m² (SE ± 26) for males and females, respectively (figure 8). There was no overall correlation between home-range size and the number of locations for either sex (MCP: male, $r_s$=-0.4, P=0.52, n=5, female, $r_s$=0.34, P=0.45, n=7; Kernel estimate: male, $r_s$=-0.7, P=0.23, n=5, female, $r_s$=0.05, P=0.91, n=7). This result suggests that the number of locations per animal was sufficient to quantify overall space use by each gecko even though it was not possible to calculate an area-observation curve for each of the tracked animals.

<table>
<thead>
<tr>
<th>Gecko ID</th>
<th>Sex</th>
<th>SVL [mm]</th>
<th>Weight [g]</th>
<th>No. of locations</th>
<th>100% MCP [m²]</th>
<th>Kernel estimate (fixed, 95%) [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>male</td>
<td>121</td>
<td>67</td>
<td>27</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>male</td>
<td>124</td>
<td>64</td>
<td>16</td>
<td>116</td>
<td>248</td>
</tr>
<tr>
<td>7</td>
<td>male</td>
<td>126</td>
<td>66</td>
<td>40</td>
<td>96</td>
<td>148</td>
</tr>
<tr>
<td>23</td>
<td>male</td>
<td>130</td>
<td>75</td>
<td>17</td>
<td>93</td>
<td>195</td>
</tr>
<tr>
<td>19</td>
<td>male</td>
<td>138</td>
<td>89</td>
<td>24</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td>Mean</td>
<td>male</td>
<td></td>
<td></td>
<td></td>
<td>73</td>
<td>132</td>
</tr>
<tr>
<td>20</td>
<td>female</td>
<td>102</td>
<td>46</td>
<td>17</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>female</td>
<td>112</td>
<td>50</td>
<td>25</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>female</td>
<td>113</td>
<td>58</td>
<td>20</td>
<td>31</td>
<td>71</td>
</tr>
<tr>
<td>16</td>
<td>female</td>
<td>114</td>
<td>52</td>
<td>19</td>
<td>64</td>
<td>115</td>
</tr>
<tr>
<td>4</td>
<td>female</td>
<td>115</td>
<td>48</td>
<td>21</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>female</td>
<td>121</td>
<td>55</td>
<td>39</td>
<td>65</td>
<td>62</td>
</tr>
<tr>
<td>15</td>
<td>female</td>
<td>128</td>
<td>62</td>
<td>17</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Mean</td>
<td>female</td>
<td></td>
<td></td>
<td></td>
<td>31</td>
<td>48</td>
</tr>
</tbody>
</table>
Both males and females showed considerable intra-sexual variation in home range size (MCP: male, 13–116 m$^2$, female, 4–65 m$^2$; Kernel estimate: male, 18-248 m$^2$, female, 3-115 m$^2$, table 3). However, with both home-range estimate, males showed greater variation and reached higher maximum values. One female (no. 3) only used a single tree, but six females and all males used 3 or more trees (range: male, 4–11 trees; female, 1–15 trees). All females and most males used 50% or more of the available trees in their home ranges during the course of this study (minimum convex polygon: males, n=4; Kernel: males, n=3).

Figure 7. Home ranges of the tagged Guenther’s geckos as minimum convex polygons.
3.1.2. **Factors influencing home-range size**

With either home-range estimate, sex of the animal or body size (estimated by snout-vent length and weight) did not significantly influence home-range size in my sample of *P. guentheri* (tables 4 and 5). While there was no significant difference between male and female home-range sizes, however, MCP as well as fixed kernel estimate suggested a strong biological trend towards males having larger home ranges than females. No trends were obvious for either SVL or weight.

**Table 4. ANOVA table of the model including sex, SVL, and weight as explanatory and the MCP area as dependent variable.**

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum of squares</th>
<th>F value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1</td>
<td>5075.2</td>
<td>4.819</td>
<td>0.059</td>
</tr>
<tr>
<td>SVL</td>
<td>1</td>
<td>145.9</td>
<td>0.139</td>
<td>0.719</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>2587.4</td>
<td>2.457</td>
<td>0.156</td>
</tr>
<tr>
<td>Residuals</td>
<td>8</td>
<td>8424.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5. ANOVA table of the model including sex, SVL, and weight as explanatory and the Kernel estimate as dependent variable.**

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum of squares</th>
<th>F value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1</td>
<td>20847</td>
<td>4.300</td>
<td>0.072</td>
</tr>
<tr>
<td>SVL</td>
<td>1</td>
<td>141</td>
<td>0.029</td>
<td>0.869</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>7975</td>
<td>1.645</td>
<td>0.236</td>
</tr>
<tr>
<td>Residuals</td>
<td>8</td>
<td>38778</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2. Morphometric measurements

In the sample of all caught animals, males and females did not differ in SVL (ANOVA; $F_{1,32} = 2.03$, $P = 0.164$; table 6). However, while the SVL of adult male and female *P. guentheri* overlapped in the range up to 128 mm, only males reached an SVL of 138 mm (figure 9A). Weight was significantly correlated with SVL (male, $r = 0.907$, $P < 0.001$, $n = 16$, female, $r = 0.857$, $P < 0.001$, $n = 18$; figure 9A). The weight of males increased quicker with increasing SVL than that of females, and there was a trend towards males being heavier at a given SVL (ANCOVA; slopes, $F_{1,30} = 8.497$, $P = 0.0067$; elevations, $F_{1,30} = 3.889$, $P = 0.058$). For the other body measurements tail length and tail width, significant correlations with SVL only occurred for male but not female geckos (tail length: male, $r = 0.610$, $P = 0.012$, $n = 16$, female, $r = -0.107$, $P = 0.673$, $n = 18$; tail width: male, $r = 0.705$, $P = 0.002$, $n = 16$, female, $r = 0.074$, $P = 0.769$, $n = 18$; figure 9C, D). Tail length of males was significantly larger than that of females at a given SVL (ANCOVA; $F_{1,30} = 10.89$, $P = 0.003$). Tail width was not explained by sex, although it increased quicker for males than for females (ANCOVA; slopes, $F_{1,30} = 6.984$, $P = 0.013$; elevations, $F_{1,30} = 2.946$, $P = 0.096$).

![Graphs showing relationships between morphometric measures](image-url)

Figure 9. Relationships between morphometric measures: (A) SVL [mm] and weight [g] for all caught animals, (B) SVL and weight for the 12 tagged and tracked animals only, (C) SVL and tail length for all caught animals, (D) SVL and tail width for all caught animals. Open circle: male, closed circle: female.
Table 6. Morphometric measurements of *P. guentheri*. Mean ± SD are shown. Figures in parentheses are sample size and range.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Snout-vent length [mm]</th>
<th>Tail length [mm]</th>
<th>Tail width [mm]</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>116 ± 7 (18, 102–128)</td>
<td>109 ± 10 (18, 86–135)</td>
<td>13.0 ± 1.0 (18, 10.9–14.8)</td>
<td>53 ± 7 (18, 38–65)</td>
</tr>
</tbody>
</table>

The 12 tagged and tracked animals were also separately analysed for the two parameters snout-vent length and weight which were included in the home-range analysis as explaining variables. The five males were significantly larger in their SVL than the seven females (ANOVA; $F_{1,10} = 8.52$, $P=0.015$, table 7). Weight was not significantly correlated with SVL (male, $r_s = 0.7$, $P=0.233$, female, $r_s = 0.643$, $P=0.139$; figure 9B). Therefore differences in weight of males and females were examined without including SVL as a covariate. The weight of males was significantly larger than that of females (ANOVA; $F_{1,10} = 17.43$, $P=0.002$).

Table 7. Morphometric measurements of the tagged and tracked *P. guentheri*. Mean ± standard deviation are shown. Figures in parentheses are sample size and range.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Snout-vent length [mm]</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>128 ± 6 (5, 121–138)</td>
<td>72 ± 9 (5, 64–89)</td>
</tr>
<tr>
<td>Female</td>
<td>115 ± 7 (7, 102–128)</td>
<td>53 ± 5 (7, 46–62)</td>
</tr>
</tbody>
</table>
3.3. Habitat use

3.3.1. Substrate preference
In a total of 282 locations, *P. guentheri* was most often observed on *Latania* (n=267) and much less frequently on rock (n=15, table 8). No animal was spotted on the ground. The mean percentage of locations on *Latania* per animal was 96% (SD ± 0.06, range 80–100%) and significantly higher than that on rock (Wilcoxon signed rank test, V=78, P=0.002). I also investigated potential differences between day (06:00–18:00 h) and night (18:00–06:00 h). At night, three of the four animals observed on rock were located there more than once. The two locations on rock during day were single locations of two animals in the afternoon. Moreover, seven of the eight rock locations of male number 7 occurred at night. When data for all animals were pooled, *P. guentheri* was spotted on rock significantly more frequently at night ($\chi^2$-test; $\chi^2=10.18$, df=1, P<0.0001, n=282, table 8). However, pair-wise comparison of the percentage of locations on rock during day and at night for each animal revealed no difference (Wilcoxon signed rank test, V=13, P=0.178).

Table 8. Number of sightings of *P. guentheri* on *Latania* or rock during day-time and night-time. Figures in parentheses are expected values.

<table>
<thead>
<tr>
<th></th>
<th>Latania</th>
<th>Rock</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>149 (143)</td>
<td>2 (8)</td>
<td>151</td>
</tr>
<tr>
<td>Night</td>
<td>118 (124)</td>
<td>13 (7)</td>
<td>131</td>
</tr>
<tr>
<td>total</td>
<td>267</td>
<td>15</td>
<td>282</td>
</tr>
</tbody>
</table>
3.3.2. Vertical height movement

Tagged geckos were recorded at a range of heights above ground (figure 10). The highest record was estimated at 5.5 m in the crown of a *Latania* palm with a trunk height of 5 m. The lowest sighting on *Latania* was on a frond at 0.2 m above ground. On two occasions, animals were spotted on a vertical rock face right above ground level.

![Figure 10](image_url)

Figure 10. Height above ground of the recorded Guenther’s geckos in the six time intervals summarized in boxplots. The bold horizontal line shows the median. The bottom and top of the box show the first and third quartiles (i.e. 50% of the data are in between). The vertical dashed lines delineate the range of 95% of the data. Outliers are plotted individually as open circles (Storrer, 1995).

There were significant differences in the height above ground of the recorded *P. guentheri* geckos in the six time intervals (square-root transformed data; ANOVA, $F_{5,214} = 3.8$, $P=0.0026$), but no differences between the sexes (square-root transformed data; ANOVA, $F_{1,214} = 2.26$, $P=0.13$). Multiple comparison of means showed that the recorded heights in the four time intervals between 10:00 h and 02:00 h differed significantly from those in the morning interval 06:00–10:00 h (table 9).

<table>
<thead>
<tr>
<th>Compared interval</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–14</td>
<td>0.027</td>
</tr>
<tr>
<td>14–18</td>
<td>0.002</td>
</tr>
<tr>
<td>18–22</td>
<td>0.005</td>
</tr>
<tr>
<td>22–02</td>
<td>0.014</td>
</tr>
<tr>
<td>02–06</td>
<td>0.201</td>
</tr>
</tbody>
</table>
3.4. Social behaviour

In all home ranges monitored, I also found untagged geckos. In the male home ranges delineated by the minimum convex polygons, two to eight geckos were observed, including the tagged focus male (table 10). Most of the co-occurring animals were females and juveniles, with at least one female found in the home range of each tagged male. Untagged males were spotted in the areas of three of the five male *P. guentheri* at four occasions. In the case of tagged male home ranges being adjacent to each other, no overlap was observed. No cases of males being simultaneously on the same tree were recorded.

In three cases I observed a strong overlap of the home range of tagged animals, always between those of a male and a female gecko (figure 11): male/female, 7/16, 11/9, 19/15. The three tagged females had home ranges that were largely contained within the home ranges of the males. Each of the females shared most of her trees with the corresponding male and had only one or two locations outside the male’s home range.

![Figure 11. Pairwise home-range overlap in three male and three female *P. guentheri*.](image-url)
Overall, between two and six geckos were spotted in the home ranges of the seven tagged females, including the tagged focus animal. In every case, there was at least one male. While overlap of male and female home ranges or co-occurrence of male and female animals was observed for all tagged animals, I was not able to clearly answer the question of overlapping female home ranges. From the perspective of male home ranges, more than one female was spotted in three of the five home ranges. Some of these females used the same tree at different times, others were never seen on the same tree but on adjacent trees. The tagged females showed no clear pattern. Three of the seven tagged females had trees that were used by another female, while in the other four cases no other females were spotted. Of particular interest were simultaneous sightings of Guenther's geckos on the same tree. Once, two female geckos were spotted on the same tree (but > 1 m apart). In six cases, a male and a female or juvenile were on the same tree (> 1 m apart). Observations of two animals close to each other (i.e. < 1 m) occurred 10 times, eight of which were a male and a female or juvenile together. Twice I spotted a female and a juvenile. In none of the cases there were any behavioural interactions between the geckos.

Table 10. Number of Guenther’s geckos that were spotted additional to the focus animal in its home range (i.e. co-occurring geckos). The total number of animals in the home range includes the tagged focus animal.

<table>
<thead>
<tr>
<th>Gecko</th>
<th>Sex</th>
<th>Males</th>
<th>Females</th>
<th>Juveniles</th>
<th>Total animals in home range</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>male</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>male</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>male</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>19</td>
<td>male</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>23</td>
<td>male</td>
<td>0</td>
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<td>2</td>
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<td>0</td>
<td>0</td>
<td>2</td>
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</table>

I also investigated whether home ranges of females overlapped with the home range of more than one male. One female was indeed sighted in the areas of two tagged males and together with each of them at close distance (i.e. < 1 m). In the same two home ranges a juvenile was found as moving between the two areas.

Individuals of four other reptile species were sighted together with *P. guentheri* at a distance of less than one metre on 31 occasions (11% of all sightings). These included ornate day gecko, *P. ornata* (26 sightings), Telfair's skink, *Leiolopisma telfairii* (three sightings), Bojer's skink, *Gongylomorphus bojeri* (one sighting), and a juvenile keel-scaled boa, *Casarea dussumieri* (one sighting). No interactions between *P. guentheri* and the other reptile species were observed in any of these encounters.
3.5. Adverse tag effects

3.5.1. Survival

One juvenile animal died in the night after tagging. On the corpse a contraction of the belly strap was clearly visible, likely having caused the death. One female animal was observed for two weeks and showed no signs of adverse effects, then dying of unknown causes.

3.5.2. Physiology

During handling prior to tagging one animal got its skin ripped on one shoulder. Therefore it was not tagged. One animal got bruised during tagging. After tagging, several animals had skin abrasions on their upper backs that were caused by the tag. The scars healed well after 1 week.

Nine animals were weighed before and after tagging. One animal had the same weight before and after. Three animals showed an increase in weight and five lost weight. Overall, there was no significant difference in these animals’ weight before and after tagging (Wilcoxon signed rank test, $V=27.5$, $P=0.204$, $n=9$).

3.5.3. Behaviour

None of the animals with skin abrasions showed any obvious signs in their behaviour (e.g. by apathetic behaviour, or trying to get their tags off). There were no signs that the animals had abrasions until the tag was removed. Movement was not visibly impaired by the tags. All tagged geckos moved without restrictions and were seen running, jumping and hiding in vegetation. I did not observe any entanglement in vegetation.

Because I did not observe any social interactions between Guenther’s geckos that were spotted together, I was not able to document any impact on such interactions.
4. Discussion

The present study brought new insights into the cryptic lifestyle of *P. guentheri* on Round Island with the first-time use of radio tagging on this species. Male and female geckos used distinct areas during breeding season in the winter months of June to August. The large variation within each sex supposedly precluded detecting any significant difference in home-range size of male and female geckos. In contrast to other studies, body size did not correlate with home-range size in *P. guentheri*. Males and females, on average, did not differ in size.

The geckos were located mostly on the fan palm (*Latania loddigesii*), both during day and at night. Despite several accounts in the past I was not able to identify a specific movement pattern, such as geckos spending their days on the palms and climbing down to forage on the ground at night. Within a home ranges, up to eight geckos were sighted. Male and female geckos used overlapping areas, several of them and were sighted close to each other on several occasions. Although animals were sighted together, no social interactions were observed during the study. Similarly, I did not see interactions between *P. guentheri* and individuals of four other reptile species that were sighted close to tagged animals.

Tagging was the likely cause of death of one juvenile while the adult animals coped well with being tagged. Skin abrasions, probably from rubbing, occurred but healed quickly. Behaviourally no adverse tag effects were recorded.

4.1. Home-range size during the breeding season

4.1.1. Home-range size and calculation method

The analysis showed that males and females of *P. guentheri* do have distinct home ranges. The home ranges usually extended over several trees, although one female was only recorded on a single *Latania* palm and the adjacent rock wall. The home-range estimate with minimum convex polygon suggested that males move in average areas of 73 m$^2$ and females in areas of 31 m$^2$. In the only other radio-tagging study of *Phelsuma* geckos, Ikeuchi *et al.* (2005) found MCP areas, extending over 384 m$^2$ for males and 78 m$^2$ for females in *Phelsuma madagascariensis kochi*, a smaller-sized relative from Madagascar.

In my sample of *P. guentheri*, fixed kernel estimates were larger than the ones obtained with the polygon method. With the 95% kernel, males had an average range of 132 m$^2$ and females of 48 m$^2$. A striking feature of the home ranges in this study is the great variation among all tagged animals, and particularly within each sex. Empirical studies have demonstrated home-range size can vary both among individuals within a population, and even seasonally for the same individual (Satrawaha & Bull, 1981; Börger *et al.*, 2006b). This variation is not contradictory to the home-range concept, but illustrates the dependence of the animals on local circumstances to meet their needs of fundamental resources, such as food (Trivers, 1976) or mating partners (Stamps, 1983). An important determining factor could be variation in habitat structure, for instance, because of different densities of trees (see habitat photos in appendix 3).
The differences in the estimated home-range sizes between the two calculation methods are based on the fact that the kernel estimator calculates probabilities of occurrence. For example, in the case of a marginal tree being used by an animal, a high probability of occurrence also extends to an adjacent tree, even if the animal was never spotted there. Animals often using trees on the edge of their home ranges thus will have larger kernel home ranges than MCP home ranges. The use of MCP or kernel estimates is still disputed (Laver & Kelly, 2008). While kernel estimates were reported to perform better for data from mammals and birds (Börger et al., 2006a), Rose (1982) highlighted that important assumptions associated with the normal distribution of sightings and randomness of location data are not met with reptiles. Therefore some herpetologists argue for the exclusive use of MCP estimation for herpetofauna (Row & Blouin-Demers, 2006; Thompson et al., 1999).

4.1.2. Factors influencing home-range size

The sex of geckos could be expected to have an influence on home-range size, because the social and physiological demands of males and females may differ. In terrestrial lizard species, home ranges of males were found to be larger than those of females in species that defend these home ranges (Turner et al., 1969). For *P. guentheri*, home ranges of males were not significantly larger than those of females although there was a statistical trend to larger home ranges for males. However, while there was a trend to males having larger home ranges, they also showed larger variation in home-range size. Therefore, it is important to bear in mind that for males the mean is also more unpredictable. An observation that supports the trend to larger home ranges in males comes from the MCP home ranges of three ‘pairs’ of male and female geckos (geckos no. 7/16, 11/9, and 19/15; figure 11). In all three cases, the tagged females occupied smaller areas than the males.

Another factor often discussed in the context of home-range size is body size of the animals. With either home-range estimate neither the snout-vent length (SVL) nor the weight of the tagged *P. guentheri* correlated with home-range size. Turner (1969) compared the home ranges of several terrestrial lizards and found an increase of home-ranges size with body weight. In the arboreal monitor lizard *Varanus tristis* this pattern was confirmed for males but not females (Thompson et al., 1999). Two of the potential reasons for increasing home-range size with increasing weight are the higher metabolic rate at larger size (McNab, 1963) and more competitiveness for the defence of a home range. Particularly within a species, it is probably not the higher metabolic rate that requires larger home ranges, but rather the ability of larger animals to win contests over smaller conspecifics. Olsson (1992) observed that large males win contests in sand lizards *Lacerta agilis*, and that fight frequency and duration decreased with increasing size difference between competitors. It could be however, that among the tagged *P. guentheri* the encountered range of weight and SVL was not broad enough to detect the effect of body size (table 7). It is still possible that home ranges of males with an SVL 100–110 mm are smaller than those of males with an SVL of 130–140 mm.
Another potential reason for the lack of correlation between body size and home-range size is that with the clumped distribution of *Latania* palms as resources, habitat quality could override habitat size. For a large male, for instance, it could be better in terms of access to females to have a smaller area but with better resources.

The lack of correlation between home-range size and body size had an important implication in my study. In the sample of 12 tagged and tracked Guenther's geckos, males had longer snout-vent lengths and were heavier than females. The fact that there was no correlation between body size and home-range size suggests that the trend to larger male home ranges cannot be attributed to males in the sample being bigger than females. Therefore, even if only a trend, the larger home ranges of males I found may be a species-specific pattern rather than a sampling artefact.

### 4.2. Morphometric measurements

Male and female *P. guentheri* geckos neither differed in their snout-vent length, nor in body weight at a given SVL. However, there was a trend to males being heavier at a given SVL. This trend suggests that males are sturdier, which would agree with personal observations. Furthermore, as had been found by Vinson & Vinson (1969), I found males reached larger maximum snout-vent length and weight than females.

Of particular interest in terms of social structure in a lizard species is tail size. Lizard tail size can have implications for the dominance position and thereby on access to the other sex (Salvador, 1995). On average, male Guenther's geckos had longer tails at a given SVL. Surprisingly, tail length only correlated with SVL in males. Potentially, males and females differ in the importance of the tail during social interactions, e.g. territorial behaviour. Territorial threat behaviours that include behaviours with the tail are known from *Phelsuma madagascariensis grandis* (Hagdorn, 1973) and *P. dubia* (Osadnik, 1987), for instance.

In contrast to tail length, tail width did not differ among the sexes. This contradicts the expectation that the tail base is wider, or the girth larger, in male geckos because they have their hemi-penis here in two skin pockets (Henkel & Schmidt, 1991). The reason for the result may be that I only measured width, but not girth, so that I did not detect this bulge.

Overall *P. guentheri* is monomorphic in colouration (Vinson & Vinson, 1969) and no overt sexual size dimorphism exists. Ikeuchi *et al.* (2005), in contrast, found strong size dimorphism between the sexes in their study on *P. madagascariensis kochi*. 
4.3. Habitat use

4.3.1. Substrate preference

Agreeing with the findings of Carpenter (2003), my results confirmed that *P. guentheri* is mainly arboreal, and is found on *Latania* palms both during day and night. For the analysis of differences in substrate preference between day and night results from pooled data for all animals differed from the ones that a pair-wise comparison of each animal provided. While results from pooled data showed that geckos were more likely to be located on rock at night, this was not the case in the individual-based analysis. Individual-based analysis was more reliable in the present case for several reasons. Firstly, only five of the twelve animals were spotted on rock at least once. Secondly, eight of the fifteen records come from a single animal (male 7). And finally, the number of locations per animal ranged from 16 to 40, indicating that not all individuals were equally represented. Therefore I conclude that substrate choice is very much dependent on the individual and specific substrate features in the home ranges. For instance, rock surfaces were not available in all of the recorded home ranges.

No tagged animals were spotted on the ground despite personal observation of untagged animals on the ground on two occasions. In some cases, the tagged geckos were on isolated trees which were only accessible from the ground. Earlier accounts as well suggest that Guenther’s geckos come on the ground (e.g. Vinson & Vinson, 1969). The lack of observations on the ground in my study could then be because the animals escaped to higher and safer perch sites on approach. The tracking equipment allowed me to detect whether the transmitter antenna and therefore the gecko was in a vertical or horizontal position. For all geckos, that had a vertical position from the start of the search, I was able to eliminate the possibility of them being on the ground. However, in the case of animals in a horizontal position at the start of the search, there was the option that they were on the ground and escaped onto a *Latania* palm or rock surface. Therefore, I most probably missed animals that were moving on the ground. More insight into their movements and behaviour on the ground could come from dietary analysis that suggests, for instance, that they feed on ground-dwelling crickets (N. Zuël, pers. comm.).

4.3.2. Vertical height movement

The findings for the vertical height above ground were closely connected to observations on the substrate. The data did not support earlier accounts of Guenther’s geckos being arboreal during the day and coming down on the ground at dusk or night. There was no consistent pattern of vertical movement. The only difference between intervals was that geckos used higher perch sites in the morning from 06:00 to 10:00 h than later during the day.

The located geckos were at variable heights in the moment of spotting. They used the full range of perch sites from the bottom of palm trunks to the very top of the fronds, and likewise on rock surfaces. Of course, the same as for the substrate applies in terms of locations on the ground and animals that I probably missed.
4.4. Social behaviour

Male and female home range overlap

The home ranges of the tagged geckos were also home to other Guenther's geckos. Between two and eight geckos were spotted in the same area. In the home ranges of all male geckos, at least one female was sighted. Likewise, there was at least one male in the home range of a tagged female. The overlap of home ranges of males and females was well documented for three ‘pairs’ of male and female Guenther's geckos. Similarly, in most of the cases when two geckos were located together on the same tree or even at close distance (i.e. < 1 m) it was a male and a female or juvenile. Ikeuchi et al. (2005) reported from *Phelsuma madagascariensis kochi* that at least one tree in the home range of a male was shared with a female or unsexed individual. One female *P. guentheri* that was seen moving between the home ranges of two males was an indicator that female home ranges could also overlap with more than one male.

Male home ranges

In *P. guentheri*, home ranges of tagged males did not overlap, but other untagged males were spotted in the areas of three of the five tagged males. Supposing that, despite low overall population size, most of the optimal habitats are occupied, then these could be males known as ‘floaters’ that drift between home ranges of territory holders (Gruber & Henle, 2004). Home ranges of males did not overlap with each other in *P. madagascariensis kochi* (Ikeuchi et al., 2005). Such exclusivity of home ranges implies territoriality. Only observations of direct interactions will further elucidate to which extent males of *P. guentheri* defend their home ranges intra-sexually. Sadly, I never spotted males close together and therefore never saw any interactions.

Overlap between home ranges of females

From the collected data, it remains unclear to which extent home ranges of females overlap. I never spotted females together, which is why no conclusions are possible in terms of behavioural interactions. It could be that females use their own areas but share some trees with other females. They might then use these trees at different times.
4.5. Adverse tag effects & criticism of tagging technique

Many studies on radio telemetry lack accounts for adverse tag effects (Kenward, 2001). In the present study, such documentation was essential to decide on future use of this technique. One juvenile died, probably directly caused by the tagging. From the contraction of the belly strap around the belly we concluded that it had probably died from suffocation. The veterinary bandage material is elastic and probably contracted to some degree after we had mounted the tag. While adult animals were able to deal with such pressure, the juvenile was too sensitive. For the second animal that died during the study cause of death was unknown.

The sensitive skin of the geckos tolerated catching and handling well. A concern was that several animals had skin abrasion in the area where the tag was situated. Additional padding helped but could not completely prevent rubbing. The abrasions healed quickly with a transparent skin growing over the rubbed area. A comparison of nine geckos before and after tagging did not indicate changes in weight. Both weight loss or weight gain could obviously have been the potential outcomes. So, there were neither adverse effects on prey capture that might have caused weight loss, nor immobilization of the geckos that could have resulted in weight gain. I did not observe any adverse effects on the behaviour of the geckos. Tagging did not prevent them from moving around and the animals were just as alert as their untagged conspecifics. Thus, overall radio tagging proved an appropriate technique for studying adult *P. guentheri*, while this was not the case for juvenile geckos.
4.6. Conclusions

**Pattern of home range size, morphometrics and social organisation in P. guentheri**

There is no clear pattern in *P. guentheri* of home-range size, male and female colouration and size, and social organisation as proposed by Stamps (1983) for territorial lizards. The study was conducted right before and during the breeding season, at the time when species-specific reproductive or territorial behaviour would be most expected to be displayed. The trend to larger home ranges in males was to some extent obscured by the large variation in both sexes. The difference, if existing, is definitely not as pronounced as for instance in *P. madagascariensis kochi*. Likewise for size of males and females. I did not find any sign that sexual selection caused males to grow larger on average than females. Both results speak against *P. guentheri* as a polygynous species. The observations on social behaviour, however, show that several geckos, usually one male and one or more female and juvenile, live in the same areas. This, together with the observation of the female that changed between the home ranges of two males, make polygamy very likely.

To which extent these ‘groups’ are hierarchical cannot be judged as there is no distinction between bright and drab colouration that would display social status in *P. guentheri*, at least to the human eye. In the Tenerife lizard (*Gallotia galloti*) ultraviolet markings were shown to be associated with gene flow (Thorpe & Richard, 2001). So UV vision could equally play a role in sexual selection. Still another possibility is sexual selection expressed in behaviour rather than morphologically (e.g. males being more active in display or territory defence) (Andersson, 1994).

**Radio tagging**

For the tagged adult animals the main point of concern was the skin abrasions. For future use of the presented tags on *P. guentheri*, I would suggest to try using some lightweight foam material to further pad the tags against the skin of the geckos. The use of glue in moderation did not seem to pose any problems in areas where there was no rubbing from the tag. However, it should be used with care and always in a well-ventilated area.

**Translocation**

The study confirmed the affiliation of *P. guentheri* with palm trees and, to a lesser extent, rock. The species requires vertical substrate, particularly in combination with hiding places. A key requirement for a translocation site is therefore either forest or at least clumps of trees in combination with gullies.

Based on the fact that home ranges of males and females overlap, we can estimate the required area for a translocated population from the average home-range size of males and the number of sexually mature animals therein. With the MCP estimate average home range size of males is $73\,m^2$. 
The kernel estimate is omitted here because the analysis of co-occurring geckos in this study was done with MCP. On average, three mature (i.e. adult) geckos co-occur in a home range. An area of 730 m² could then host 30 geckos, and to get a minimum-viable population of 4'000 animals (Traill et al., 2007) around 10 ha would be required. Thus, Ile aux Aigrettes with its 25 ha would be suitable in terms of size and vegetation.

Home range areas measured after translocation will most probably differ from the data in this study because uninhabited habitat will be occupied in a different way until all suitable habitats are used. According to the ideal free distribution theory (Fretwell & Lucas, 1970), at low population density movement may be restricted as all individuals are able to occupy optimal habitat.

One of the things to be careful about is the choice of animals for translocation. One should be aware that juveniles are susceptible, as was the case in the juvenile casualty. It could definitely be useful to limit the minimum SVL to avoid casualties during catch, handling or transport.
5. Acknowledgements

The project was an amazing chance. It took me a while to grasp the extent of the field of island conservation it initiated me to. The project was special in many respects, one of them being that it was only possible through the help and enthusiasm of many people along the way.

I would like to thank my supervisor Christine Müller for the chance to do such a conservation-oriented project and for all advice and support throughout the study. Dennis Hansen encouraged me in many situations with optimistic and pragmatic advice, and somehow had the talent to be there when support was most essential. Nicolas Zuël shared his expertise in Guenther's gecko and the Round Island ecosystem with me. I would like to thank him for numerous hours of help in the field and the station when catching and tagging the geckos. I am well aware that this study would not have been possible without his cooperation throughout the project.

During preparation I greatly relied on the people from Sirtrack Ltd. (New Zealand) for an effort to produce the tags in almost no time at all. Dylan van Winkel was ready with good advice for constructing the backpacks. Maja Weilenmann supported me for the home range analysis by sharing an extensive range of background material and her own knowledge in this enticing but also challenging field. And Thomas Schulz supported me in all the GIS-related analyses and preparation of maps, thank you for that. In Mauritius, many people from the Mauritian Wildlife Foundation (MWF) offered me their help or were there for a good chat. I am particularly thankful to Vikash Tatayah, Ashok Khadun and Nadine Armelle for all the advice and support in organizing the unique research trip to Round Island. My thanks go to Nik Cole, Adem Fehmi, and Yuvna Chutto for practical help and advice in the field. A special thanks to Zayd Jhumka not only for practical help but also his helpfulness and his delicious cooking that was a great change from the often strenuous work.

Three friends, Angela, Samuel, and Clemens, accompanied me along the way. Thank you for your friendship and many hours of good chats. My girl-friend Martina I thank for her support with a lot of loving care. I also owe a lot to my parents and family who have been supporting me not only for this thesis but all the way through the studies at university.

“Zyt zum Danka dära Kraft, wo mir hät gholfä, dass i s ha gschafft.
Über Berg und über Tal, danke viel Mal!”
Gölä, Swiss songwriter
6. References


7. Appendix

Appendix 1: Map of the seven habitats on Round Island
### Appendix 2: Monitoring protocol for locations of *P. guentheri*

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<th>Comment</th>
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<tbody>
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<td>Animal</td>
<td>Record of the exact geographic position, e.g. measured to an absolute reference tree with a measure tape and a compass (Recta DS 40, 2° accuracy). Northing and easting were calculated in the data table.</td>
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<td>Date</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>GPS coordinate</td>
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</tr>
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<td><em>Latania sp.</em>, <em>Pandanus sp.</em>, rock, ground, other</td>
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<tr>
<td>Microsite</td>
<td>Frond, crown, trunk, rock face, rock overhang</td>
</tr>
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<td>Measured at an accuracy of 0.1m from 0 to 3m and estimated at an accuracy of 0.5m at a height of &gt; 3m</td>
</tr>
<tr>
<td>Aspect</td>
<td>Relative orientation of the back of an animal to the sun, in steps of 45 degrees</td>
</tr>
<tr>
<td>Exposed to sun</td>
<td>Yes  No  Partial</td>
</tr>
</tbody>
</table>
| Behaviour                              | Still = motionless  
Basking = motionless, in the sun  
Walking  
Feeding/drinking  
Social  
Others (followed by detailed comment) |
| Presence of other reptiles (within a distance of 1m) | Record: number; species; interactions, e.g. for *P. ornata* differentiate between juvenile and adult and for *L. telfairii* juv., subadult, adult |
| Body condition assessment              | General: assessment of general body condition to see whether animal is well nourished (signs of malnourishment: backbone, pelvis or neck bones visible)  
Colouration (in 2 categories grey, brown plus account whether pattern is visible or not)  
Remarks (e.g. not available, shedding) |
| Backpack condition                     | Fit on the animal and if there were any bruises from the backpack, condition in terms of straps and glue                                      |
| Signal strength                        | Strong, weak                                                                                                                             |
| Sky condition                          | clear, cloudy, overcast                                                                                                                    |
| Wind                                   | Estimate according to the Beaufort scale (categories 1 – 6)                                                                                |
| Air temperature                        | Temperature was recorded with a digital multistem thermometer (accuracy 0.1°C)  
0.5m above ground vertically below (or above if the animal was on ground) the spot of sighting. |
| Remarks                                |                                                                                                                                           |
Appendix 3: Habitat photos

The habitat photos portray the home ranges of several tagged geckos and illustrate how different the distribution of palm trees can be.

Figure 1. The single tree of female 3 and the rock wall next to it (both in the foreground).

Figure 2. The two Latania palms male 5 was most often spotted on.
Home range, habitat use and social behaviour of *Phelsuma guentheri*

Figure 3. The dense clump of trees of female 4.

Figure 4. Scattered trees in the home range of male 7 and female 16.