Habitat selection of a Critically Endangered reptile *Gongylomorphis bojerii* in Mauritius

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ABSTRACT

In the face of widespread biodiversity decline, species recovery programs are one method of mitigating species loss. Species recovery programs often include techniques such as habitat rehabilitation or conservation translocations to areas where threats can be mitigated. However, for these types of conservation interventions to be successful, we first need to have a robust understanding of the focal species' habitat requirements. Habitat selection studies are one way of determining high-quality habitats for threatened species. The Bojer's skink (*Gongylomorphis bojerii*) is a Critically Endangered species endemic to Mauritius. Although once widespread over Mauritius Island and several offshore islets, the skink is now confined to only 8 offshore islets due to threats such as invasive species and habitat loss. This includes three small islets on the southeast coast which are known to be genetically distinct from the populations on northern islets. I undertook a habitat selection study using habitat data and 10 years of monitoring data collected by the Mauritius Reptile Recovery Programme to determine whether Bojer's skinks on the southeastern islets are selecting certain habitat types. Using habitat layers in QGIS, I compared the distribution of skinks to a null hypothesis of random distribution across the island, as well as tested whether body condition (weight, with size as a covariate) differed between habitat types. Results of exact binomial tests revealed that skinks are found more often than expected in grassy habitats, but body condition results are equivocal. My study indicates that grassy habitats may be important for Bojer's skinks, but more research, including fitness measures in these habitats, may help highlight whether these habitats confer a fitness benefit to the species. Our understanding of habitat use and selection for threatened species is critical if we are to make informed conservation decisions for declining populations.

INTRODUCTION

Widespread biodiversity loss is one of the most critical challenges facing conservationists today (Hooper et al., 2012; Cahill et al., 2013; Ceballos et al., 2015). Loss of biodiversity may lead to less stable ecosystems (Worm et al., 2006), decrease in ecosystem services (Myers, 1996; Worm et al., 2006), lost revenue from ecotourism (Myers, 1996), and declines in human welfare (Blaikie and Jeanrenaud 1996). Because of the high level of endemism that has evolved on many islands, the conservation of island biodiversity is of global importance (Kier et al., 2009). The inherent isolation of islands is a double-edged sword; on one hand, their often low species richness and evolutionary isolation make them particularly susceptible to threats such as invasive species (Reaser et al., 2007), while on the other hand, their relatively small area and isolation make islands particularly amenable to conservation efforts. Given the current biodiversity crisis, an emphasis on the conservation of island species may be an effective and efficient way to preserve global biodiversity.

Species recovery programs, both on islands and in mainland systems, include a range of *ex situ* and *in situ* techniques for increasing population abundance and stability. Translocation is one technique that has been used in a range of different conservation interventions, including reintroduction of a species to part of its former range (Bendel and Therres, 1994; Hayward et al., 2007), assisted migration to habitats within the current range (Griffith et al., 1989), assisted migration into suitable habitats outside of the species' historic range (Thomas, 2011), and "marooning" of populations on small islands where threats can be more easily mitigated (Lloyd and Powlesland, 1994; Miskelly and Powlesland, 2013). An important component of species translocations involves confirming that suitable habitat exists at the release site (Gibbon et al., 2000; Michel et al., 2008). According to the IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN, 2013), "matching habitat suitability and availability to the needs of candidate species is central to [the] feasibility and design" of conservation translocations. If suitable habitat does not exist, habitat rehabilitation techniques can help prepare the site for translocation (IUCN 2013). Habitat rehabilitation techniques can also be used within the current range of threatened species in order to mitigate threats such as habitat fragmentation (Webb and Shine, 2000). Therefore, a thorough understanding of the required or preferred habitat of threatened species is critical for conservation managers considering translocation or habitat rehabilitation as a species conservation tool.

Habitat selection studies are one way in which conservation managers can determine suitable habitat for a focal species (Webb and Shine, 1998). Although the occurrence of individuals in certain areas does not necessarily constitute selection (Jones, 2001), measuring the distribution of a species within different habitat types is the first step toward determining the suitability of habitats for threatened species. Distribution or abundance can be compared between used and unused habitats, or between used and available habitats (Jones, 2001). If there is a disproportionate use of a habitat type relative to its availability, there may be evidence that habitat selection is occurring (Johnson, 2007). However, disproportionate use does not necessarily constitute selection, since animals may be relegated to this habitat for some other reason (e.g. Banko et al., 1999). In other words, habitat selection theory assumes that animals are "free" to select between different habitat types, and that habitat use is a decision-making process (Pulliam and Danielson, 1991; Jones, 2001). Habitat use data can therefore be combined with survival, reproduction, or body condition data to develop a deeper understanding of whether certain habitats are used (i.e. selected) to increase individual fitness (Jones, 2001). This view of habitat selection assumes that habitat choices are adaptive, i.e. that there is a fitness benefit of the choice. However, other authors argue that animals do not always select the highest quality habitats, leading to the concept of ecological traps (Gates and Gysel, 1978; Kolbe and Janzen, 2002; Johnson, 2007). For my research, I will use the definition given by Jones (2001) which describes habitat selection as a behavioural choice which can increase survival and fitness.

BACKGROUND

The Mascarene Islands in the western Indian Ocean were once home to the highest reptile species richness of any oceanic island system in the world (Austin and Arnold, 2006). However, since the arrival of humans to the island in the 16th century, almost half of the island system's reptile species have gone extinct due to threats such as invasive species and habitat loss. Among those that remain are 13 species of reptiles found in country of Mauritius (Michaelides et al., 2015). Of these 13, 6 are confined to small offshore islets where threats are reduced or mitigated. In this system, small offshore islets have become a refuge for threatened species which are unable to survive under the pressures of introduced predators and habitat loss on 'mainland' Mauritius island (Cole et al., 2009; Michaelides et al., 2015).

The *Gongylomorphis* skinks are a genus of slit-eared skinks that are endemic to the Mascarene Islands (Vinson and Vinson, 1969; Austin et al., 2009). This genus includes the

Bojer's skink (*G. bojerii*), a small diurnal lizard which was once widespread over the main island of Mauritius and most offshore islets (Arnold, 1980; Austin et al., 2009). Bojer's skinks are known to inhabit an array of habitat types, including forest, grassland, open ground, and rock piles/crevices (Cole, 2008). They have adaptations for semi-fossorial habits such as short legs and a closable internal structure within the ear. Females lay eggs in loose earth and beneath logs, rocks, and leaf litter. Their diet consists of mainly invertebrates, and sometimes fruit and carrion (Cole, 2008).

Due to threats from invasive species such as the introduced wolf snake (*Lycodon capucinus*), the Bojer's skink became confined to only six offshore islets: Flat Island (253 ha), Gabriel Island (42 ha), Gunner's Quoin (76 ha), Pigeon Rock (0.6 ha), Round Island (219 ha), and Serpent Island (32 ha), all of which are situated off the northern coast of Mauritius island, and Ilot Vacoas (1.06 ha), which is off the southeastern coast (Fig. 1; Jones, 1993; Austin et al., 2009; Cole et al., 2009). Due to continued threats of invasive species and small population size, the skink is classified as Critically Endangered by the IUCN (IUCN, 2015). Genetic analyses have revealed that there is substantial genetic differentiation between the northern and southeastern islets, making them distinct conservation units as defined by Moritz (1994) (Austin et al., 2009; Michaelides et al., 2015). The small size of the Ilot Vacoas population (numbering 490 individuals in 2000), combined with its genetic distinctiveness, has made the Ilot Vacoas Bojer's skink a population of particular conservation concern (IUCN, 2015; Michaelides et al., 2015).

In an effort to increase the area of occupancy, extent of occupancy, and carrying capacity of the Ilot Vacoas Bojer's skink (hereafter Bojer's skink), as well to decrease the chances that a stochastic event would wipe out the entire southeastern population, a series of translocations were initiated by the Durrell Wildlife Conservation Trust, Mauritius Wildlife Foundation, and National Parks and Recreation Service (with support from the Darwin initiative) as part of the Mauritius Reptile Recovery Programme. The purpose of these translocations was to reintroduce the Ilot Vacoas Bojer's skink to neighbouring islets with similar habitat where the skinks had historically existed. In 2007, the first of 3 translocations was made to Ile aux Fouquets (2.8 ha; Fig. 1; Cole et al., 2009). After discovery of skinks on Ile de la Passe (2.5 ha; Fig. 1) in 2009, either by natural dispersal or accidental movement by people, more skinks were later translocated to this islet in an effort to maintain the genetic health of this population (Cole et al., 2014). As of the 2014 Reptile Recovery Programme report (Cole et al., 2014), the populations on

these three islets were 432 (95% confidence interval (CI): 261-602) on Ilot Vacoas; 1027 (95% CI: 635-1783) on Ile aux Fouquets; and 516 (95% CI: 247-1258) on Ile de la Passe.

Although all three southeastern islets are dominated by similar habitat types (i.e. grassland habitat interspersed with shrubs, trees, and sometimes abandoned buildings; Fig. 2, Table 2), no formal study has investigated the habitat preference of the Ilot Vacoas Bojer's skink. High-quality habitat patches can be essential for various aspects of lizard ecology and population dynamics, including physiology (e.g. thermoregulation; Blouin-Demers and Weatherhead, 2001; Pringle et al., 2003) and reproduction (Kolbe and Janzen, 2002). An understanding of habitat preference in Bojer's skinks may therefore be essential for future habitat rehabilitation or translocation projects.

PROPOSED PROJECT

Aims

The aims for my project are to i) develop an understanding of habitat selection in reptiles; ii) use GIS tools to test hypotheses and habitat use and selection; iii) determine whether the Critically Endangered Bojer's skink is selecting certain habitats; and iv) help inform future management decisions for the Bojer's skink, in the context of habitat rehabilitation or translocation projects.

Hypotheses/Predictions

If skinks are selecting certain habitat types in their current southeastern range because these habitats are of high quality, then i) the number of skinks encountered will be higher in some habitat types than would be predicted if there was a random distribution of skinks among all habitat types, and ii) skinks occupying these habitats will have higher body condition because these habitats are of higher quality and confer a fitness advantage.

Alternately, if skinks are not occupying certain habitat types more than others, their distribution will not be significantly different from a random distribution across the landscape. If skinks are found more often in certain habitats for reasons other than habitat selection, such as ease of observation or relegation to the habitat, then body condition (an index of fitness) will not differ between habitat types.

Methodology

In order to test my hypothesis that Bojer's skinks are selecting certain habitat types in the southeastern part of their range, I did a habitat use study using data collected by the Mauritian Wildlife Foundation's Reptile Recovery Team for the Mauritius Reptile Recovery Programme (Cole et al., 2009). For this programme, teams of 1-3 programme staff have visited Ilot Vacoas, Ile aux Fouquets, and Ile de la Passe 1-4 times per year since 2006 to do surveys of the Bojer's skink populations on these islands. Belt transects are done across the entire island, and observed Bojer's skinks are caught by hand and sometimes using pitfall traps (Mauritius Reptile Recovery Program, 2010). The skinks can be difficult to catch by hand, but sometimes the team will startle the skink from a refuge site (e.g. grass) in order to catch it (François Colin pers. comm.). Any Bojer's skinks that are caught are then weighed, measured (snout-vent length (SVL), tail length), and photographed, and a GPS location of the capture point is taken; the skink is then re-released. Using this method, the Reptile Recovery team has produced a dataset detailing 2130 skink captures (including the GPS location) over 10 years (2007 – 2016) on the three islands (Table 1).

In addition to skink location and measurement data, the Reptile Recovery Team has produced GIS habitat layers for each of the three islands. Habitat data such as dominant plant species and substrate were collected using a combination of several methods, including aerial photos, Google Maps, and ground-truthing, and are thought to be accurate to +/- 1m (Nik Cole, pers. comm.). These habitat data have been projected into QGIS and converted into usable shapefiles for analyses (Fig. 2). A detailed description of each habitat type can be found in Table 2.

To determine whether the skink distribution differs from random distribution across the islands, I first summed the number of skink captures on each island (549 for Ilot Vacoas, 1007 for Ile aux Fouquets, and 574 for Ile de la Passe; Table 1). I then projected a random number of equivalent points across each island (excluding the tidal zone), creating an 'expected' distribution based on the random distribution hypothesis. I used the intercept tool in QGIS to determine the habitat layer (Table 2) in which each point fell, for both observed Bojer's skinks and random points. This method of creating an expected distribution based on random points, then comparing this pattern to the actual distribution of an animal, has been used in other habitat studies (e.g. Frair et al., 2004; Fortin et al., 2009).

After determining the habitat layer for each point, it was apparent that in some cases, the point fell in a region with overlapping habitat layers (excluding the 'land' layer which

overlapped which all other habitat types: 5/1098 points on Ilot Vacoas; 766/2014 points on Ile aux Fouquets; 76/1148 points on Ile de la Passe). The names of these layers were therefore combined to represent a 'cover' type. For example, if the point fell within both '*Stenotaphrum*' and '*Tournefortia*', it was classified as cover type '*Stenotaphrum*; *Tournefortia*'. This was done in order to accurately represent the location of the point, while avoiding pseudoreplication by avoiding a count of multiple habitat layers for a single point. In total, Ilot Vacoas had 10 habitat/cover types after combination of some layers; Ile aux Fouquets had 27; and Ile de la Passe had 20 (Table 3).

All subsequent statistical analyses were done in RStudio 3.4.0 (R Core Team 2017). I wished to compare the counts of 'expected' (random) and 'observed' points in each habitat layer using an exact multinomial test (the equivalent of the chi-square test for small sample sizes; Chapanis, 1962). However, I was not able to run the test in R, likely because of the large number of habitat categories in the dataset (Chapanis, 1962). Instead, I used an exact binomial test to compare expected and observed point counts in each layer individually, as would have been done as a post-hoc analysis for the multinomial test (Campbell, 2014). Because of the high number of comparisons being made, I used a Bonferroni correction for my p-values (Armstrong, 2014). These analyses were done for each island separately since each island had its own unique set of habitat layers (Table 2).

Although precise measurements of body condition can be generated by killing an animal and directly measuring fat content, there are many non-destructive ways to generate an index of body condition, such as using the residuals of an ordinary least squares (OLS) regression of weight against a measurement of body size (Green, 2001). However, OLS regression has been shown to generate spurious results if assumptions are not strongly adhered to (Green, 2001). Therefore, I decided to use the suggestion of Green (2001) and use a multivariate model with mass as the dependent variable and several size measurements as predictor variables. However, it should be noted that I only had data for two size variables: SVL and tail length. Since the tails of Bojer's skinks can break off (pers. obs.), I decided this was not a reliable measurement of size and I have used only SVL in my analyses.

To estimate body condition, I constructed a linear mixed effects model (Oberg and Mahoney, 2007) using package nlme (Pinheiro et al., 2017). I constructed this model for each island separately, and separately for males and females since preliminary analyses indicated that they had different weights based on size (ANOVA (weight~size+sex); F value=5.954, p=0.0027)

and the reproductive status of females may influence condition estimates. I excluded juveniles because these individuals could not be sexed. Weight (g) was the dependent variable in the mixed effects models, and size (SVL in mm), habitat, and reproductive status (in the case of females: gravid, not gravid, unknown) were fixed effects. I included a random effect of year since many variables such as meteorological conditions, current population size and biology, and other parameters could influence the slope of the model from year to year. Because of problems with model convergence, I re-scaled SVL and weight variables to a numerical scale of 1-100. All p-values were assessed at a significance level of 0.05.

RESULTS

For each island, there were several habitat/cover types in which Bojer's skinks were found in significantly higher numbers than would be expected from a random distribution. Because of the very large number of habitat layers and associated p-values for the exact binomial tests, only significant results are presented in the text (without their respective p-values); results for all layers for all three islands, including all p-values, are presented in Table 3.

On Ilot Vacoas, skinks were observed significantly more than expected in *Stenotaphrum* grass and in the combined layers of '*Cynodon* grass, rock, and sand' and '*Tournefortia*'. Ilot Vacoas skinks were also found significantly less than expected in *Pemphis* and on bedrock ('land' layer; Table 3).

Ile aux Fouquets skinks were observed significantly more than expected in the combined layers of 'buildings' and 'short *Stenotaphrum*'; 'buidlings', 'short *Stenotaphrum*' and 'long *Stenotaphrum*'; '*Casuarina*' and 'short *Stenotaphrum*'; 'rock outcrops' and 'short *Stenotaphrum*'; 'rock outcrops', 'short *Stenotaphrum*' and 'long *Stenotaphrum*'; 'sedge, lowgrass, and sand' and 'short *Stenotaphrum*'; 'short *Stenotaphrum*' and 'long *Stenotaphrum*'; and the single layer 'short *Stenotaphrum*'. Skinks on this island were also found significantly less than expected in ephemeral pools; *Pemphis*; rock and sand; sandy sedge; *Scaevola*; and on bedrock (Table 3).

Ile de la Passe skinks were observed significantly more than expected on buildings, concrete, and cisterns; concrete platforms; short *Stenotaphrum*/herb; the combined layers of 'long *Stenotaphrum*' and '*Pandanus*'; and the combined layers of '*Tournefortia*', 'walls', and 'long *Stenotaphrum*'. Skinks on Ile de la Passe were also observed significantly less than expected in *Tournefortia* and on bedrock (Table 3).

As expected, linear mixed effects models showed a significant positive effect of size on weight in all models ($p>0.0001$ in all models). Gravid females had significantly higher weights on all three islands (Ilot Vacoas: $p=0.0087$; Ile aux Fouquets and Ile de la Passe: $p>0.0001$).

On Ilot Vacoas, males were significantly heavier in the combined layer of '*Cynodon*, rock, and sand' and '*Tournefortia*' ($p=0.041$; Table 4). On Ile Aux Fouquets, males and females had significantly higher weights in the combined layer of 'rock outcrops' and 'short *Stenotaphrum*' ($p=0.014$ males, $p=0.022$ females), and males had significantly lower weights in the combined layer of '*Caserina*' and 'short *Stenotaphrum*' ($p=0.017$; Table 4). There were no differences in weights between habitats for males or females on Ile de la Passe (Table 4).

DISCUSSION

My results support the hypothesis that Bojer's skinks on Ilot Vacoas, Ile aux Fouquets, and Ile de la Passe do not have random distributions across habitats, but occupy certain habitat types significantly more often than would be expected by chance. Of the 15 habitat/cover types where skinks are more likely to be found, 13 contain at least one species of grass. In fact, 87% of the habitat layers/cover types with higher than expected skink counts contained at least one species of grass, versus 55% of the total layers. Most of these grass layers specifically include the species *Stenotaphrum dimitiatum*; habitat layers containing this species cover on average 49% of each island (38% Ilot Vacoas, 69% Ile aux Fouquets, 41% Ile de la Passe; Table 2). My results suggest that Bojer's skinks are more likely to be found in grassy areas (the dominant habitat type on the southeastern islands) compared to other habitat types, a finding that is supported by the existence of the same pattern across all three islands.

There is some support, although equivocal, that skinks in these grassy habitats have higher body condition. In two of the 15 layers where skinks were observed more often than expected, either males, or both males and females, had higher weights than skinks in other habitats. However, in another habitat where skinks were similarly observed more than expected, males actually had significantly lower weights. I recommend accepting these results with caution. Upon closer inspection the data, it was clear that the number of skinks in each of these cases was quite low. In fact, there were only 8 female and 6 male skinks in the combined layer of 'rock out crops' and 'short *Stenotaphrum*', and there was only one male skink in '*Cynodon*, rock, and sand' and '*Tournefortia*' combined layers, as well as '*Caserina*' and 'short *Stenotaphrum*'

combined layers. Therefore, my body condition results may be influenced by very small sample sizes, and I am hesitant to draw any conclusions from these models.

Therefore, although I can confidently say that skinks are more often found in grassy habitats, I cannot conclude that this pattern reflects habitat selection. Part of the difficulty in drawing conclusions lies in the definition of habitat selection. There is a dearth of scientific literature on the topic of habitat selection, yet there is not one clear definition (Jones, 2001; Johnson, 2007). Many authors suggest that habitat selection must be shown to confer a fitness advantage (Pulliam and Danielson, 1991; Jones, 2001). For this reason, I attempted to investigate the effects of habitat on a body condition index in the hopes of understanding the fitness advantages of certain habitats. However, although habitat quality has been linked to lizard body condition (Amo et al., 2007), most investigations of habitat selection of reptiles or other ectotherms compare only the animal's use of habitats to available habitats, often by tracking individual animals, and do not attempt to test the fitness advantages of these habitats (but fitness is often inferred; e.g. Madsen and Shine, 1999; Blouin-Demers and Weatherhead, 2001; Pringle et al., 2003; Baldwin et al., 2006). In an investigation of snapping turtle (*Chelydra serpentina*) habitat selection, Kolbe and Janzen (2002) investigated the link between nest site selection and hatching success, and illustrated that 'preferred' habitats could actually act as an ecological trap and reduce fitness. This further highlights the ambiguity in definitions of habitat selection, since animals can be shown to select lower-quality habitats if specific cues cause the animal to perceive the habitat as high-quality (Gates and Gysel, 1978; Johnson, 2007). Because of the ambiguity in definitions, even if I were confident in my statistical results for body condition, the lack of support for this prediction would not necessarily constitute evidence to reject the habitat selection hypothesis.

Using the definition of habitat selection which includes fitness measures (Jones, 2001), my results suggest that skinks may not be selecting grassy habitats on the southeastern islets of Mauritius. If skinks are not selecting these habitats, why are they found to differ from a random distribution across the islets? I propose two alternate hypotheses to explain this pattern. First, it may be that skinks are more easily detected in these habitats, and so are more frequently observed and captured in grassy habitats compared to others. Although this is certainly a possibility, skinks seem to be even more detectable and easier to catch in other island habitats such as rock and sand, especially since these habitats have no possible refuges unlike grassy habitats where the skinks may hide (François Collins, pers. comm.). Therefore, I find this

explanation unlikely. Second, it could be that skinks are relegated to this habitat for some other reason. The islands are heavily used by people (Cole, 2012; Cole et al., 2013), and it's possible that although higher-quality habitat may exist elsewhere, skinks are unable to use these habitats due to human disturbance. One could perhaps argue that if skinks are selecting grassy habitats to avoid human disturbance, then they are selecting the higher fitness habitat and the habitat selection hypothesis still holds. However, habitat selection theory assumes that an animal is able to select from habitats, i.e. they are "free" (Fretwell and Lucas, 1969); if skinks are barred from using certain areas of the island due to human use, then they cannot be seen to be selecting against these areas. The same logic applies if the Bojer's skinks are relegated to grassy habitats due to strong interference competition with other species, such as Button's skink (*Cryptoblepharus boutonii*) or house gecko (*Hemidactylus frenatus*). However, these species have been shown to exist in the same habitats (Cole, 2011), therefore this explanation is also unlikely.

An alternate hypothesis is that Bojer's skinks do confer a fitness benefit from grassy habitats that was not captured in my body condition analyses. My index of condition was a simple measurement of weight based on size, which may be an inadequate measure of fitness. Other measures, such as an index of condition using multiple size measurements, or measures of reproductive success, could indicate that skinks do have higher fitness in grassy habitats. If this is the case, there would be strong support for the hypothesis that Bojer's skinks select grassy habitats in order to incur fitness benefits from these habitats. If not, further studies could investigate whether skinks are relegated to these habitats for some other reason.

Limitations

The ambiguity in definitions of habitat selection (e.g. Jones, 2001; Johnson, 2007) made it difficult to make explicit predictions about what patterns I might expect if habitat selection is occurring. I dealt with this limitation by selecting and using a particular definition for this project, but the development of a robust conceptual framework with clear terminology would be very useful.

There were several practical limitations which influenced the success of my study. First of all, unlike some studies that collect data about sites which are not used by animals in order to compare them to sites which are used (Pringle et al., 2003; Baldwin et al., 2006; Fortin et al., 2009), I only had data for sites where skinks were observed and caught. Therefore, I could not

test the effects of several variables such as weather, temperature, and time of year on site selection, since I did not have equivalent "non-occupied" sites with which to compare occupied sites. Factors such as temperature (Blouin-Demers and Weatherhead, 2001; Pringle et al., 2003), weather (Jorde et al., 1984; Huey, 1991), and time of day (Godvik et al., 2009) have been shown to have a significant influence on habitat selection, but I could not test the effects of these factors using my chosen analysis methods.

The statistical analyses I chose also had some limitations. Because of the large number of habitat categories, an exact multinomial test could not be performed (Chapanis, 1962). This led to the use of a binomial exact test for each habitat type, meaning that there were 56 of these tests performed. Even though I tried to address this by using a Bonferonni correction, multiple comparisons will increase the probability of a type I error (Keppel and Wickens, 2004). A different statistical approach that does not require multiple comparisons might have been able to address this limitation, but I was unable to find a suitable one.

My body condition analysis was also not ideal, since there was only one reliable measurement of size for Bojer's skinks. The best methods of estimating body conditions are often destructive (Green, 2001), and would not be appropriate for this Critically Endangered species. An index of condition was therefore more appropriate, but with only one measure of size, my analyses may not have captured a good estimate of true body condition. The unreliability of mass-size residuals using OLS regression (Green, 2001) also made it difficult to develop a reliable index of condition in this case.

Lastly, there were some problems using the island habitat shapefiles in QGIS to generate overlapping habitat layers. Adjacent habitat polygons were often not properly abutting each-other, creating gaps between layers or small overlaps where there should have been none. In addition, some of the overlapping layers may not have been true overlaps, e.g. when buildings overlapped with other layers such as grass; in this example, the grass may not have been actually growing on the building yet the layers were overlapping in the GIS. The way in which the layers were constructed were also unconventional, as habitat layers were sometimes split into multiple polygons, making calculations and GIS processes unwieldly. These problems meant that I could not create a usable "cover type" in QGIS, but instead needed to manually combine the layer names in Microsoft Excel, which took some time and increased the probability of human error.

Recommendations

There are four recommendations I would make for any future studies on habitat selection in Ilot Vacoas Bojer's skink. First, to ascertain what factors might influence habitat selection, I recommend collecting habitat data in areas where skinks are not present. This, combined with data on weather, time of day, season, and other factors specific to the data collection location can be used to test how multiple environmental factors influence Bojer's skink habitat use. This will be valuable information to help tease out what specific variables may influence skink habitat use.

Second, more morphometric data should be collected on skinks when they are captured, such as leg length or head width. This data will allow the development of a better index for body condition, which may be essential for determining the fitness consequences of habitat use. This is especially the case since other measures of fitness, such as reproductive fitness, may be very difficult to measure in individual skinks due to their small size and the infeasibility of marking individuals for identification from a distance.

Third, due to some of the difficulties encountered when attempting to combine and analyze layers in QGIS, I would recommend these layers be carefully revised if any future analysis work will be done with them. This would include ensuring that all adjacent habitat layers are properly abutting each-other and there are no overlapped layers in the GIS which are not overlapped in reality.

Lastly, with the knowledge that Bojer's skinks occupy grassy habitats within the southeastern part of their range, I would recommend taking steps to prevent human disturbance on these parts of the inhabited islets. Due to its classification as Critically Endangered, it is imperative that habitats which are currently being used by the skinks be properly preserved. Fencing may be one possible way, if permission can be granted, of decreasing human disturbance in these areas. In addition, education campaigns may help inform the public about the skink and encourage visitors to stay away from sensitive areas.

Conclusion

Determining patterns of habitat use and selection in threatened species may help inform various species recovery techniques such as habitat rehabilitation or translocation. Using a habitat selection study, I have shown that the Critically Endangered Bojer's Skink in the southeastern part of its range in Mauritius occupies grassy habitats more often than would be predicted from a random distribution. However, there is no clear evidence that occupation of these habitat types

confers a fitness advantage. Future studies should collect further habitat and skink morphometric data in order to better explain these patterns. Given the current biodiversity crisis (Ceballos et al., 2017), it is imperative that we make informed, scientifically-based decisions as a part of species recovery programs.

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FIGURES AND TABLES

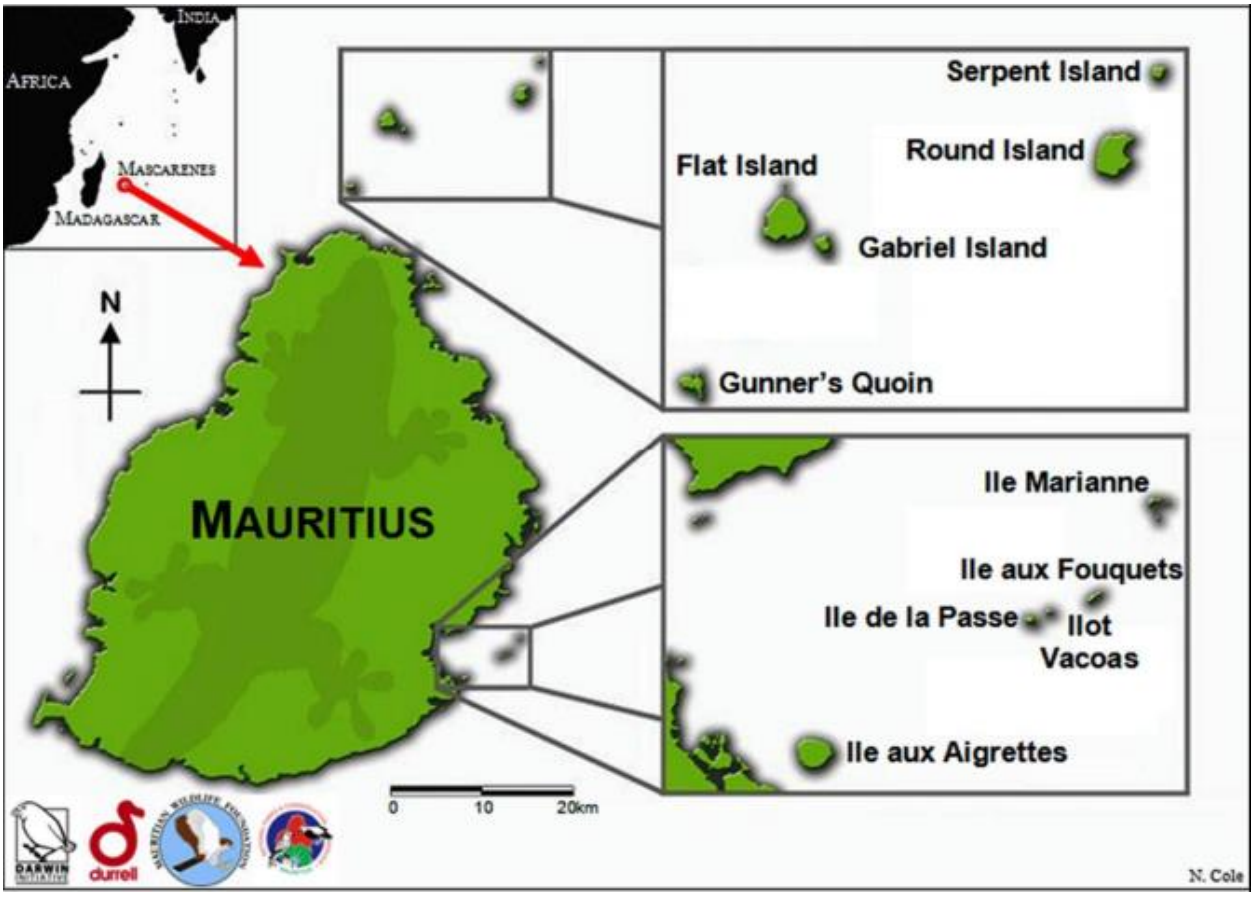


Fig. 1: The island of Mauritius, with specific reference to the locations of northern islets (Flat Island, Gabriel Island, Gunner's Quoin, Pigeon Rock, Round Island, and Serpent Island) and southeastern islets (Ile aux Fouquets, Ile de la Passe, Ilot Vocoas) where Bojer's skinks (*Gongylomorphis bojerii*) are currently found. Taken from *Mauritius Reptile Recovery Program* (2010).

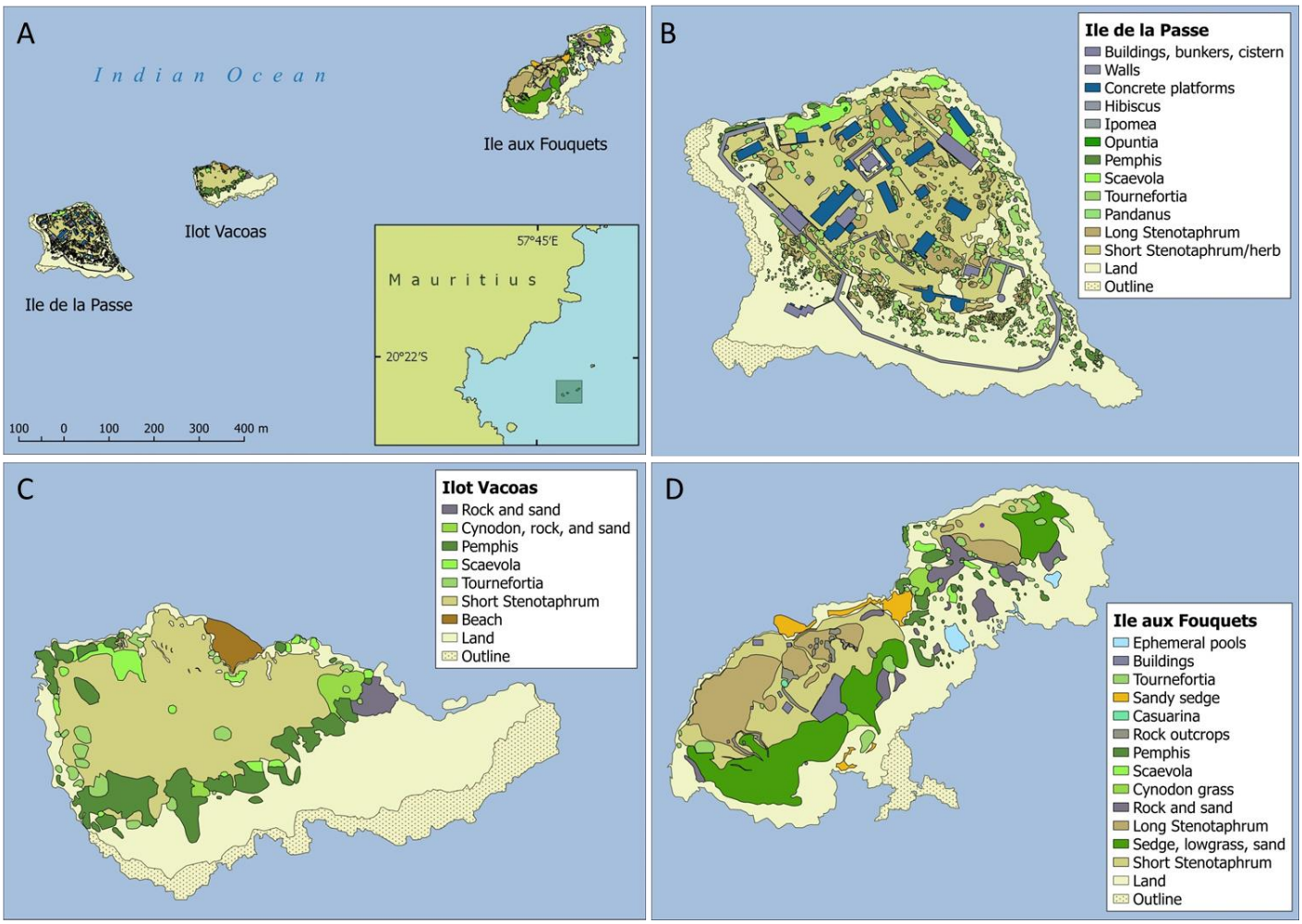


Fig. 2: Habitat cover on the three southeastern islands which are currently home to the Ilot Vacoas Bojer's skink. A) The geographical locations of the three islands in relation to Mauritius Island and to each-other. B)-D) Habitat types on Ile de la Passe, Ilot Vacoas, and Ile aux Fouquets, respectively. Descriptions of the different habitat types can be found in Table 2. The 'outline' layer includes the tidal zone, which was not used in any of the analyses.

Table 1: Number of Bojer's skink captures per year that were accompanied by a GPS location. '--' indicates that there was no GPS data collected for that year, and 'NA' indicates that there were no observed skinks on the island in that year.

	Year										
Island	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	**Total**
Ilot Vacoas	--	52	33	31	--	41	64	84	124	120	**549**
Ile aux Fouquets	48	136	121	20	62	87	97	141	140	155	**1007**
Ile de la Passe	NA	NA	18	83	18	--	67	95	165	128	**574**

Table 2: Descriptions of GIS habitat layers for Ilot Vacoas, Ile aux Fouquets, and Ile de la Passe. Several of the habitat types can be found on all three islands. Area (m^2) of each habitat type is also given for each island. The sum of all habitats for each island is larger than the area for the entire island because of overlapping habitat layers. The total area for each island include the tidal zone, which was not included as a habitat layer in any of the analyses.

Island/Habitat Layer	Habitat Description	Area (m^2)
Ilot Vacoas		***11,347***
Beach	Open sand along coastline, little to no vegetation	196
Cynodon, rock, sand	*Cynodon* grass, rocks, and sand	180
Land	Bedrock that is not part of the tidal zone	10,046
Pemphis	*Pemphis acidula* (woody shrub) and some *Suriana maritima* (woody shrub)	1178
Rock and sand	Rock and sandy habitat with minimal to no vegetation	139
Scaevola	*Scaevola taccada*, native woody shrub	243
Stenotaphrum	*Stenotaphrum dimidiatum* grass	3842
Tournefortia	*Tournefortia argentea* (alternate name *Heliotropium foertherianum*), a shrub or small tree	249
Ile aux Fouquets		***27,726***
Buildings	Lighthouse, concrete platforms	417
Caserina	*Caserina*, introduced tree	16
Cynodon grass	*Cynodon* grass, also some sedge	297
Ephemeral pools	Salty temporary pools	281
Land	Bedrock that is not part of the tidal zone	26,725
Long *Stenotaphrum*	*Stenotaphrum dimidiatum* grass, patches of longer growth	3270
Pemphis	*Pemphis acidula* (woody shrub) and some *Suriana maritima* (woody shrub)	679
Rock and sand	Rock and sandy habitat with minimal to no vegetation	1223
Rock outcrops	Areas of only rock	334
Sandy sedge	Sand and *Fimbristylis cymosa* sedge	591
Scaevola	*Scaevola taccada*, native woody shrub	190
Sedge, lowgrass, sand	Mixed *Fimbristylis*, low-growing *Stenotaphrum*, and sand	4418
Short *Stenotaphrum*	*Stenotaphrum dimidiatum* grass, patches of shorter growth	10,850
Tournefortia	*Tournefortia argentea* (alternate name *Heliotropium foertherianum*), a shrub or small tree	542
Ile de la Passe		***24,011***
Buildings, bunkers, cistern	Unused buildings, bunkers, and cistern left from previous island fortification (from 19^{th} century)	575
Concrete platforms	Concrete platforms left from island fortification	1132
Ipomoea	*Ipomoea macrantha*, flowering vine	25
Land	Bedrock that is not part of the tidal zone	22,859

Long *Stenotaphrum*	*Stenotaphrum dimidiatum* grass, patches of longer growth	2170
Pandanus	*Pandanus vandermeeschii*, or screw pine; endemic tree	43
Pemphis	*Pemphis acidula* (woody shrub), some *Suriana maritima* (woody shrub)	23
Scaevola	*Scaevola taccada*, native woody shrub	554
Short *Stenotaphrum* herb	Short *Stenotaphrum dimidiatum* grass, some fragmented herbaceous plants	7155
Tournefortia	*Tournefortia argentea* (alternate name *Heliotropium foertherianum*), a shrub or small tree	2088
Walls	Walls left from island fortification	676

Table 3: Skink occurrences and random point counts for each habitat layer, or combinations of layers when they overlap ('cover type'). P-values are based on the results of binomial exact tests for each habitat layer/cover type. Corrected p-values are Bonferonni-corrected values based on the number of comparisons made within each island.

Habitat layer/cover type	**Bojer's skink count**	**Random point count**	**p-value**	**Corrected p-value**
Ilot Vacoas				
Beach	9	11	0.6485	1.00
Cynodon, rock, sand	3	6	0.3014	1.00
Cynodon, rock, sand; *Tournefortia*	2	0	2.20E-16	2.20E-15 *
Land	13	217	2.20E-16	2.20E-15 *
Pemphis	7	61	2.20E-16	2.20E-15 *
Pemphis; *Stenotaphrum*	0	3	0.08247	0.825
Rock and sand	0	5	0.01182	0.118
Scaevola	8	15	0.06639	0.664
Stenotaphrum	487	215	2.20E-16	2.20E-15 *
Tournefortia	20	16	0.308	1.00
Ile aux Fouquets				
Buildings; short *Stenotaphrum*	28	12	5.49E-05	0.00148 *
Buildings; short *Stenotaphrum*; and long *Stenotaphrum*	1	0	2.20E-16	5.94E-15 *
Caserina; short *Stenotaphrum*	4	0	2.20E-16	5.94E-15 *
Cynodon	3	5	0.5018	1.00
Cynodon; short *Stenotaphrum*	2	2	1.00	1.00
Ephemeral pools	0	11	2.66E-05	7.18E-04 *
Land	13	424	2.20E-16	5.94E-15 *
Long *Stenotaphrum*	0	1	0.6319	1.00
Pemphis	0	15	6.29E-07	1.70E-05 *
Rock and sand	13	36	1.30E-05	3.51E-04 *
Rock and sand; short *Stenotaphrum*	11	10	0.7487	1.00
Rock outcrops; sedge, lowgrass, sand; and short *Stenotaphrum*	1	1	1.00	1.00
Rock outcrops; short *Stenotaphrum*	26	4	1.90E-13	5.13E-12 *
Rock outcrops; short *Stenotaphrum*; and *Caserina*	0	1	0.632	1.00
Rock outcrops; short *Stenotaphrum*; and long *Stenotaphrum*	19	3	4.95E-10	1.34E-08 *
Sandy sedge	2	16	3.72E-05	0.001 *
Scaevola	0	8	5.61E-04	0.0151 *
Sedge, lowgrass, sand	14	79	2.20E-16	5.94E-15 *
Sedge, lowgrass, sand; and short *Stenotaphrum*	142	86	4.98E-09	1.34E-07 *

Short *Stenotaphrum*	440	156	2.20E-16	5.94E-15 *
Short *Stenotaphrum*; long *Stenotaphrum*	270	117	2.20E-16	5.94E-15 *
Tournefortia	2	9	0.01119	0.302
Tournefortia; short *Stenotaphrum*	16	7	0.003205	0.0865
Tournefortia; *Pemphis*	0	1	0.632	1.00
Tournefortia; sandy sedge	0	1	0.632	1.00
Tournefortia; short *Stenotaphrum*	0	1	0.632	1.00
Ile de la Passe				
Buildings, bunkers, cistern	27	7	5.18E-09	1.04E-07 *
Concrete platforms	59	33	2.07E-05	4.14E-04 *
Ipomoea	0	1	0.6318	1.00
Ipomoea; short *Stenotaphrum* herb	2	1	0.2642	1.00
Land	27	253	2.20E-16	4.40E-15 *
Long *Stenotaphrum*	44	47	0.7037	1.00
Long *Stenotaphrum*; *Pandanus*	1	0	2.20E-16	4.40E-15 *
Pandanus; short *Stenotaphrum* herb	0	2	0.2774	1.00
Pemphis	0	3	0.08251	1.00
Scaevola	0	3	0.08251	1.00
Scaevola; long *Stenotaphrum*	3	1	0.08014	1.00
Scaevola; short *Stenotaphrum* herb	0	2	0.2774	1.00
Short *Stenotaphrum* herb	368	156	2.20E-16	4.40E-15 *
Tournefortia	4	19	5.76E-05	0.00115 *
Tournefortia; concrete platforms	0	2	0.2774	1.00
Tournefortia; long *Stenotaphrum*	13	10	0.3347	1.00
Tournefortia; short *Stenotaphrum* herb	18	19	0.9073	1.00
Tournefortia; walls; and long *Stenotaphrum*	1	0	2.20E-16	4.40E-15 *
Walls	7	13	0.1197	1.00
Walls; *Tournefortia*	0	2	0.2774	1.00

Table 4: Degrees of freedom (DF), t-statistic, and p-value for linear mixed models used to test the effect of habitat on skink weight. Each level of the factor 'habitat layer/cover type' is compared to the factor level 'land' as a reference (Table 2). An * indicates significance ($p<0.05$).

Habitat layer/cover type	**Males**			**Females**		
	DF	**t-value**	**p-value**	**DF**	**t-value**	**p-value**
Ilot Vacoas						
Beach	210	-1.329287	0.1852	216	1.043389	0.2979
Cynodon, rock, sand	NA	NA	NA	216	0.106365	0.9154
Cynodon, rock, sand; *Tournefortia*	210	2.052341	0.0414 *	216	0.095066	0.9244
Pemphis	210	-0.524464	0.6005	216	-0.332961	0.7395
Scaevola	210	0.462375	0.6443	216	-0.325930	0.7448
Stenotaphrum	210	1.076410	0.2830	216	-0.101603	0.9192
Tournefortia	210	0.762757	0.4465	216	0.503409	0.6152
Ile aux Fouquets						
Buildings; short *Stenotaphrum*	367	-0.29701	0.7666	263	0.869341	0.3855
Buildings; short *Stenotaphrum*; and long *Stenotaphrum*	367	-0.77092	0.4413	NA	NA	NA
Caserina; short *Stenotaphrum*	367	-2.39589	0.0171 *	263	-0.722627	0.4706
Cynodon	NA	NA	NA	263	-0.102874	0.9181
Cynodon; short *Stenotaphrum*	367	0.65710	0.5115	263	-0.872264	0.3839
Rock and sand	367	-0.69415	0.4880	263	0.517568	0.6052
Rock and sand; short *Stenotaphrum*	367	0.87067	0.3845	263	-0.390142	0.6967
Rock outcrops; sedge, lowgrass, sand; and short *Stenotaphrum*	NA	NA	NA	263	0.005974	0.9952
Rock outcrops; short *Stenotaphrum*	367	2.46770	0.0141 *	263	2.308513	0.0217 *
Rock outcrops; short *Stenotaphrum*; and long *Stenotaphrum*	367	0.11810	0.9061	263	0.128319	0.8980
Sandy sedge	NA	NA	NA	263	0.817636	0.4143
Sedge, lowgrass, sand	367	-1.44655	0.1489	263	-0.546686	0.5851
Sedge, lowgrass, sand; short *Stenotaphrum*	367	0.48746	0.6262	263	0.001437	0.9989
Short *Stenotaphrum*	367	0.46391	0.6430	263	0.341208	0.7332
Short *Stenotaphrum*; long *Stenotaphrum*	367	1.58139	0.1146	263	0.524196	0.6006
Tournefortia; short *Stenotaphrum*	367	0.34288	0.7319	263	0.079240	0.9369
Ile de la Passe						
Buildings, bunkers, cistern	224	0.987932	0.3243	120	-0.221603	0.8250
Concrete platforms	224	-0.734183	0.4636	120	0.292871	0.7701
Ipomoea; short *Stenotaphrum* herb	224	-0.511707	0.6094	120	0.958647	0.3397

Long *Stenotaphrum*	224	-0.929501	0.3536	120	-0.434182	0.6649
Long *Stenotaphrum*; *Pandanus*	224	0.066390	0.9471	NA	NA	NA
Scaevola; long *Stenotaphrum*	224	-0.468202	0.6401	NA	NA	NA
Short *Stenotaphrum* herb	224	-1.223929	0.2223	120	0.396399	0.6925
Tournefortia	224	-0.153809	0.8779	120	-0.085638	0.9319
Tournefortia; long *Stenotaphrum*	224	-0.342139	0.7326	120	-0.116793	0.9072
Tournefortia; short *Stenotaphrum* herb	224	-0.841880	0.4008	120	0.967342	0.3353
Tournefortia; walls; and long *Stenotaphrum*	NA	NA	NA	120	0.627674	0.5314
Walls	224	-0.584474	0.5595	120	0.583661	0.5605