

Habitat associations and conservation status of an endemic forest dwarf chameleon (*Bradypodion* sp.) from South Africa

Walter J. Reisinger, Devi M. Stuart-Fox and Barend F.N. Erasmus

Abstract We quantified habitat associations and evaluated the conservation status of a recently identified, undescribed species of dwarf chameleon, *Bradypodion* sp. nov. Dhlinza, endemic to scarp forest remnants in KwaZulu-Natal Province, South Africa. At the micro-habitat scale the Dhlinza dwarf chameleon was found more often in forest gaps and near paths than highly disturbed edges or forest interior. Chameleon presence was not explained by forest physiognomic variables such as vine cover, shrub and tree density, or canopy cover. Presence near gaps may be better explained by the combined effects of the thermal microenvironment and food availability. The species is moderately common where

it occurs, with estimated densities of 4.7, 8.7 and 29.7 individuals per ha within forest interior, edges and gaps respectively. At the landscape scale, the chameleon occurs only in three remnant forests: the Dhlinza, Entumeni and Ongoye Forests. The species' extent of occurrence was estimated to be 88 km² and its area of occupancy 49 km². Based on the small area of remaining suitable habitat, this species meets the requirements for categorization as Endangered according to IUCN Red List criteria.

Keywords Abundance, *Bradypodion*, chameleon, edge effect, fragmentation, gaps, scarp forest, South Africa.

Introduction

Dwarf chameleons of the genus *Bradypodion* represent a radiation endemic to southern Africa, with 15 currently recognized species, although several new species are being described (W.R. Branch, K.A. Tolley & C. Tilbury, unpub. data). Of the currently described species, several (*B. damaranum*, *B. caffrum*, *B. nemorale*, *B. transvaalense* and *B. setaroi*), are restricted to indigenous South African forest (Branch, 1998), and are among the few South African reptile species that are indigenous forest obligates. Forest is the least extensive biome in South Africa with the total remaining area comprising c. 7,000 km² or 0.56% of the total land area (Low & Rebelo, 1996; Eeley *et al.*, 2001). This indigenous forest is highly fragmented and patchily distributed, with most remnants being small (<1 km²; Cooper, 1985; Low & Rebelo, 1996) and occurring mainly in coastal areas and along the country's eastern escarpment (Midgley *et al.*, 1997). Although there is substantial pressure on forests in terms of resource use (Lawes *et al.*, 2004) little research on the ecology of forest communities or forest-restricted taxa has been conducted, despite disproportionately high levels of biodiversity within this

biome (Geldenhuys & MacDevette, 1989; Eeley *et al.*, 2001). It is thus no exaggeration to suggest that South African indigenous forest is the neglected biome of South Africa.

One of the dwarf chameleon species restricted to indigenous forest is a recently identified species found in Dhlinza, Entumeni and Ongoye forest reserves (Raw, 2001) as well as in the garden environs of the town of Eshowe (28.89°S, 31.46°E). Phylogenetic work by Tolley *et al.* (2004) showed that the dwarf chameleon found in Dhlinza Forest is not closely related to *B. nemorale* (12% ND2 mtDNA divergence), the species to which these populations were previously thought to belong. Moreover, the minimum divergence for the mitochondrial ND2 gene between chameleons from Dhlinza and any other species of dwarf chameleon is 10.5%, which is at the higher end of sequence divergence among any two currently recognized *Bradypodion* species (2–16.5%; Tolley *et al.*, 2004). Raw (2001) has also indicated that these chameleons should be classified as different species based on morphological characters. Not only do chameleons from Dhlinza, Entumeni and Ongoye forests represent highly genetically divergent, morphologically distinguishable populations, but they also differ in their habitat associations. Dhlinza, Entumeni and Ongoye forests are classified as scarp forest, having different floral species assemblages and physiognomic structure to higher altitude Afromontane mixed mist belt forest such as Nkandla and Qudeni where *B. nemorale* is found (Eeley *et al.*, 2001). Pending their formal description and for

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the purposes of this study, chameleons occurring in Dhlinsa, Entumeni and Ongoye forest will be referred to as *Bradypodion* sp. nov. Dhlinsa or the Dhlinsa dwarf chameleon.

Although the Dhlinsa dwarf chameleon has yet to be formally described, its genetic distinctiveness and highly restricted range (Fig. 1) make it of immediate conservation concern. An understanding of the factors that may limit its distribution and abundance within remaining habitat patches is particularly useful for conservation management and planning. Here, therefore, we quantify the habitat associations of chameleons in Dhlinsa forest. Specifically, we tested whether the abundance of Dhlinsa dwarf chameleons differed between low-disturbance gaps in the forest, high-disturbance edges and intact forest. We hypothesized that chameleons should prefer gaps because gaps provide an opportunity for thermoregulation (Greenberg, 2001) whereas such forest-restricted species may be intolerant of edges bordering urban environments, which are often characterized by infestations of alien vegetation. Chameleons in Madagascar have been found to be more abundant in forests of low disturbance than in patches of high disturbance (Jenkins *et al.*, 2003). We also estimated the density of this chameleon in the Dhlinsa forest and the potential habitat remaining in KwaZulu-Natal. Based on these results, we assess the conservation status of this species in accordance with IUCN guidelines (IUCN, 2001).

Study species and site

Dwarf chameleons of the genus *Bradypodion* are small, insectivorous, strictly arboreal reptiles and generally have allopatric, restricted ranges. All species are viviparous, produce up to two litters a year, and reach sexual maturity in 1–2 years (Branch, 1998). At night, chameleons roost on peripheral vegetation (tips of vines and leaves), presumably to avoid predators.

We surveyed chameleons in the Dhlinsa Forest, near Eshowe in KwaZulu-Natal (Fig. 1). The protected, 265 ha Dhlinsa forest is a remnant indigenous scarp forest (Eeley *et al.*, 2001; Lawes *et al.*, 2004). It is partly fragmented and surrounded by suburban development and sugarcane fields. The forest occurs at an altitude of 500 m, with a rainfall of c. 1,200 mm per annum.

Methods

Survey techniques and sampling design

We conducted nocturnal surveys (19.30–23.00) from 22 March to 20 April 2004, a period in which chameleons are active, using a distance sampling protocol that has been used in previous studies of chameleon population status and density (Brady & Griffiths, 1999; Jenkins *et al.*, 1999; Jenkins *et al.*, 2003). To obtain perpendicular distance from the transect we recorded the horizontal distance to the chameleon and the vertical perch height and

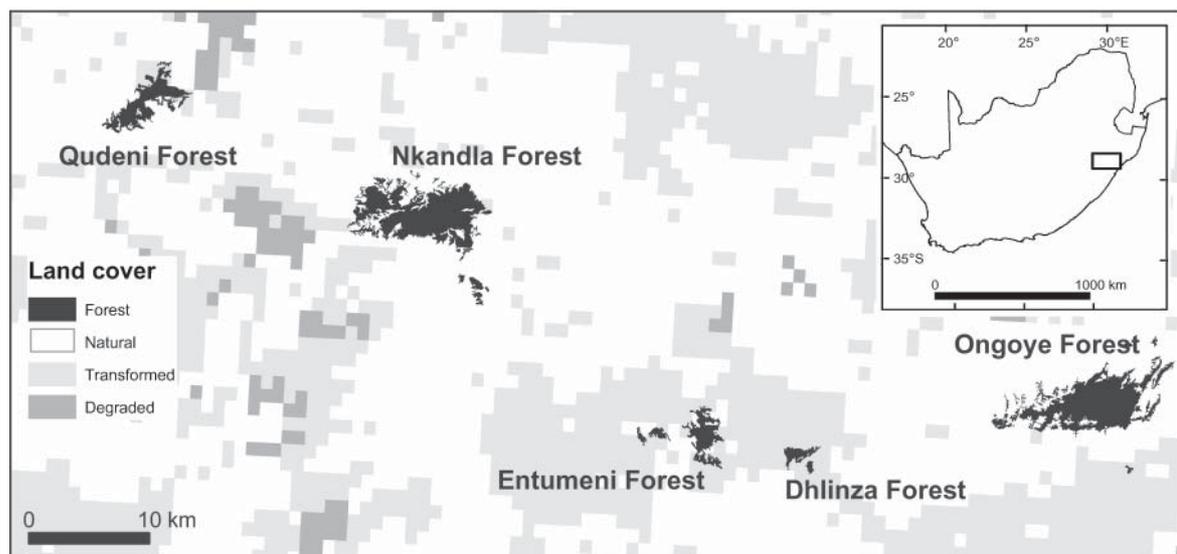


Fig. 1 Study location (Dhlinsa Forest) and associated indigenous forest remnants in southern Zululand, South Africa (Mucina *et al.*, 2004). The rectangle in the inset map indicates the area of study; detailed location maps are available on request. Entumeni, Dhlinsa and Ongoye are scarp forest, whereas Qudeni and Nkandla are Afromontane forest. The available land cover information dates from 1994 (Fairbanks *et al.*, 2000), and does not reflect the current extent of transformation and degradation but does give an indication of the isolated nature of these forest fragments. The natural land cover class refers to natural vegetation (not including forest), the transformed class refers to agriculture, forestry and built up areas, and the degraded class refers to areas of artificially low vegetation cover, i.e. overgrazed areas (see Fairbanks *et al.*, 2000, for more details).

calculated the length of the hypotenuse. Our vertical detection ceiling was 10 m rather than 6 m, as used in other studies (Jenkins *et al.*, 1999; Jenkins *et al.*, 2003), because we used a powerful hand-held spotlight enabling good visibility.

We surveyed 32 line transects, each 100 m long. Transects were categorized as (1) along the forest edge (13 transects), (2) along edges/gaps within the forest (e.g. tree-fall gaps, small clearings, paths <3 m wide; seven transects), and (3) within the forest interior (12 transects). Edge transects were generally highly disturbed, characterized by an abrupt transition between forest and suburban environment or tarmac road, and often with infestations of dense, alien vegetation. Gap transects were less disturbed, largely free of alien vegetation, and characterized by small breaks in intact forest. Transects were placed to maximize coverage and ensure adequate representation of the forest, and were placed a minimum of 50 m apart to preclude recaptures. We moved slowly (*c.* 1 m per minute; 1.5 hours per transect) along each transect, systematically searching the vegetation for roosting chameleons.

Where possible we captured chameleons with a 5 m telescopic fibreglass rod by inserting the tip of the rod underneath the chameleon and lifting it up, thereby forcing it to cling onto the rod. For each chameleon captured we recorded (1) snout-vent length (SVL), in mm, using callipers, (2) sex, indicated by the presence of hemipenal bulges in males, (3) age class (adult or juvenile), (4) perch height (m), and (5) height to the first fork of the perch plant (m). We noted whether the perch plant was a vine or a tree. We released the chameleon where it was captured and marked the spot with flagging tape.

The following day we returned to transects surveyed the previous night and marked 10 * 10 m plots every 25 m along the transects. If the location of a chameleon

did not fall within a plot we marked out additional 10 × 10 m plots surrounding the location of each individual. Within these plots we recorded 11 microhabitat variables (Table 1). Thus, for each transect we measured microhabitat variables for plots with chameleons, and up to four plots without chameleons. This enabled us to determine which, if any, microhabitat characteristics were associated with the presence or absence of chameleons within the forest.

Habitat associations

To determine which microhabitat variables were associated with probability of chameleon occurrence, we first converted absolute number of chameleon captures to presence and absence for each plot (*n* = 131) within each transect. To account for potential spatial autocorrelation of plots within transects we applied a generalized estimating equation (Liang & Zeger, 1986), which is a specialized general linear model (GLM) that accounts for the correlation between observations in regression models. Plot was specified as the repeated measure within each transect, and the independent variables are given in Table 1. Statistical analyses were performed using *PROC GENMOD* in SAS version 9.1 (SAS Institute, 2003). Model selection was by backward elimination with a criterion for remaining in the model of *P* < 0.1.

Extent of suitable habitat

To identify the potential distribution of the species we estimated the extent of scarp forest left in southern Zululand, and the distances between and sizes of remnants of this forest type using ArcGIS (ESRI, 2003) and the most recent vegetation coverage for southern Africa (Mucina & Rutherford, 2004). This information provided

Table 1 Microhabitat variables recorded within 10 * 10 m habitat plots along each transect in the Dhlinda scarp forest, KwaZulu-Natal, South Africa.

Variable	Description
Transect type	Edge, gap or forest interior.
Distance to nearest gap (m)	Distance to tree fall gap or path; if no gap was present within 15 m, a nominal 18 m was recorded.
Distance to forest edge (m)	Calculated based on GPS coordinates for each plot, using ArcGIS (ESRI, 2003).
Canopy cover (%)	Using a spherical densiometer.
Canopy height	1, up to 5 m; 2, 5–10 m; 3, 10–15 m; 4, ≥ 15 m.
Tree circumference at breast height (cm)	Woody vegetation of 5 m or more in height; circumference obtained with a measuring tape; converted to woody stem density per quadrat.
Number of trees	Woody vegetation > 5 m in height.
Number of shrubs	Vegetation 1–5 m in height.
Vine cover estimate	1, 0–25%; 2, 25–50%; 3, 50–75%; 4, 75–100%; vines were classified as Low Vine (occurring in the lower 5 m stratum of forest), and Tall Vine (occurring above 5 m).
Vertical visibility (m)	Visibility from the observer on the transect to the canopy. Estimated using the 8 m long noosing rod as a proxy, whereby the rod's length was used to judge visibility.
Horizontal visibility (m)	Horizontal distance from the transect into the forest; estimated using the noosing rod.

area values of the extent of occurrence and area of occupancy (IUCN, 2001). We measured extent of occurrence using a minimum convex polygon, and estimated area of occupancy as the area of scarp forest within the extent of occurrence.

Density, population size and conservation status

Density estimates were derived using the software *Distance v. 4.1* (Thomas *et al.*, 2004). One of the main assumptions of distance sampling is that transects are placed randomly such that habitat types are sampled proportionally to their occurrence. If this assumption is met density estimates can be extrapolated to estimate population size (Buckland *et al.*, 2001). As our transects were not randomly distributed, we estimated density for each habitat type (gaps, edges and forest interior) and multiplied it by the area represented by that transect type (see below) then summed the three separate abundance estimates to obtain an estimate of population size. Low numbers of individuals precluded reliable calculation of a separate detection function (and therefore density estimate in *Distance*) for each habitat type. Instead, we simply multiplied the mean adult density by the proportion of individuals found in habitat type A divided by the proportion of habitat type A surveyed. For instance, only 15% of individuals were found in forest interior yet forest interior represented 37.5% of transects surveyed. Thus, density in forest interior = mean adult density * 0.15 / 0.375. This method of estimating density for each transect type implicitly assumes that detection functions are similar between transect types. There were no significant differences among transect types in chameleon perch height or horizontal distance from the transect, suggesting that detection functions should be similar.

Area of edge habitat was estimated as the length of the forest perimeter (derived from the vegetation coverage) multiplied by a width of 4.5 m (mean horizontal visibility). We used the estimate of Oribi & Lawes (2004) of 7.8% for the area of forest under natural gap phase. This estimate was derived for coastal Pondoland scarp forest in South Africa. The proportion of forest interior was calculated as the remaining area not composed of edges and gaps.

Results of the habitat selection study, density estimate and information on extent of occurrence and area of occupancy were used to determine conservation status in accordance with IUCN Red List Criteria version 3.1 (IUCN, 2001).

Results

We found a total of 29 chameleons, of which 18 were adults (nine males, nine females), nine were juveniles

(five males, four females), and four were not captured and therefore could not be sexed (two of these were clearly adults judging from their large size). Seventeen chameleons were found perching on vines and 12 on the leaves of various indigenous tree species. On average chameleons occurring at or near gaps were found at a mean distance of $2.18 \pm \text{SE } 0.57$ m from a gap. We found chameleons at an average perch height of $4.2 \pm \text{SE } 0.45$ m above ground, and $2.97 \pm \text{SE } 0.41$ m from the edge of a transect.

The average vertical and horizontal visibilities along transects were $6.1 \pm \text{SE } 0.20$ m and $4.5 \pm \text{SE } 0.23$ m, respectively. The chameleons we found thus fell well within this range of visibility. Furthermore, neither the horizontal distance from transects nor the perch height of captured chameleons differed significantly between the three habitat types (one-way ANOVA, $F_2 = 0.14$, $P = 0.87$ for horizontal distance and $F_2 = 0.47$, $P = 0.63$ for perch height).

Habitat associations

Habitat type significantly affected the probability of chameleon presence (Table 2). Specifically, gap transects were significantly more likely to have chameleons present than either forest interior transects ($F = 8.28$, $df = 1$, $P = 0.004$) or edge transects ($F = 4.68$, $df = 1$, $P = 0.031$). We found on average $2.0 \pm \text{SE } 0.5$ chameleons per gap transect, $0.8 \pm \text{SE } 0.3$ chameleons per forest edge transect, and only $0.4 \pm \text{SE } 0.2$ chameleons per transect in the forest interior. There was a weak trend for the probability of chameleon occurrence to increase with decreasing distance to the nearest gap, although this relationship was not significant at $P < 0.05$ (Table 2). No other variables were retained within the final model.

Extent of suitable habitat

Only 28,400 ha of scarp forest remain in KwaZulu-Natal. The closest remnants to Dhlhlinza are the Entumeni (829 ha) and Ongoye (3,445 ha) forest reserves (6.2 km and 16.8 km in a direct line from Dhlhlinza, respectively). There are no other forest remnants in the area that could constitute available habitat (Fig. 1). The extent of chameleon occurrence was 88 km² and the area of occupancy was 49 km².

Table 2 Factors predicting presence of chameleons. Only variables remaining within the final model are shown.

Independent variable	<i>F</i>	<i>df</i>	<i>P</i>
Intercept	14.37		<0.001
Distance to gap	2.82	1	0.093
Transect type	6.68	2	0.036

Density and population size

The mean density of chameleons was $11.8 \pm \text{SE } 4.3$ chameleons per ha for adult chameleons, and $19.2 \pm \text{SE } 5.5$ chameleons per ha for all observed chameleons. Density for forest interior was estimated as $11.8 * 0.15 / 0.38 = 4.7$ individuals per ha. Similarly, density for gaps was $11.8 * 0.55 / 0.22 = 29.7$ individuals per ha, and density for edges was $11.8 * 0.30 / 0.41 = 8.7$ individuals per ha. Gaps, edges, and forest interior were estimated to comprise 7.8, 3.4 and 88.8% of the area of Dhlinza forest (265 ha) respectively. Based on these estimates of density for each transect type and the area occupied by each, we calculated the projected population size for Dhlinza to be $2,453 \pm \text{SE } 894$ adult chameleons.

Discussion

Habitat preferences

The Dhlinza dwarf chameleon prefers gaps within scarp forest. These gaps are typically minor paths and tree fall gaps, and thus represent only moderately disturbed forest. The higher probability of chameleon presence near gaps was not an artefact of greater visibility or ease of sighting chameleons in this habitat type because neither visibilities nor the horizontal distances and perch heights of captured chameleons differed significantly between the three habitat types. Jenkins *et al.* (1999, 2003) similarly found that chameleons in Madagascar were more abundant in forests of low disturbance than in patches of high disturbance and that some species were more common on path transects than forest-interior transects. The edges of the forest were often highly disturbed habitat and characterized by dense vegetation (often dense vines), with high levels of invasive alien vegetation, predominantly *Lantana camara* and *Chromolaena odorata*; chameleons were not often found in such overgrown areas. This indicates that this dwarf chameleon species prefers naturally disturbed habitats in scarp forest.

Neither shrub or tree density, nor vine densities, predicted chameleon presence. Although chameleons were often found roosting on vines, they were found as often on the leaves of trees or shrubs. As almost all plots had a combination of shrubs, trees, and low and high vines, the exact proportions of these structural microhabitat features do not appear to be a limiting factor for chameleons. Similarly, canopy cover may not explain chameleon presence because many of the gaps within the forest did not involve large canopy gaps; minor paths still had a largely intact canopy above. Thus the effect of transect type appears to be independent of differences in any single aspect of habitat structure between gaps, edges and forest interior. An alternative possibility is that the preference of chameleons for gaps may be associated with other factors such as food availability or thermal

properties rather than the microhabitat features measured. For example, forest gaps have higher arthropod abundance, in large part due to the higher light levels, which increase primary productivity (Murcia, 1995; Greenberg, 2001). Furthermore, forest gaps may represent the best trade-off between thermal environment, food availability, availability of perches and protection from predators.

Conservation status

This study suggests that the Dhlinza dwarf chameleon should be categorized as Endangered based on IUCN criteria (IUCN, 2001) B1ab(i) + 2a; i.e. the extent of occurrence is $< 5,000 \text{ km}^2$, highly fragmented and declining, and the area of occupancy is $< 500 \text{ km}^2$ and also highly fragmented. Apart from Dhlinza the only other patches of suitable habitat are the Entumeni and Ongoye reserves (Fig. 1). The extent of occurrence (88 km^2) is considerably lower than the cut-off limit of $5,000 \text{ km}^2$ for Endangered (IUCN, 2001). Furthermore, a large component of the Dhlinza Forest is made up of habitat that is not suitable to these dwarf chameleons.

Despite the high degree of habitat fragmentation and the small area of occupancy, these chameleons appear to be reasonably common where they occur. The density estimates that we obtained were in the mid-lower range of density estimates obtained for various chameleon species from Madagascar (Brady *et al.*, 1999; Jenkins *et al.*, 1999). In addition, we obtained an initial population estimate of 1,560–3,350 chameleons for Dhlinza forest but we are not aware of any analysis of minimum viable population size for chameleons. Although chameleons have relatively high fecundity, they experience high mortality and anecdotal evidence suggests that population size may fluctuate dramatically between years (Branch, 1998). Given these considerations and the limited mobility of chameleons, which has implications for finding mates, any conclusions regarding the viability of the Dhlinza population would be premature.

Our density and population size estimates are initial estimates that should be treated as indicative only. Ideally surveys should be conducted within Entumeni and Ongoye forests and the resulting data used to obtain independent density estimates, estimate total population size and to cross-validate the habitat selection model for this taxon (Guisan & Zimmermann, 2000). However, results of this study provide important initial baseline estimates of habitat preferences and density that are independent of the taxonomic designation of the Dhlinza population. Furthermore, there is strong evidence that chameleons found in Dhlinza, Ongoye and Entumeni scarp forests constitute a separate species that qualifies for Endangered status based on geographic features (extent of occurrence and area of occupancy), and should

receive this status following its formal taxonomic description. Our study highlights the need to protect and maintain indigenous forest remnants, for which dwarf chameleons could serve as a flagship species.

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Biographical sketches

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