Identifying important areas for the conservation of dwarf chameleons (*Brookesia* spp.) in Tsingy de Bemaraha National Park, western Madagascar

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Abstract Many of Madagascar's endemic chameleon species have restricted ranges and require relatively intact forest for survival but information on their response to habitat degradation is generally lacking, especially in western deciduous forests. We assessed the abundance and density of endemic chameleons from nocturnal surveys of roosting animals in Parc National Tsingy de Bemaraha in western Madagascar. We found 444 *Brookesia brygooi*, 192 *B. perarmata*, 98 *B. exarmata*, 22 *Furcifer nicosiai* and two *F.* cf. *petteri*. The highest pooled density was for *B. brygooi* (53.2 ha^{-1}), followed by *B. perarmata* (29.2 ha^{-1}) and *B. exarmata* (18.7 ha^{-1}). *B. brygooi* was ubiquitous, with the highest density and abundance in the disturbed Ankazomanga forest outside the Park, where the similarly sized *B. perarmata* was absent. *B. perarmata*, a species endemic to the Park, was abundant in three of the five survey sites, especially where there was a well-developed leaf litter and understorey. *B. exarmata*, a species endemic to the Bemaraha plateau, was associated with an open understorey and small protrusions of limestone karst. Spatial variation in the density of *B. perarmata* is an important consideration when interpreting monitoring data and this species is a conservation priority because of its restricted distribution and apparent sensitivity to forest degradation.

Keywords *Brookesia*, chameleon, deciduous forest, endemic, karst, Madagascar, Tsingy de Bemaraha.

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Introduction

Madagascar is a global hotspot for biodiversity conservation and 92% of its 340 reptile species are endemic to the island (Goodman & Benstead, 2005). The island has three endemic chameleon genera, and most *Brookesia* and *Calumma* species are considered to be forest specialists and are therefore threatened by habitat degradation and fragmentation (Raselimanana & Rakotomalala, 2003). The deciduous forests in western Madagascar are subject to chronic degradation both inside and outside protected areas, threatening a number of endemic species, including chameleons (Smith et al., 1997; Harper et al., 2007). It is therefore important to understand how chameleons respond to forest degradation so that conservation resources can be directed to the most vulnerable species.

The chameleon fauna of western Madagascar is generally less well known than that of the eastern forests but the Parc National Tsingy de Bemaraha is an exception (Schimmenti & Jesu, 1996; Jesu et al., 1999). Activities that threaten chameleons in the Park include overgrazing by cattle, bushfires, removal of trees, and agricultural expansion. In addition to this, commercial reptile collection is believed to occur although its extent is difficult to ascertain.

Brookesia perarmata is endemic to the Park and is categorized as Vulnerable on the IUCN Red List (IUCN, 2007), is on CITES Appendix I, and is strictly protected from collection under Malagasy law. There are two other restricted range chameleons found in the area, *Brookesia exarmata* and *Furcifer nicosiai*, which have yet to be evaluated for the IUCN Red List but are nevertheless considered priority taxa by the Park's conservation team. Information is needed to identify the most important forest areas for these chameleons to assist the Park's conservation and monitoring plan. We compared chameleon densities and habitat use in five different forests in the Park to inform the location of priority conservation sites and the potential impact of forest degradation.

Study area

The study was conducted in the north of Parc National Tsingy de Bemaraha, Fivondronana Antsalova, Melaky Region, Mahajanga Province (Fig. 1). The area is characterized by limestone karst geology. The climate is tropical, with well defined dry (June–October) and wet (November–May) seasons. Maximum monthly rainfall occurs from January to March. A number of vertebrate species are endemic to the Park and it is of growing importance as a tourist destination (Rasoloarison & Paquier, 2003).

Methods

We selected five forest sites in the Park (Fig. 1) across a range of disturbance levels from relatively intact to highly disturbed forest (Table 1). We generally surveyed with two teams per night, each consisting of two people, and with team composition rotating nightly (Table 1). Transects were located randomly in the forest using existing trails as access points and we completed three 50 m length transects each night. The three lines were demarcated the day before the survey and were c. 20 m apart. We adopted the methods previously described for surveying chameleons in Madagascar and used the software *Distance v. 4.1* to calculate density (Buckland et al., 2001; Thomas et al., 2004); for more details on survey methodology see Brady & Griffiths (1999).

Chameleons are active during the day, when they are highly cryptic and difficult to observe, but at night they roost on plant parts above the ground and their pale

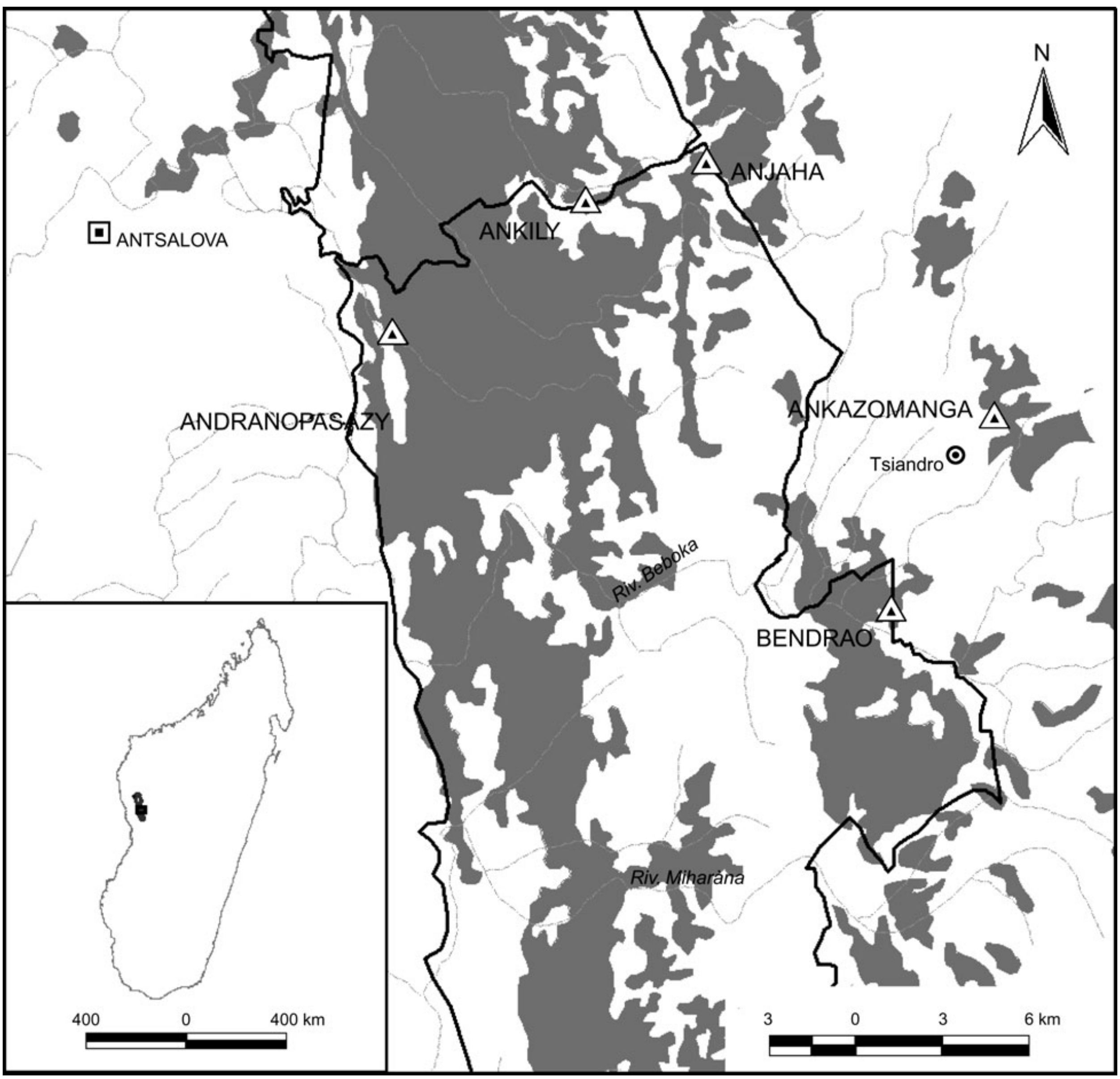

Fig. 1 Location of the study sites (triangles) in the five surveyed forest areas (Table 1) within and around Parc National Tsingy de Bemaraha Réserve/Naturelle Intégrale des Tsingy de Bemaraha (thick solid line), Madagascar; the shading represents areas of deciduous forest. The shaded area on the inset indicates the location of the main map in Madagascar.

Table 1 The geographical coordinates, altitude and status of the five surveyed forest sites (Fig. 1), and the survey dates and effort in man hours (based on a standard team of two people spending 2 hours per night) at each site.

Site	Coordinates	Altitude (m)	Status	Survey dates (man hours)
Andranopasazy	18°70′86.1" S, 44°71′72.8" E	100–130	National Park	14–31 Jan. 2006 (124)
Ankily	18°66′91.9" S, 44°78′10.8" E	286–310	National Park & Integrated Natural Reserve	6–13 Feb. 2006 (64)
Anjaha	18°65′72.0" S, 44°82′20.8" E	320–428	National Park & buffer zone	16–23 Feb. 2006 (64)
Bendrao	18°79′73.2" S, 44°88′15.1" E	382–400	National Park	27 Feb.–6 Mar. 2006 (64)
Ankazomanga	18°73′63.8" S, 44°91′38.5" E	497–563	Outside National Park	9–16 Mar. 2006 (64)

colouration affords easy detection using torch light. Two surveyors with head torches searched a flank each side of the transect line. We measured the perpendicular distance from the transect line to each chameleon, as well as the height of the roost perch. We marked a sample of chameleon perches each night with a coloured tag and returned the following morning and placed a quadrat (5 × 5 m) on the ground with the perch at the centre. In the quadrat we counted the number of standing, fallen and cut trees, and visually estimated the percentage of open litter and understorey cover. Also, using a 1 m stick marked with cm gradations, we recorded whether there was contact with ground vegetation in four height categories (0–0.24, 0.25–0.49, 0.50–0.74 and 0.75–1.0 m) every 10 cm along two 5 m lines with the perch at the centre. An emergent *tsingy* (local name for a distinctive, sharp limestone protrusion) index was calculated by multiplying the length × width × height of all bare rock and dividing by the number of distinct rock patches in each quadrat. We also assessed the habitat of two random quadrats per transect line in areas where no chameleons were located during the night, giving us data from areas with and without roosting *Brookesia*.

We used non-parametric statistics on chameleon abundance to test for differences between forest sites. We were unable to calculate abundance indices because of small sample sizes for some sites (Jenkins et al., 2003). ANOVA was used to test for differences between habitat features at each site. ANOVA comparisons were made between quadrats with and without chameleons, and post-hoc tests (Fisher's PLSD) indicated which factor was significantly different.

Results

We found a total of 758 chameleons (734 *Brookesia* and 24 *Furcifer*). The most frequently encountered species was *Brookesia brygooi* (n = 444), followed by *B. perarmata* (192), *B. exarmata* (98), *F. nicosiai* (22) and *F.* cf. *petteri* (2). The density of *B. brygooi* was the highest across sites (53.2 ha^{-1}, coefficient of variation, CV, 8.1%), followed by *B. perarmata* (29.15 ha^{-1}, CV 17.1%) and *B. exarmata* (18.74 ha^{-1}, CV 21.6%). *F. nicosiai* was only found at low densities (1.50 ha^{-1}, CV 25.11%). There were clear differences in density of *Brookesia* between the five sites (Table 2). Ankazomanga forest contained no *B. perarmata,* a low density of *B. exarmata* and the highest density of *B. brygooi.* Of the four sites with three sympatric *Brookesia* species the highest densities were recorded at Bendrao. *F. nicosiai* was encountered too infrequently for detailed comparisons but was recorded at all sites except Bendrao.

There were significant differences in the abundance of the *Brookesia* species between the five sites (Kruskal Wallis df = 4; *B. perarmata* $H = 61.4$, $P < 0.001$; *B. exarmata*, $H = 73.3$, $P < 0.01$; *B. brygooi*, $H = 48.7$, $P < 0.001$). Patterns in abundance were similar to density, with *B. brygooi* most abundant at Ankazomanga where the other two species were absent or uncommon. *B. exarmata* and *B. perarmata* were most abundant in Bendrao (Table 2).

There were significant habitat differences between quadrats around chameleon roosts and randomly placed quadrats (Table 3). Roosting *B. perarmata* were typically found in areas with well-developed leaf litter and understorey and few emergent *tsingy* rocks. *B. exarmata* roosts were associated with emergent *tsingy* rocks but also an open leaf litter layer and low understorey cover. Roosting areas used by *B. brygooi* were found in disturbed areas with cut trees and a tall vegetation layer.

Discussion

The Parc National Tsingy de Bemaraha is an important site for reptile conservation in Madagascar and is the only known location for *B. perarmata.* There are no published records of *B. perarmata* outside the Park, although a report cited in Schimmenti & Jesu (1997) of it occurring in another forest in the region needs to be investigated further. We found *B. perarmata* in the four sites within the Park but not in Ankazomanga, a degraded forest 10 km from the Park's

TABLE 2 Number, abundance and density (with % coefficient of variation, CV, and 95% confidence interval, CI) of the three *Brookesia* chameleon species recorded in the five surveyed forest sites (Fig. 1, Table 1) within and close to Parc National Tsingy de Bemaraha, and df and model type used for determination of density using *Distance*.

Site	Species	n	Abundance (per 100 m ± SE)	Density (ha^{-1})	% CV	95% CI	df	Model
Andranopasazy	*B. perarmata*	6	0.2 ± 0.07	1.35	43.66	0.57–3.17	30.00	Uniform/Cosine
	B. exarmata	8	0.2 ± 0.07	3.78	59.49	1.20–11.85	21.60	Hazard/Cosine
	B. brygooi	102	2.3 ± 0.32	51.00	18.71	35.25–73.76	82.30	Half-normal/Cosine
Ankily	*B. perarmata*	38	1.5 ± 0.46	18.62	61.81	5.93–58.46	47.82	Hazard/Hermite
	B. exarmata	15	0.7 ± 0.25	26.14	42.33	11.32–60.39	24.33	Half-normal/Hermite
	B. brygooi	34	1.5 ± 0.40	28.02	29.00	15.50–50.67	20.22	Uniform/Polynomial
Anjaha	*B. perarmata*	66	2.8 ± 0.45	57.53	19.86	38.22–86.61	20.94	Uniform/Cosine
	B. exarmata	9	0.4 ± 0.24	11.02	69.81	2.97–40.91	20.75	Half-normal/Hermite
	B. brygooi	48	2.0 ± 0.25	45.80	16.40	32.89–63.74	34.87	Half-normal/Polynomial
Bendrao	*B. perarmata*	86	3.4 ± 0.79	98.87	32.99	51.90–188.36	53.71	Hazard/Polynomial
	B. exarmata	60	2.3 ± 0.57	60.92	25.20	36.41–101.96	21.72	Half-normal/Cosine
	B. brygooi	87	3.6 ± 0.47	66.39	14.48	49.56–88.95	34.82	Half-normal/Polynomial
Ankazomanga	*B. perarmata*	0						
	B. exarmata	6	0.5 ± 0.15	5.00	48.31	1.92–13.00	19.96	Uniform/Cosine
	B. brygooi	104	7.3 ± 0.91	78.79	12.37	60.90–101.94	19.49	Uniform/Polynomial

boundary. *B. exarmata* is also thought to be endemic to the karst forests of the Park (Schimmenti & Jesu, 1996) but we cannot rule out the possibility that it also occurs in other forests in the region where suitable habitat occurs. *B. brygooi* has a relatively wide distribution in western Madagascar (Raxworthy & Nussbaum, 1995), over 17–23°S, and it was ubiquitous in the forests of northern Parc National Tsingy de Bemaraha; the species is restricted to deciduous forest and is thought to tolerate a wide range of environmental conditions (Carpenter & Robson, 2005).

Brady & Griffiths (1999) highlighted the problem of small sample sizes and the associated high errors in the resulting density estimates calculated with *Distance,* and suggested that a coefficient of variation of < 30% was appropriate for calculating reliable density estimates of forest *Calumma* chameleons in Madagascar. Seven of our density estimates yielded a coefficient of variation of ≤ 30% and this was achieved with 34–104 observations per species. Density estimates based on < 10 individuals need to be interpreted with due caution.

Differences in the density of chameleons between sites may be related to vegetation structure/habitat quality, illicit collection (past or present), seasonality or altitude. Although we sampled sites sequentially, visits were short (mean 9.4 days) with only a mean of 2.8 days between sites, and even though we cannot rule out a relationship between chameleon abundance and the progression of the rainy season, long-term climatic data from Antsalova (ANGAP (Association Nationale pour la Gestion des Aires Protégées), unpubl. data) demonstrates higher monthly precipitation in January, February and March than December or April, thus justifying our study period.

TABLE 3 ANOVA (*F*) comparisons and mean (± SE) habitat characteristics recorded in quadrats either with or without roosting *Brookesia* in and close to Parc National Tsingy de Bemaraha (Fig. 1, Table 1). Differences in six pair-wise comparisons in post-hoc tests are indicated by superscript lower case letters, where the same letter indicates that the habitat characteristic was significantly different.

Habitat	*B. perarmata* (n = 62)	*B. exarmata* (n = 49)	*B. brygooi* (n = 83)	No *Brookesia* (n = 261)	*F*
Understorey (%)	55.2 ± 3.4^{bc}	38.8 ± 4.04^{ab}	48.7 ± 2.76^{a}	45.0 ± 1.65^{c}	3.87**
Litter (%)	70.9 ± 2.89^{ab}	62.4 ± 3.59	54.9 ± 3.54^{a}	54.5 ± 1.79^{b}	6.24**
Small trees (n)	36.1 ± 1.85^{bc}	32.2 ± 2.47^{a}	24.7 ± 1.87^{ab}	27.7 ± 1.01^{c}	6.63**
Cut trees (n)	0.01 ± 0.05^{ab}	0.0 ± 0.00^{a}	0.5 ± 0.18^{c}	0.2 ± 0.04^{c}	4.80**
Fallen trees (n)	1.8 ± 0.19	1.9 ± 0.21	1.6 ± 0.14	1.8 ± 0.10	0.71
Vegetation (0.0–0.24 m)	6.0 ± 0.38	5.9 ± 0.39	6.3 ± 0.33	5.5 ± 0.17	2.2
Vegetation (0.25–0.49 m)	4.4 ± 0.33	4.1 ± 0.39^{a}	5.1 ± 0.29^{ab}	4.0 ± 0.16^{b}	4.08**
Vegetation (0.50–0.74 m)	3.4 ± 0.24	3.0 ± 0.28	2.3 ± 0.25	3.0 ± 0.14	2.55
Vegetation (0.75–1.0 m)	2.9 ± 0.29	2.9 ± 0.32	3.6 ± 0.25^{a}	2.8 ± 0.14^{a}	3.11*
Tsingy rock	1.3 ± 0.32^{ce}	4.9 ± 0.61^{acd}	2.0 ± 0.37^{ab}	4.1 ± 0.25^{bde}	10.90**

*P < 0.05; **P < 0.001

Altitude is potentially an important factor because other *Brookesia* species are often restricted to narrow altitudinal ranges (Raxworthy & Nussbaum, 1995; Glaw et al., 1999), although usually in montane sites with a wider altitudinal span than in our study. *B. perarmata* density and abundance increased with altitude but the species was not recorded at the highest elevation in Ankazomanga (497–563 m). Future surveys should focus on intact forest at 500 m to determine whether the absence of *B. perarmata* from Ankazomanga is related to elevation as well as habitat structure.

Brookesia habitat preferences are poorly known, with knowledge generally based on the collection of a few individual animals (Raxworthy, 1991; Raxworthy & Nussbaum, 1995; Glaw et al., 1999). There is evidence that certain *Brookesia* are intolerant of severe habitat modification (Jenkins et al., 2003) and, although a few taxa have been found in degraded sites (Glaw et al., 1999), they are generally considered to be dependent on relatively intact forest (Carpenter & Robson, 2005). Although all three *Brookesia* species coexisted at four forests in our study there were inter-specific differences in the habitat associated with nocturnal perches. *B. exarmata* roosts were associated with areas of forest that had relatively little understorey but a high leaf litter cover and notable surface area covered by emergent *tsingy* rock. Schimmenti & Jesu (1996) reported *B. exarmata* from dense sub-humid forest but this was based on only a small number of observations. *B. perarmata* was also associated with open areas but with a more developed understorey layer. Overgrazing by cattle and fire are therefore potential threats to these two *Brookesia* species because of the damage to leaf litter, loss of native understorey and colonization of pioneer species. Although little is known about the diurnal foraging of *Brookesia* there are significant differences in nocturnal perch height between sympatric species in Parc National Tsingy de Bemaraha (Randrianantoandro et al., 2007) and changes to vegetation structure are therefore likely to affect these chameleons.

The Park has a permanent ANGAP (Association Nationale pour le Gestion des Aires Protégées) team with field officers who regularly patrol the forest and conduct nocturnal monitoring of *Brookesia* between January and March. It would also be helpful to install permanent vegetation plots in the areas monitored for *Brookesia* to follow any long-term changes in vegetation structure. Illegal collection of reptiles from the Park is more difficult to monitor.

B. perarmata was most common in Bendrao where it was sympatric with *B. exarmata* and *B. brygooi*. As the most intact forest and with the highest densities of priority chameleon species we recommend that particular effort is given to conserving this site. However, this was the only site in which we did not locate *F. nicosiai*; this may also be related to forest structure because *Furcifer* chameleons are generally associated with open habitats or forest edges (e.g. Andreone et al., 2005; Rabearivony et al., in press). At Anjaha the forest inside the Park boundary was disturbed by people but some areas of the unprotected buffer zone were relatively undisturbed and require additional conservation measures to prevent the removal of timber.

Carpenter & Robson (2005) reported that 2,215 *B. perarmata* were exported to the USA between 1996 and 2001 but that numbers dropped to three by 2003 following its inclusion on Appendix I of CITES. Under Malagasy law the collection of *B. perarmata* from Parc National Tsingy de Bemaraha is illegal, yet anecdotes of reptile collection from the Park continue. Personnel from ANGAP and the Malagasy government began checking passenger baggage on Air Madagascar flights departing from Antsalova, west of the Park, in 1997. Consignments of *B. perarmata* were intercepted in 1998 and 2000, and one of these contained 250 alive and 10 dead chameleons hidden inside a radio cassette player. Better coordination is needed between the authorities in major towns east of the Park to develop a more comprehensive strategy for monitoring illegal trade.

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Biographical sketches

J. Christian Randrianantoandro has studied chameleons since 1998 and is currently developing monitoring protocols for chameleons in protected areas in western Madagascar. Roma Randrianavelona has also studied *Zonosaurus* plated-lizards, and is particularly interested in working with communities to conserve *Mantella* frogs. Raphali R. Andriantsimanarilafy is a student at the University of Toliara and is focusing on the biogeography of reptiles in karst forest. Elisoa Hantalalaina is a student at the Université d'Antananarivo and is studying the ecology of forest chameleons. Daniel Rakotondravony is the head of the Département de Biologie Animale, Université d'Antananarivo and specializes in the conservation of small mammals. Hery Lala Ravelomanantsoa is the director of the Tsingy de Bemaraha National Park. Mamy Randrianasolo coordinates the conservation and monitoring activities in the Park. Richard K.B. Jenkins coordinates projects to conserve Malagasy endemic vertebrates and their habitats, with current efforts focusing on bats, chameleons, amphibians and bushmeat.