Chapter 42
The Impact of Alopecia Syndrome on Female Reproductive Parameters in Ring-Tailed Lemurs (*Lemur catta*) in Berenty Reserve, Madagascar

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Abstract Alopecia syndrome was identified in ring-tailed lemurs in the Berenty Reserve, southern Madagascar, in the late 1990s and spread extensively in 2001–2003. A ring-tailed lemur population inhabiting a 14.2-ha area has been studied with individual identifications since 1989. To understand the alopecia syndrome, we recorded the fur condition of all individuals (around 100 lemurs) in 2001, 2004, and 2005. The number and ratio of alopecic lemurs decreased over time from 19 lemurs (22%) in 2001 to 6 (6%) in 2004, to only 3 (3%) in 2005. Of the 19 alopecic lemurs in 2001, 15 were females and only 4 were males. They ranged in age from 2 to 15 years, with by far the highest occurrence of alopecia among young lemurs (2 years old: 55%; 3 years old: 50%; and 4 years old: 40%). Nine of the 19 animals (47%) recovered their fur condition over 3 years. The mortality rate of the alopecic females over the same period was 43%, similar to that of nonalopecic females (40%) as was their birth rate. Infant mortality was higher for alopecic mothers (57%) than for nonalopecic females (19%), although the difference was not significant.

Resume Le syndrome d'alopécie qui touche les lémurs cattas de la Réserve de Berenty, située au sud-est de Madagascar, a été identifié à la fin des années 90, et s'est répandu entre 2001 et 2003. Une population de lémurs cattas, occupant une zone d'étude de 14.2 ha, et dont les individus sont tous suivis individuellement est étudiée depuis 1989. Pour mieux comprendre le syndrome d'alopécie, nous avons

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évalué la condition de la fourrure de tous les individus (environ 100 lémurs) en 2001, 2004 et 2005. Le nombre et la proportion de lémurs touchés par le syndrome d'alopécie a diminué, passant de 19 lémurs (22%) en 2001 à six (6%) en 2004, et seulement trois (3%) en 2005. Sur les 19 lémurs alopéciques observés en 2001, 15 étaient des femelles et seulement quatre des mâles. Les animaux atteints étaient âgés de deux à 15 ans, mais étaient bien plus souvent des jeunes (deux ans : 55% ; trois ans : 50% ; quatre ans : 40%). Neuf animaux sur 19 (47%) ont recouvré une bonne condition de fourrure en trois ans. L'alopécie n'a affecté ni le taux de mortalité des femelles (43% pour 40%), ni leur taux de natalité. La mortalité infantile des femelles alopéciques était plus élevée (57%) que celles des femelles non alopéciques (19%), bien que cette différence ne soit pas significative.

Introduction

Ring-tailed lemurs (*Lemur catta*) in Berenty Reserve, south-eastern Madagascar, have been studied since the 1960s (Jolly 1966, 2012; Jolly et al. 2002). Alopecia syndrome was identified in the population in the late 1990s and spread extensively between 2001 and 2003 (Crawford et al. 2006). The most severely afflicted animals lost most of their body fur.

Alopecia has been reported in many mammals including primates (chimpanzees in Gombe: Wallis and Lee 1999; gorillas in Buwndi National Park: Macfie 1996; Mudakikwa 2001; Kalema-Zikusoka et al. 2002) and is most commonly caused by mite infestations. Until the detection of alopecia, however, no evidence of infectious diseases had been found in the ring-tailed lemurs of Berenty. An introduced plant (*Leucaena leucocephala*) was targeted as a potential cause of the syndrome (Crawford et al. 2006), and several researchers focused their research accordingly (Jolly 2009b; Chaps. 39 and 41), although the causes and consequences of the syndrome remain obscure. A program to remove *Leucaena* trees from the tourist area began in late 2004, although lemurs continue to eat the leaves of some small trees remaining in the forest (Jolly et al. 2006; Chap. 39; Ichino personal observation).

We believe the causes and long-term consequences of the syndrome can best be understood through detailed information on individuals acquired over several years. Our group has been studying a population of known ring-tailed lemur individuals within a 14.2-ha area since 1989 (Koyama et al. 2001, 2002). To add to the knowledge base of alopecia in Berenty's ring-tailed lemurs, we contribute our observations and discuss the syndrome's impact on the population over several years.

Methods

Berenty is a 250-ha private reserve located in south-eastern Madagascar. Its semideciduous gallery forest is dominated by tamarind trees (*Tamarindus indica*), and the area is bounded by the Mandrare River and commercial sisal plantations (Jolly 2004; Jolly et al. 2006; Chap. 39).

Ring-tailed lemurs (*Lemur catta*) are diurnal animals that live in multimale, multifemale groups consisting of around 15 individuals. Approximately 100 individuals comprising seven troops were present in the area during our study. Ages and kin relationships were known for all individuals born after 1989 (Koyama et al. 2001, 2002). We monitored the population over three study periods, in which we recorded fur condition (1) April 2001 to January 2002, (2) September 2004, and (3) November 2005 to January 2006. The first two study periods predated the *Leucaena* eradication project.

Scoring fur condition without observer bias is difficult, although methods have been proposed (Berg et al. 2009; Jolly 2009a). We minimized bias by considering only those individuals with severe hair loss alopecic, corresponding to the "bald (body fur score 5)" and "sheared (body fur score 4)" criteria of Berg et al. (2009). These extreme conditions are unlikely to be overlooked by different observers. The fur condition of all individuals was recorded at least twice when the focal animals were on the ground, and scores were assigned by a single observer (Ichino).

Most of our data were collected between 2001 and 2002, when alopecia syndrome was most severe. Interannual comparisons included data for September 2001 and 2004 and November 2005. We compared mortality and birth rates of females, and infant mortality for alopecic and nonalopecic mothers using the data collected in 2001 and 2004. When estimating mortality, we considered only females because ring-tailed lemurs show female philopatry, and males sometimes emigrate to troops outside the study area (Jones 1983; Sussman 1992; Koyama et al. 2002).

Results

Characteristics of Alopecia Syndrome

During the 10-month study period in 2001–2002, the fur condition of the lemurs changed seasonally from relatively good in April 2001 (the end of rainy season; Fig. 42.1), becoming progressively worse through the dry season until September, when fruit was scarcest. Their fur condition was still bad in January 2002, the early rainy season (Fig. 42.2), when several lemurs were bald (Fig. 42.3). However, new fur growth appeared at that time. The animals' fur condition also changed from year to year. In 2001, 19 lemurs (21.6% of the population) were alopecic, but the proportion decreased to 6 lemurs (5.8%) in 2004, and only 3 (2.7%) in 2005.

Fur condition was variable among troops (Table 42.1). In 2001, alopecic lemurs were observed in four of seven study troops, especially Troop C1 (61.1%). Troops with alopecic lemurs occupied the area most visited by tourists comprising a number of bungalows surrounded by exotic plant species (Fig. 42.4). There was also a great deal of individual variation in fur condition, with alopecic females outnumbering alopecic males every year. In 2001, we recorded 14 females and only 5 males with severe hair loss; in 2004, this number dropped to four females and two males; and by 2005, we noted only two females and one male with alopecia. Because of the

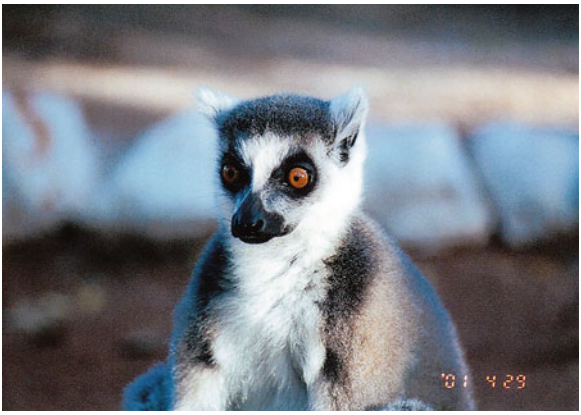

Fig. 42.1 A ring-tailed lemur (ME-8993♀) with good fur condition in April 2001 (photo by Ichino)

Fig. 42.2 The same ring-tailed lemur (ME-8993♀) with bad fur condition in January 2002 (photo by Ichino)

Fig. 42.3 A bald ring-tailed lemur (ME-8994♀) in January 2002 (photo by Ichino)

Table 42.1 The number and percentage of alopecic lemurs in each troop in September 2001 and 2004

	2001			2004		
	No. alopecic			No. alopecic		
Troop	Troop size	Lemurs	%	Troop size	Lemurs	%
C1	18	11	61.1	21	0	0.0
C2A	9	2	22.2	12	2	16.7
C2B	6	1	16.7	1	0	0.0
CX	11	0	0.0	9	0	0.0
T1A	13	0	0.0	16	1	6.3
T1B	13	5	38.5	11	2	18.2
T2	18	0	0.0	19	0	0.0
YF	–	–	–	14	1	7.1
Total	88	19	21.6	103	6	5.8

Note: Troop YF did not exist in September 2001 (see Ichino and Koyama 2006)

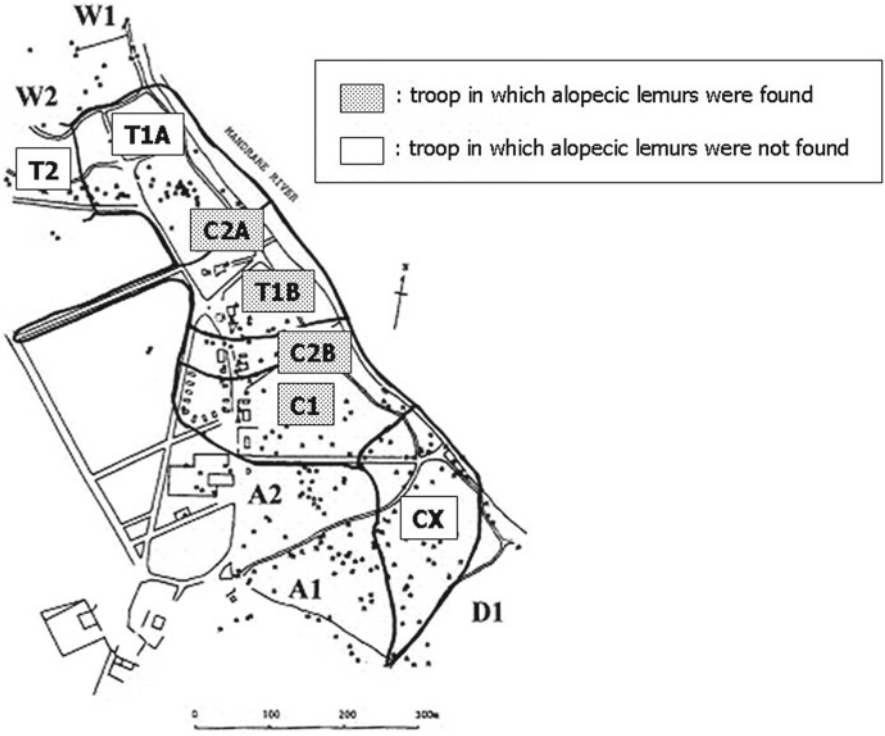

Fig. 42.4 Locations of the home ranges of seven study troops within the study area in 2001 (modified from Koyama et al. 2002)

limited sample size, the difference in the affliction of males and females was not significant ($\chi^2 = 3.18$, df = 1, Fisher's exact test, two-tailed $P = 0.12$).Variation was also age related. Alopecic lemurs ranged from 2 to 15 years in age, but no 1-year-old

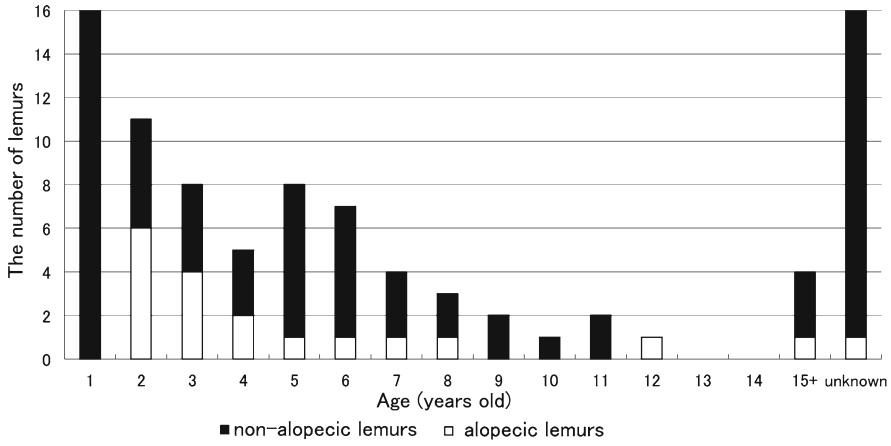

Fig. 42.5 Numbers of alopecic and nonalopecic lemurs in each age category in 2001

animals were affected. In 2001, the proportion of alopecic lemurs was the highest among younger animals (2–4 years old; Fig. 42.5): 54.5% ($n=11$) of 2 years old, 50% ($n=8$) of 3 years old, and 40% ($n=5$) of 4 years old were alopecic.

Comparison Between 2001 and 2004

The 19 alopecic lemurs recorded in 2001 experienced a variety of fates. By 2004, six (31.6%) had died, and two (10.5%) had disappeared from the study site, either through emigration or death outside the area. Only two lemurs (10.5%) were still alopecic. Nine animals (47.4%) were still alive and had recovered their fur condition; thus, alopecia syndrome was not necessarily fatal.

The mortality rate of alopecic females from 2001 to 2004 was 42.9% (6/14), not significantly different from that of nonalopecic females (40.0%, 10/25) ($\chi^2=0.03$, df = 1, Fisher's exact test, two-tailed $P=1$). However, this result might simply reflect the age composition of the population. Of 14 alopecic females, 9 were young (2–4 years old), and the remaining 5, 5 years or older. Among the young alopecic females, only two (22.2%) died within the 3-year period, while four of the five older females (80%) died during this time.

In 2001, the birth rate of the alopecic females was 77.8% (7/9), while that of nonalopecic females was 72.7% (16/22), and not significantly different ($\chi^2=0.09$, df = 1, Fisher's exact test, two-tailed $P=1$). These values are also similar to the annual birth rate over 10 years, from 1989 to 1998 (75.0%, range: 63.3–85.7%), in the same population (Koyama et al. 2001). Infant mortality among alopecic mothers was 57.1% (4/7), higher than that among nonalopecic mothers (18.8%, 3/16) as well

as the average 3-month infant mortality over 10 years in the same population (27.9%: Koyama et al. 2001). The difference between alopecic and nonalopecic mothers was not significant ($\chi^2 = 3.39$, df = 1, Fisher's exact test, two-tailed $P = 0.14$). Additionally, in September 2004 we witnessed a case where the infant of an alopecic female in Troop T1B had difficulty clinging to its mother and fell down. Ultimately the infant disappeared from the troop.

Discussion

We describe the age and sex profile of the ring-tailed lemurs afflicted with alopecia syndrome in Berenty Reserve, south-eastern Madagascar between 2001 and 2005; the troop distribution of the alopecic animals; and the consequences of the syndrome for female reproduction. The only clear disadvantage to female reproductive success is the difficulty infants experience in clinging to the mothers' scant fur, leading to higher infant mortality. Alopecia syndrome is not necessarily fatal to the sufferers themselves, and 47.4% of alopecic lemurs recovered their fur condition between 2001 and 2004, especially young individuals 2–4 years old. Birth rates were not statistically different between alopecic and nonalopecic females in 2001. Rambeloarivony (unpublished data) observed similar results in 2005. Thus, barring the effects of maternal hair loss on infant mortality, alopecia syndrome appears to be a relatively low risk disease for Berenty's ring-tailed lemurs.

However, our data also show that the effects of alopecia may be different for different age groups. Although we found no significant difference in mortality between alopecic and nonalopecic females, this may simply reflect the age composition of the alopecic group, which was biased toward young animals. Alopecia may indeed raise mortality for older animals. Fortunately, the present number of alopecic lemurs is far lower than in 2001–2003 and we can no longer examine our results statistically.

Causes of Alopecia Syndrome

Crawford et al. (2006) proposed three possible causes of alopecia syndrome (1) infectious disease, (2) malnutrition or stress associated with high population densities, and (3) the toxic effects of an introduced plant, *Leucaena leucocephala*. Our data provide insight into the cause by tracking the distribution of the syndrome over several years: it occurred only among troops frequenting the part of the forest that has been most transformed for human habitation by building tourist bungalows and planting exotic plant species (Fig. 42.4). This implies that anthropogenic changes to the forest are related to the occurrence of alopecia in Berenty's ring-tailed lemurs.

Alopecia syndrome among wild mammals is often caused by mite infestations, as seen in other wild primates (Wallis and Lee 1999; Macfie 1996; Kalema-Zikusoka

et al. 2002; Mudakikwa 2001). At Berenty, a species of tick [*Haemaphysalis* (*Rhipistoma*) *lemuris* Hoogstraal 1953] was found on the eyes and external auditory meatuses of ring-tailed lemurs (Takahata et al. 1998), but mange has not been reported among Berenty's mammals. The veterinary study by Crawford et al. (2006) found no evidence of commonly recognized diseases among the lemurs, and a parasitologist from the Koyama team could not find any mange-inducing ectoparasites on the skins of captured alopecic lemurs in 2001 (Hirai, personal communication). The fact that alopecic lemurs were observed in two different parts of the reserve (Crawford et al. 2006; Jolly 2009b) also argues against the infection hypothesis.

A second possible cause of alopecia is malnutrition or stress associated with high population densities or directly associated with tourism (Crawford et al. 2006). Within our study area, the population of ring-tailed lemurs has increased since 1989 (Koyama et al. 2001) as has an introduced population of hybrid brown lemurs (*Eulemur rufifrons*×*E. collaris*) (Jolly et al. 2002; Pinkus et al. 2006). Thus, competition within and between troops has been increasing over the last two decades. However, no evidence of malnutrition was found by Crawford et al. (2006).

In our study, alopecic lemurs were found in troops C1, C2A, C2B, and T1B (Table 42.1, Fig. 42.4). We did not observe alopecic lemurs in troop CX in 2001 or 2004 (Table 42.1). Within the range of CX, the availability of tamarind fruits, the most important food item in the dry season, was lower than that of other areas (Koyama et al. 2006). Soma (2006) reported that troop CX often entered the ranges of C1, C2A, and C2B and fed there, suggesting that food resources within the range of CX were less abundant than in the C1, C2A, and C2B ranges. Indeed, Soma (unpublished data) showed that CX females consumed lower quantities of food than C1 females. There is no evidence that food resources were scarce in 2001, and year-to-year changes in food availability do not explain the numbers of alopecic lemurs in our population. Thus, our data do not support the malnutrition hypothesis.

The third hypothesis is that toxin from a newly introduced tree species (*Leucaena leucocephala*) caused fur loss (Crawford et al. 2006). *Leucaena* contains mimosine, a nonprotein amino acid which disturbs cell division and causes feather/fur loss among some birds, ruminants, and fruit bats. Ring-tailed lemurs within the study area feed on leaves, flowers, and young seeds of *Leucaena* (Simmen et al. 2006; Soma 2006; Ichino unpublished data). Several researchers are studying the relations between *Leucaena* and alopecia at Berenty (Jolly 2009b; Chaps. 39 and 41). *Leucaena* trees were removed from our study area following this study (Chap. 39), although a few small trees remain in the forest (Ichino personal observation). In the intervening years (until November 2011), we have rarely observed severely alopecic ("bald" or "sheared") lemurs (Ichino and Soma, unpublished data). Our results are hence most consistent with the *Leucaena* hypothesis, but questions remain (1) Why did the number of severely alopecic lemurs decrease in the years preceding *Leucaena* removal? (2) Why were there more alopecic females than males? (3) Why was the proportion of alopecic lemurs higher among young lemurs? These questions urge research into the physiological mechanisms underlying alopecia as the surest means of controlling outbreaks of the syndrome.

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