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Short communication

Population decline of *Macaca sylvanus* in the middle atlas of Morocco

Andrea Camperio Ciani [a,*], Loris Palentini [a], M. Arahou [b], L. Martinoli [a], C. Capiluppi [c], M. Mouna [b]

[a] *Department of General Psychology, University of Padova, 80 via Belzoni, Padova 35139, Italy*
[b] *Institute Scientifique, Université Mohammed V, Rabat, Morocco*
[c] *Department of Statistics, University of Padova, Padova, Italy*

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Abstract

An eight-year-long census and habitat evaluation of the *Macaca sylvanus* population was conducted in a 484-km^2 area of the central region of the Middle Atlas Mountains in Morocco between June 1994 and October 2002. The authors walked a 93.5-km circuit – divided into 16 transect segments – 30 times with teams of trained research assistant volunteers, collecting data on a total of 2,805 linear km. Previous studies had reported an average density of 44–70 individuals per km^2, while data from the present study indicate a progressive population decline, from 25 to 30 individuals per km^2, down to a current average density of 7–10 I/km^2. The population decline is attributed to the loss of prime habitat, mainly cedar forest, which has significantly decreased from 1994 to 2002, due to the growing impact of overgrazing by mixed flocks of goats and sheep and consequent forest degradation. At present, human-caused habitat deterioration in the Middle Atlas risks further compromising the future of the world's only remaining large *M. sylvanus* population.

Keywords: *Macaca sylvanus*; Conservation status; Demography; Habitat degradation; Population decline; Overgrazing

1. Introduction

Macaca sylvanus is the only surviving primate in Africa north of the Saharan desert. A former inhabitant of all Europe and northern Africa, this species is now limited to relict forest areas in Algeria and Marocco (Fa et al., 1984; Camperio Ciani, 1986; Menard and Vallet, 1993; Scheffrahn et al., 1993). A few, scattered groups can be found in disturbed habitats in the Rif and coastal Mediterranean regions, and a small relict population dwells in the High Atlas, in Morocco (Mehlman, 1989; Fa et al., 1984). The only areas where *M. sylvanus* is thought to live still yet in abundance are the great, but dwindling cedar forests of the Middle Atlas mountains in Morocco, where a density of 44–70 I/km^2 has been reported by various authors (Fa et al., 1984; Deag, 1977, 1980; Taub, 1977), Indeed it was estimated that up to 65–75% of the world's remaining population lived in this area (Camperio Ciani, 1986), and the central region of the Middle Atlas has therefore a crucial role on the *M. sylvanus* species survival (Fa et al., 1984; Camperio Ciani et al., 2001). Mehlman (1989) first suggested that deforestation, overgrazing, and human interference were the main causes of the demographic differences observed between the *M. sylvanus* populations living in the marginal Rif region and those in a relatively intact habitat in the Middle Atlas.

In a study evaluating the threat posed by overgrazing in the Middle Atlas, Drucker (1984) evaluated the density and composition of flocks that graze in the forests

* Corresponding author. Tel.: +39-335-6256126; fax: +39-049-8278451.
E-mail address: andrea.camperio@unipd.it (A.C. Ciani).

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of this region and its consequential deforestation effects, finding macaques in ecological competition with these flocks.

Altogether, the results from these studies indicate that any hope of improving the probability of survival of *M. sylvanus* depends on our better understanding the dynamics and factors that influence the demography of macaques in this region (Taub, 1984; Oates, 1994).

The present study investigated *M. sylvanus* ecology and demography, during eight expeditions, which were conducted over an eight-year period (from 1994 to 2002) in the central region of the Middle Atlas. Our purpose was to evaluate if, how, and why habitat conditions in this region have worsened and to examine the phenomenon's consequences on the possible decline of *M. sylvanus*.

2. Methods

2.1. Circuit and transect segments

Through vegetation maps and Global Positioning System (GPS), we delineated a 93.5-km long circuit to be covered on foot in the central region of the Middle Atlas, which lies to the east of the cities of Azrou (33°15′N, 5°15′W), Ifrane, and Ain Leuh and where a high macaque density (44–70 I/km^2) had been previously reported (Deag, 1977; Taub, 1977; Fa et al., 1984). This choice was based on these reports on macaque density distribution and on our own preliminary observations from studies conducted previously, between 1985 and 1993. We subdivided this long circuit into sixteen rectilinear segments, each of which could be walked within a day (Fig. 1). The sixteen segments location were distributed, with the help of a vegetational map, at the beginning of the study in order (1) to cover all large patches of forest available at that time; (2) starting and arrival points could be reached by a vehicle. The segments were never changed during the study period. We took special precautions to avoid disturbing wildlife and habitat, such that each transect segment did not follow a pre-made trail: only starting points, arrival points, and transect segment lengths were fixed. Transect segments were covered by walking through the forest, with a stopwatch and compass and were located by a commercial GPS (Sutherland, 1996).

We then walked the entire circuit 30 times over a period of 8 years, in 8 expeditions, for a total of 2,805 km, gathering data on macaque and grazing animal density and habitat conditions. Two expeditions each were conducted in 1994 and 1995, one each for the years 1997, 1998, 2000 and 2002 (Fig. 2). All expeditions were conducted in either early summer or fall. The 93.5 km circuit itself was our statistical unit. In an effort to increase statistical power and to verify if a trend would emerge from our study, and to render our data comparable with data from previous studies of shorter time span (Deag, 1977; Taub, 1984; Fa et al., 1984; Mehlman, 1989), we further classified all our data into three expedition blocks of 12, 10, and 8 circuits. The first 12 circuits referred to the first 4 expeditions occurring between 1994 and 1995, the next 10 circuits referred to 3 expeditions that took place between 1998 and 2000, and the last 8 circuits referred to the single expedition of 2002.

2.2. Density estimates

Monkey group and grazing animal (sheep and goat) distribution were continually recorded over the course of the transect. To calculate monkey density, defined as the number of individuals per square kilometre (I/km^2), we identified the total surface sampled in each circuit, by multiplying the sum of each of the 16 transect segment lengths by their respective widths. Segment lengths were measured by GPS. We followed the recommended procedure for measuring transects of undefined width (Caughley, 1977; National Research Council, 1981, Sutherland, 1996), estimating segment widths as the average distance to the first sighting of an animal in each monkey group (average visibility), which varies for each habitat type encountered along the circuit (see below for habitat type description). To calculate grazing animal density in forests, we used the same surface area obtained for monkey sightings as an estimate of the sampled surface and then counted each head of sighted flocks, subdivided by sheep and goats.

2.3. Habitat condition

The habitat condition data were scan sampled along each transect segment, while walking, at five minutes intervals, corresponding approximately at 200 linear meters distance from each other, depending on the nature of the terrain (Camperio Ciani, 1995). For classification purposes we defined uninterrupted to 50%-covered forest canopy surfaces as *closed* habitat, while *open* habitat defined surfaces where the canopy covered less than 50% of the terrain. Lastly, *grassland* referred to treeless surfaces. We further classified forests according to their dominant species of trees: Cedar (*Cedrus atlantica*), Oak (*Quercus rotundifolia*), or Mixed (a composite of Oak, Cedar and other trees). Therefore, dominant trees and canopy closure allowed us to classify each scan sample in one of seven main habitat types: *closed cedar, open cedar, closed oak, open oak, closed mixed, open mixed, and grassland* (Drucker, 1984).

Also underbrush condition can be considered an indirect indicator of forest exploitation for grazing, and thus we classified underbrush condition of each scan sample into one of the following three qualitative categories: *in-*

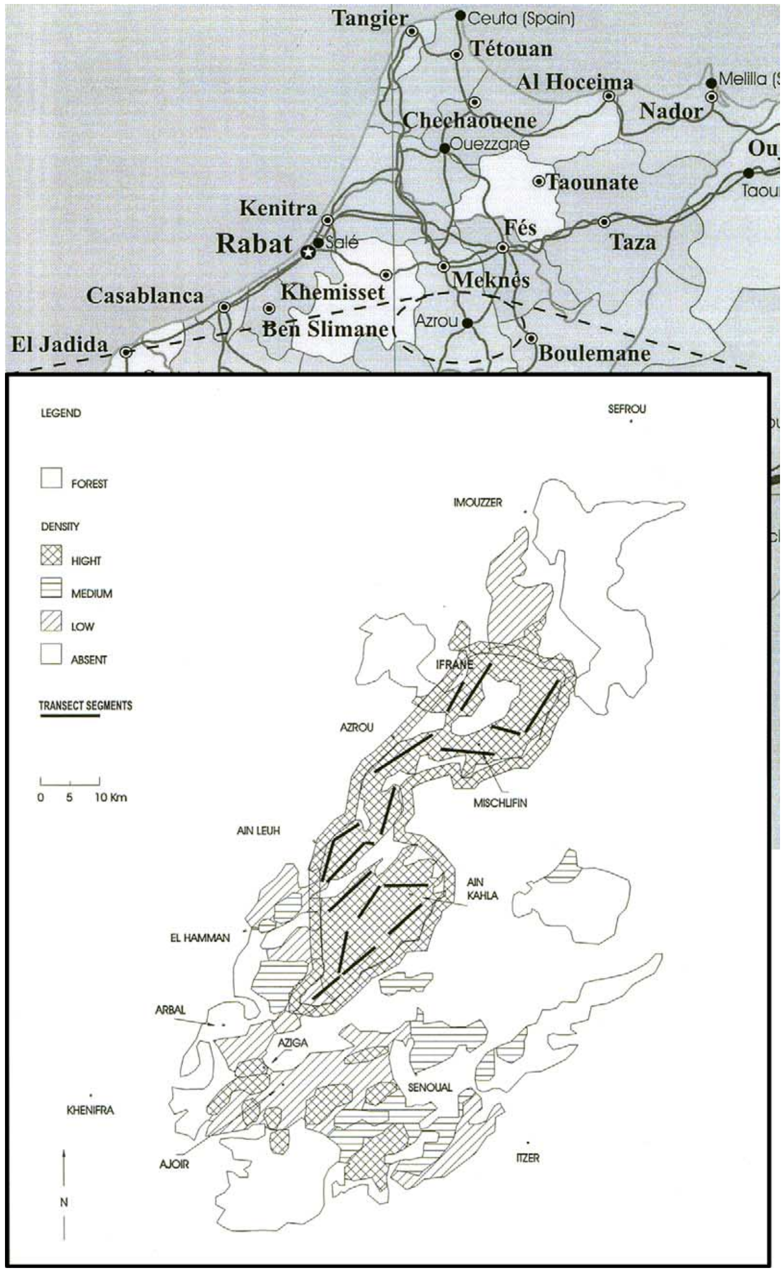

Fig. 1. Study area, forest distribution, macaque density previous to our study (Fa et al., 1984) and distribution of the 16 transect segments composing the circuit that was replicated 30 times along eight years.

tact (relatively undamaged), *intermediate*, and *degraded*, according to Camperio Ciani (1995), which is based on the presence–absence of herbaceous plants and ground seedlings.

Volunteer research assistants (groups of graduate and undergraduate university students from European and Moroccan universities) assisted the authors with data collection. The research assistants were first trained by the authors in animal identification and habitat classification, at the start of each expedition, until trainer–trainee consensus had reached a minimum level of 90%. In order to further minimise any sample bias due to data collector subjectivity, we implemented an interpenetration sampling scheme where observers for each transect segment were rotated daily, thereby guaranteeing consistency in data quality over the entire study period (Fellegi, 1964; Biewer and Stokes, 1985).

3. Results

With our 30 circuit replications (average width 96 m, length 93.5 km) throughout the entire 8-year study period, we directly observed and sampled a total of 274

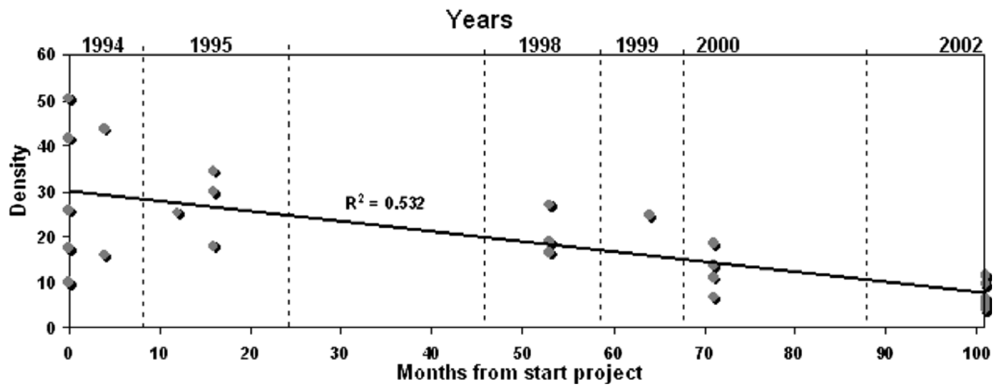

Fig. 2. Macaque density regression analysis. Each dot represent the density observed in each circuit as I/km^2 in the corresponding month from the study inception. It can be seen that the observation are naturally subdivided in three blocks because both in 1996–97 and 2001 no expedition could be conducted.

km^2, with an average about 9 km^2 of forest surface scanned and sampled in each circuit.

3.1. Density

Fig. 2 shows how the relatively high number of replications (30) of our statistical unit, a 93.5-km long circuit comprising 16 segments, helped reveal a clear trend indicating that since the beginning of our investigation, *M. sylvanus* density has suffered a serious decline. Density has fallen from the average 28.19 I/km^2 observed in the expeditions conducted between 1994 and 1995, to the mere 7.26 I/km^2 observed in the 2002 expedition. Indeed, the regression analysis between densities per circuit and time elapsed from the beginning of the study, shown in Fig. 2 is highly significant ($\beta = -0.729$, $R^2 = 0.532$, $p < 0.001$).

3.2. Forest quality and the effect of grazing animals

Table 1 compares, along the circuit, the observed mean surface, in square kilometre, of each of the seven habitat types, for each of the three expedition blocks. Since our circuit was never changed this corresponds to effective habitat changes in the region. One can observe that Cedar forests, at present account for a small proportion of the habitat; Further, *Cedar* forest has undergone a progressive decline since the project's inception (highly significant for *open cedar* $p < 0.01$), and *open oak* and *grassland* has and significantly increased ($p = 0.05$).

Moreover, by comparing the same data collected by Drucker (1984), we noted that the ratio of closed to open canopy forest decreased from 1:1.05 in 1980 to 1:0.36 in 2002.

Table 2 compares the relative density of sighted macaques across the same three expedition blocks, with respect to the seven habitat types. One can observe that the recorded macaque density per square kilometre in the various habitat varies sharply. Given the recent decline of *cedar* forest surface it could be expected that relative density in the remaining *cedar* habitat could increase, on the contrary there was a steep and significant decline in macaque density both in *closed* and *open*

Table 1
Forest surface relative to sampled habitat and significant comparison in the three expedition blocks

	I period 1994–1995 ($N = 12$)		II period 1998–1999–2000 ($N = 10$)		III period 2002 ($N = 8$)		ANOVA	
	Mean[a]	DS	Mean	DS	Mean	DS	*F*	*p*
Closed cedar	**0.8**	0.34	**0.6**	0.19	**0.5**	0.11		
Open cedar	**1.3**	0.61	**0.9**	0.28	**0.6**	0.31	*6.03*	*<0.01*
Closed mixed	**1.7**	0.67	**2.2**	0.35	**2.0**	0.28		
Open mixed	**2.1**	0.52	**2.0**	0.53	**2.2**	0.35		
Closed oak	**0.8**	0.23	**1.1**	0.37	**0.9**	0.15	*4.98*	*0.01*
Open oak	**0.7**	0.14	**0.6**	0.29	**0.9**	0.21	*3.27*	*0.05*
Grassland	**1.6**	0.38	**1.6**	0.43	**2.0**	0.27	*3.29*	*0.05*

Only significant values are indicated.
Bonferroni post hoc test showed significant difference $p < 0.05$ for *Open cedar* between first and third period, for *Closed Oak* between first and second period, for *Open oak* between second and third period. Similar conclusions were confirmed by non parametric Kruskal Wallis test.
[a] Surface mean and standard deviation in Km^2 observed in the circuit in each expedition block.

Table 2
M. sylvanus density in sampled habitat and significant comparison in the three expedition blocks

	I period 1994–1995 ($N=12$)		II period 1998–1999–2000 ($N=10$)		III period 2002 ($N=8$)		ANOVA	
	Mean[a]	DS	Mean	DS	Mean	DS	*F*	*p*
Closed cedar	**82.6**	49.40	**70.0**	60.28	**14.0**	12.56	*5.35*	*0.01*
Open cedar	**49.5**	48.03	**18.0**	24.18	**9.3**	11.07	*3.99*	*0.03*
Closed mixed	**32.2**	29.45	**20.4**	11.09	**16.0**	10.27		
Open mixed	**23.4**	25.08	**10.0**	9.93	**5.2**	3.76		
Closed oak	**9.4**	14.25	**10.4**	8.64	**4.4**	7.06		
Open oak	**19.3**	45.79	**5.6**	12.34	**2.1**	4.10		
Grassland	**8.2**	9.22	**3.4**	5.67	**0.6**	1.11	*3.29*	*0.05*

Only significant values are indicated.
Bonferroni post hoc test showed significant difference $p<0.05$ for *Closed Cedar* is both first period with third and second period with third. For *Open cedar* and *Grassland* it is significantly different first period with third. Similar conclusions were confirmed by non parametric Kruskal Wallis test, except for *Grassland* ($p=0.13$).
[a] Density mean and standard deviation of *M. sylvanus* as I/km^2 observed in the circuit in each expedition block.

cedar forests, their favourite habitat. This was also recorded for *grassland*, while the decline is less evident in the other habitats.

In Table 3 compares underbrush conditions in the three expedition block. One can note the decline in the portion of *intact* areas and the increase in *degraded* terrain particularly between the first two expedition blocks, whereas data from the 2002 expedition indicate that the situation has slightly stabilized over the last few years.

As a result, only 14% of the terrain surveyed could be classified as *intact*, while 48% presented recent signs of grazing (*intermediate*), and 38% showed alarming signs of overgrazing (*degraded)*.

Table 4 compares monkey density, with respect to underbrush type, shows a severe decline in all underbrush surface categories, which seems to start in degraded underbrush.

Not only habitat has degraded but grazing animals has further increased in the region. In fact, during the 1994–1995 expeditions, the maximum density of animals grazing in the forest was estimated for sheep at 130 vs. 316 I/km^2 observed for the 1998–2000 expeditions ($T=-5.822$ and $p<0.001$). The same trend is evident for goats, whose density grew from the 18 I/km^2, observed during the 1994–1995 expeditions to the 51 I/km^2 recorded between 1998 and 2000 ($T=-5.419$ and

Table 3
Forest surface relative to underbrush sampled and significant comparison in the three expedition blocks

	I period 1994–1995 ($N=12$)		II period 1998–1999–2000 ($N=10$)		III period 2002 ($N=8$)		ANOVA	
	Mean[a]	DS	Mean	DS	Mean	DS	*F*	*p*
Intact	**2.3**	0.40	**1.2**	0.60	**1.3**	0.36	*18.20*	*<0.001*
Intermediate	**4.1**	0.67	**4.4**	1.19	**4.3**	0.71		
Degraded	**2.4**	0.73	**3.4**	1.37	**3.4**	0.76	*3.74*	*0.04*

Only significant values are indicated
Bonferroni post hoc test showed significant difference $p<0.05$ for *Intact* between first and second period and first and third period. Similar conclusions were confirmed by non parametric Kruskal Wallis test
[a] Underbrush surface mean and standard deviation in km^2 observed in the circuit in each expedition block.

Table 4
Macaque density relative to underbrush sampled and significant comparison in the three expedition blocks

	I period 1994–1995 ($N=12$)		II period 1998–1999–2000 ($N=10$)		III period 2002 ($N=8$)		ANOVA	
	Mean[a]	DS	Mean	DS	Mean	DS	*F*	*p*
Intact	**30.5**	19.95	**28.2**	15.18	**10.5**	7.32	*4.21*	*0.03*
Intermediate	**31.8**	22.96	**18.6**	9.25	**8.7**	5.03	*5.35*	*0.01*
Degraded	**22.1**	18.94	**10.2**	11.84	**4.1**	1.84	*4.41*	*0.02*

Only significant values are indicated.
Bonferroni post hoc test showed significant difference p<0.05 for all three kind of underbrush between first and third period. Similar conclusions were confirmed by non parametric Kruskal Wallis test except for degraded underbrush ($p=0.07$).
[a] Density mean and standard deviation of *M. sylvanus* as I/km^2 observed in the circuit in each expedition block.

$p < 0.001$). Unfortunately the data from the 2002 expedition were collected quite late in the season, when many flocks had been relocated to winter in the plains, and therefore could not be used for this particular analysis.

4. Discussion

Few other studies on the *M. sylvanus* population in Morocco are pertinent to the present one for historical density comparison. The first was conducted by Deag in 1968 (Deag, 1974) in the Ain Khala region, within our same study area which reported, trough a focal method study, a density of 70 I/km^2. Then Taub (1977) trough a transect survey by car estimated a density of 44 I/km^2. Another study was conducted by Mehlman from 1982 to 1983 (Mehlman, 1989) in the Gomara region in the Rif mountains, a marginal and degraded habitat, were he found a low macaque density (6.73 I/km^2). Both Deag (1974) and Mehlman (1989) collected their data within a limited surface area using a focal animal sampling method (vs. our transect method), and then extrapolated them to the entire region. This methodological difference makes it delicate to compare these data with ours, as it can be understood by observing the great variability in density between the various habitats as shown in Table 2. These data suggest however that the decline of the macaque population in the Middle Atlas has started long ago, but is now rapidly accelerating toward density similar to the other degraded areas in Morocco such as the Rif mountains (Mehlman, 1989).

The Middle Atlas monkeys feed the entire year on more than 200 plants found in the forest underbrush, supplementing their diet with various invertebrates found under stones and in the soil (Drucker, 1984). In winter, when snow blocks access to the underbrush, the macaques resort to feeding on cedar buds as well. *M. sylvanus* is thus an efficient opportunistic forager, but it is also a direct competitor with domestic herbivores brought to graze in the forest (Mehlman, 1989). Moreover, since this primate feeds in the underbrush on the ground, it represents an excellent natural biological indicator of the state of the forest (Camperio Ciani et al., 1999, 2001; Camperio Ciani and Palentini, 2003; Mouna et al., 1999).

At present, macaque densities in the various habitats is declining even faster than habitat degradation itself. We found that macaque decline is mainly due to the growing impact of mixed flocks of goats and sheep grazing in the forest. Goats cause the worse forest degradation effects, especially when grazing in with large numbers of sheep. In fact, while sheep graze on grass, goats are forced to resort to other food sources, pulling up roots and stripping bark from young trees, dramatically accelerating desertification. Our analysis of the density of the population in this region clearly shows a progressive and drastic decline especially in cedar habitat types, and degraded underbrush.

The present data on habitat degradation and grazing animal density are in line with Thirgood (1984), indicating that these forests, especially cedar ones, are in rapid decline and that degraded underbrush surface is on the rise. This effect, which is due to a large increase in the presence of composite flocks of sheep and goats grazing in the forest, has been aggravated, in part, by a drought, affecting the area in recent years. Indeed, we observed that as forest grazing increases, the underbrush first undergoes degradation. Then, actual forest degradation occurs only in a secondary phase. In fact, humans inhabiting the area cut cedar branches (a practice termed *branchage*) to forage their flocks only when the underbrush becomes too depleted, and flocks can no longer find ground-level plants to forage on, and all this have dramatic effects on wild macaque populations.

Our experience suggests that density estimate, however, is not the most efficient measure available for rapidly demonstrating, the demographic decline of *M. sylvanus*. In fact, since these monkey groups are cryptic and are constantly on the move around their home range, and since forest observers have limited visibility, the probability of a sighting during a transect survey remains highly stochastic, and reliable population density estimates depend therefore on an extremely large number of observations such as those conducted for the present study (e.g. Sutherland, 1996).

The population density trend, however, depends a great deal on the proportion of immature animals in a given population, which over time will substitute the adult reproducing population.

In fact, already in 1995, we predicted an inevitable reduction of population density in the future, by observing demography changes in age and sex classes of these macaque populations (Camperio Ciani, 1995; Camperio Ciani et al., 1999). The drastic reduction of immatures, and the progressive increase of adult males immigrating from elsewhere, predicted the decline that this study now confirms. Southwick et al. (1980) have estimated that, as a rule, whenever the proportion of immature animals falls below one and a half the proportion of adult females, the macaque population starts declining. This was clearly observable during our first expedition block of 1994–1995 and was alarmingly low several times over the course of our later observations (Camperio Ciani et al., 1999; Camperio Ciani and Palentini, 2003; Mouna et al., 1999). The proportion of immature animals in the population surviving the first dry season (summer) depends on habitat conditions, such as the availability of food and predator pressures. We suggested, therefore, that the proportion of immature animals in a population, as well as sex-ratio variations, as a measure of immigration, might be better population demography indicators, which are easier and faster to survey than density itself, and can effectively monitor the decline of this species and its natural habitat (Camperio Ciani et al., 1999; Camperio Ciani and Castillo, 2000).

In conclusion, we recommend to establish a national park in the refuge forests of this region, restricting the access of grazing animals and especially of goats, before it is to late. Conservation initiatives, such as fencing and guarding the forest, promoting public awareness, and educating the local population about more sustainable use of the forest, have become more pressing than ever, even if they might occasionally clash with local traditions. Should the macaque population decline described herein remain constant, and should no action be taken to arrest the effects of the diverse – chiefly human – factors that are currently destroying the forest surface and underbrush, then we predict that within just a few decades, this important forest refuge area will have disappeared, taking with it the world's last large population of *M. sylvanus*.

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