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Research Article

An endangered species in captivity: Husbandry and management of the lion-tailed macaque (*Macaca silenus*)

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Abstract

The species that are endangered in their wild habitats also need to be maintained as sustainable populations in captivity. The lion-tailed macaque (*Macaca silenus*) endemic to the Western ghats of India, is an endangered species. The captive breeding programmes for this species have been taken up in North America, Europe and India. However, the management practices for the captive population need to be standardized. We propose that an assessment of the biological potential of a captive population at any given time can help predict future population dynamics. Since systematic data on the captive populations of the lion-tailed macaque in European institutions are available for the past several decades, we use those data to trace the development of the population in a historical perspective, and then use this perspective to develop a husbandry and population management manual for the lion-tailed macaque in captivity. We propose husbandry guidelines for individual groups, and also propose that each group should be considered a part of a metapopulation.

Keywords: Lion-tailed macaque, captive management, husbandry, Western Ghats, fragmentation

Introduction

It has been realized for the past few decades that the species that are endangered in their wild habitats also need to be maintained as self-sustainable captive populations. The ultimate aim of captive management is to have a long-term viable population for captivity as well as a reserve for the wild population. The captive population serves the purpose of public education and awareness as well as a model for the wild population within the framework of research for conservation and management. Achieving a viable population

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requires optimizing reproductive success and maintaining genetic variability. During its evolution, a species acquires behavioural and other traits that maximize reproductive success. The management practices, therefore, should be such that the captive environment allows an expression of the full range of such behaviours and traits.

The first step in the process of establishing captive management programmes is to assess the biological potential of a captive population at any given time. Such an assessment can help predict the future population dynamics. Since many species have been maintained in captivity for several decades, a useful approach to the analysis of biological potential would be to go back to the founder population of the existing population, and trace its development through generations. In addition to the analysis of development of the population, the variations, if any, in the critical life-history patterns such as age at first birth, birth interval, individual reproductive success, infant mortality etc. could also be analyzed. The population development pattern and life-history traits could then be compared with those in the wild populations inhabiting relatively undisturbed habitats. These trends could also be analyzed with reference to the models of small population biology. The proximate reasons for the deviations in trends and traits, if any, from the wild population could be analyzed and the management of keeping system could then address these reasons. This approach, therefore, incorporates (a) the existing information on the biology and ecology of the species in its natural habitats and conservation concerns, (b) an analysis of developmental process in the captive populations, (c) the data from the studies on the biology and behaviour of the species in captivity, and (d) institutional experiences in management of captive populations. Using this approach, we develop a husbandry and management programme for the lion-tailed macaque.

The lion-tailed macaque

The lion-tailed macaque (*Macaca silenus*) is one of the most endangered of the macaque species (and Primates in general) listed in the Red Data Book (IUCN 2003). The species is endemic to the Western ghats in southern India. The lion-tailed macaque has retained many primitive traits since its radiation (Fooden 1982). The species is of conservation concern due to its small numbers in the natural habitats, small area of occupancy and fragmentation of the remaining habitats. At present, there are about 3,500 individuals in the wild and about 600 in captivity. Although keeping of lion-tailed macaques in zoos has been documented since 1885 (Gledhill 1996), it has been realized that the species is difficult to keep. Because of the slow development and endangered status of the captive populations due to breeding problems, coordinated breeding programs were established in 1980s. These programs helped improve the status of the species to a considerable extent, however, there still remain a large number of institutions where breeding success is far below expectations and requirements. It is obvious that management of captive populations needs to be improved. The published documents provide recommendations for certain aspects of husbandry and management. Here we attempt to provide a more comprehensive approach to husbandry and long-term management that should support and guide the international breeding programmes for the species.

Taxonomy and distribution

Order—Primates; Family—Cercopithecidae; Genus—Macaca; Species—*Macaca silenus. The lion-tailed* macaque is a monotypic species. There is, however, a marked sexual dimorphism. The average weight of adult male and female is 6.8 kg (range: 5.0–10.0) and 5.0 kg (range: 3.0–6.0) respectively (Fa 1989; Dixson 2003). The respective head to body length in males and females is 510–610 mm and 460 mm (Fa 1989). The tail length in males and females is 254–386 mm and 254–370 mm respectively.

The Palghat gap (approximately 10°8″ N and 76°7″ E) divides the population of the lion-tailed macaque into southern and northern populations in the Western ghats. However, even within these large subpopulations, the habitats are fragmented and the remaining population is now found fragmented in 49 unconnected subpopulations (Molur et al. 2003), varying in size from six to about 700 individuals. During the recent studies, the population size, number of groups, density and demography have been reported for the populations at Periyar Hills, Anaimalai Hills, Silent Valley, Sringeri Range and Sirsi-Honnavara (Singh et al. 1997a,b, 2000, 2001; Ramachandran and Joseph 2000; Kumara and Singh 2004). However, the populations at Mundanthurai-Kalakad ecosystem, Nelliampathy Hills, Siruvani Hill, Charmadi ghats, Kudremukh National Park and the forests south of Sharavathy River still need to be properly documented in order to know the actual status of the species.

Behavioral biology

The lion-tailed macaques live in small groups. A modal group's size in contiguous forests is 13.17 individuals, whereas in forest fragments, the size varies from six to 53 individuals (Singh et al. 2002). Adult male to female ratio is 1:2.11 and adult to young ratio is 1:0.84. The lion-tailed macaque society is 'female-bonded' and the females form the permanent core of the group. The females remain in their natal groups (philopatry) whereas adult males migrate among groups. The immigration of an adult male into a group might result in agonistic interactions with the resident male(s), but the adult females appear to prefer migratory male to the resident male in all their social interactions including mating (Kumar et al. 2001). The group members are largely dispersed during the day, and social interactions, as compared with many other macaque species, are much lesser. However, during the rest periods, females form small clusters for grooming. The infants remain close to the females but the juveniles, at such times, form play groups that could be away from their mothers. The social interactions between adult females and adult males are few, and between adult males (if there is more than one in the group), almost none. A group has a home range of several square kilometers and in contiguous forests, the home ranges of several groups overlap. Frequent intergroup encounters occur in the overlapping areas. The groups appear to have some selected sites for sleeping during nights. They form small clusters of a few individuals to sleep. Although we have no data on which individuals form such clusters in the wild, but on the basis of our observations of captive groups, we could presume that the clusters are probably formed by matrilines.

In the natural habitats, births are observed almost throughout the year. However, there is a peak from January to April (Sharma 2002). In captivity, births occur almost at the same rate over all months (Lindburg et al. 1989; Krebs and Kaumanns 2001, 2002). The female age at first birth is about 80 months in the wild (Kumar 1987) and about 48 months in captivity (Lindburg et al. 1989; Krebs and Kaumanns 2001: 65.2 months). The inter-birth interval in the wild is about 30 months and infant survivorship is about 0.87 (Kumar 1987; Sharma 2002). The average inter-birth interval in captivity is about 20 months. Kumar (1987) compared 10 macaque species and observed that the lion-tailed macaque had the most delayed age at first birth, and also had the lowest birth rate of all macaque species compared, thus indicating a low reproductive potential of this species. The adult females show a conspicuous sexual skin swelling in the sub-caudal region that varies in intensity during the follicular phase. The cycle length in the wild has been observed to range from 15 to 87 days (mean=40.55 days) (Sharma 2002) in a forest fragment, and from 17 to 47 days (mean=30) in a contiguous forest (Kumar, 1987). The follicular phase lasts from about 14 to about 23 days. The mean cycle length in captivity is reported to be 32.2 days (Heistermann et al. 2001). The females have regular cycles up to the age of 20 years. Most matings occur during the follicular phase exhibited by swelling (Kumar 1987; Lindburg and Harvey 1996). Females make loud and conspicuous calls when in estrous. In the lion-tailed macaque, a Multiple-Mount-to-Ejaculate (MME) system was found. The males take lesser number of mounts to ejaculate when females are swelling, and during the deflated phase, the mounts hardly ever result in ejaculation (Sharma 2002). Adult females and juveniles are often observed to disrupt a mating pair, especially when the mating female is in estrous.

Free-ranging lion-tailed macaques have a very diversified diet. Results of previous nutritional studies in the natural habitat showed that the lion-tailed macaques consume a large variety of fruits and seeds. Depending on seasonality, fruits are selected only with a specific level of ripeness. Lion-tailed macaques are also known to feed on a variety of invertebrate fauna, and sometimes even on the vertebrates including young birds, lizards, frogs and mammals to the size of Malabar giant Squirrel. Furthermore, observations in fragmented habitats indicate that the lion-tailed macaque may have a rather wide range of dietary adaptations. In the wild, food is highly dispersed and many food items require processing, which makes foraging very time consuming. Individuals are highly dispersed during foraging (Kumar 1987; Krishnamani and Kumar 2000; Kumara et al. 2000; Singh et al. 2001; Singh and Kaumanns 2004).

Global captive status

An International Studbook for the Lion-Tailed Macaque was established in 1981 (Gledhil 1996). The studbook listed the first lion-tailed macaque in captivity in 1885. According to the latest edition of the International Studbook (Fitch-Snyder 2002), lion-tailed macaques are currently maintained in captivity in India (Coordinated Breeding Program—CBP), North America (Species Survival Plan—SSP), Europe (European Endangered Species Breeding Program—EEP), Japan, Southeast Asia, and Australia. The total population of 581 (285.280) individuals in 2002 (Fitch-Snyder 2002) is shown in figure 1.

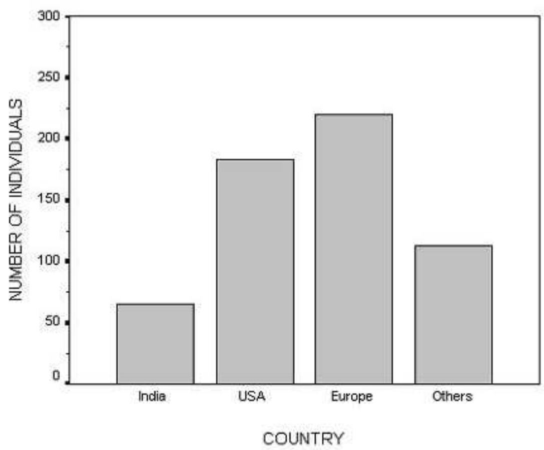

Figure 1: Number of lion-tailed macaques in captivity in different countries as on January 1, 2002.

European population

The European Studbook for the Lion-tailed macaque (Krebs and Kaumanns 2001, 2002) lists a historical captive population of 730 (334.345.51) individuals in Europe. As end of December 2002, 237 (114 .117.6) lion-tailed macaques were alive. The living population is kept in 41 institutions with a mean group size of 5.24 individuals (Krebs and Kaumanns 2002). In Europe, lion-tailed macaques are kept since 1924. In 1989, an European Endangered Species Program (EEP) was established, in which most of the continental European institutions participated (Kaumanns and Rohrhuber 1995). The European lion-tailed macaque population started with 85 (36.49) individuals in 12 institutions. In 1991/92 five institutions from Eastern Europe and seven institutions from the United Kingdom/Ireland joined the program. These zoos participated with 54 (23.30.1) lion-tailed macaques in the EEP. From that time, the European lion-tailed macaque population grew by about 70%. The growth rate corresponds to a mean annual increase of 9.8 individuals only. [Individuals imported from the American captive population (SSP) are included here (see figure 3)].

Population development

Figure 2 shows the crude population growth of the European lion-tailed macaque population over a period of more than 50 years (1950-2002). During the first ten years, the population remained small. In the following years, it increased slowly but steadily. The first documented captive birth occurred in 1956. Figure 3 shows the annual number of births, deaths, and imports in the population. It demonstrates that the growing phase of the population in the 1960s and 1970s was mainly influenced by the imports of wild-born individuals and not by births. During the last two decades (1980-2000), imports from the wild were very rare. However, between 1985 and 1997, 39 individuals were imported from the American captive population (SSP).

A more detailed analysis of the demographic parameters shows that the mean annual birth rate increased slightly over the five decades (figure 4). Mean mortality rate decreased considerably from 1950 to 1979, and it has remained more or less constant since then. On the other hand, it is obvious that the annual number of births was only slightly higher than the annual number of deaths (see also figure 3). The mean infant mortality rate increased over time reaching about 35% in the 1990s (figure 4).

The development of the population has also been affected by considerable variance in reproduction by the females. It had 56 potential founder females of which only 39.3% reproduced. These females contributed a mean of 4.2 surviving infants (Table 1). When calculated for the total females, the mean contribution per female turned out to be only 1.7 infants.

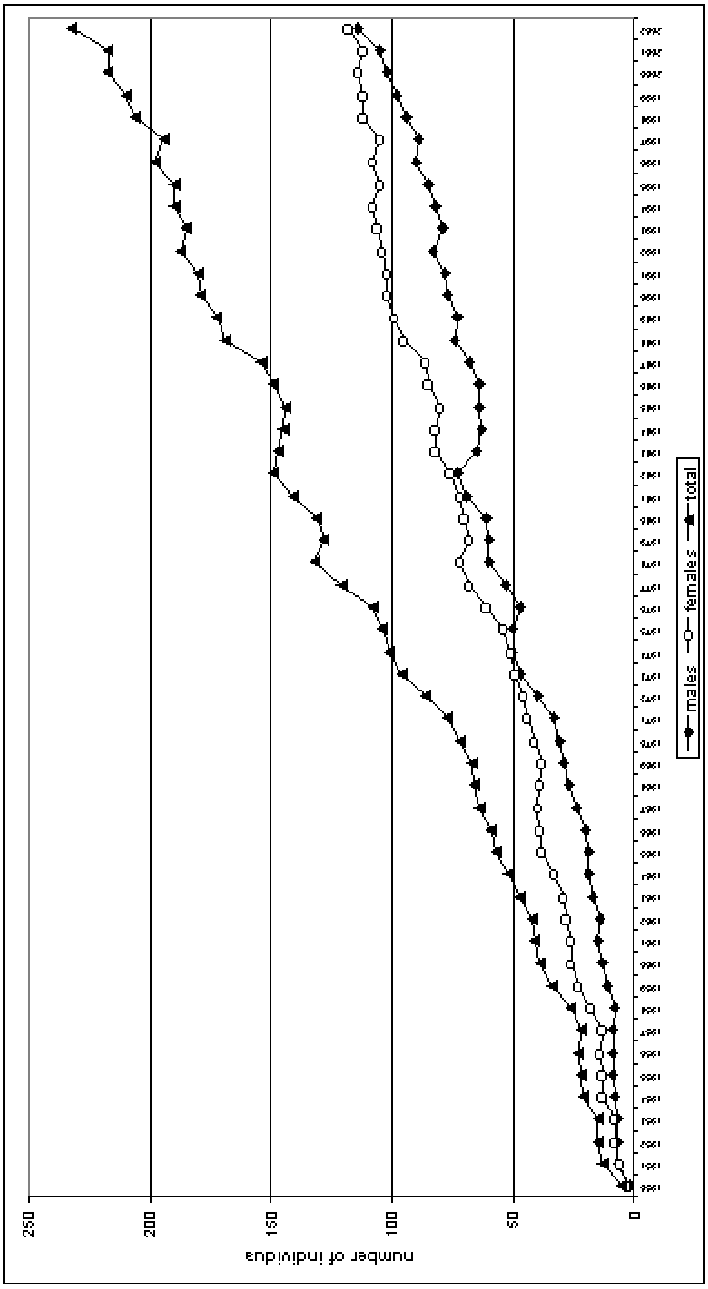

Figure 2: Crude population growth of the European lion-tailed macaque population over a period of more than 50 years (1950-2002).

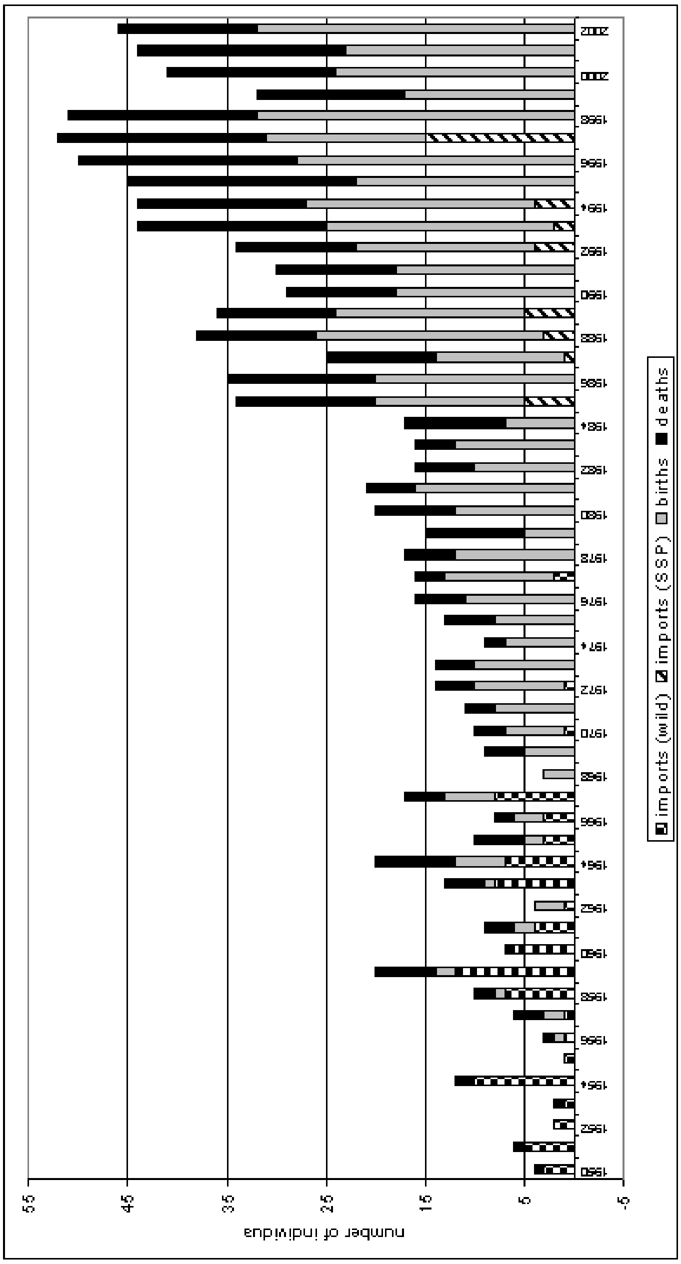

Figure 3: Annual number of births, deaths, and imports into the European population between 1950 and 2002.

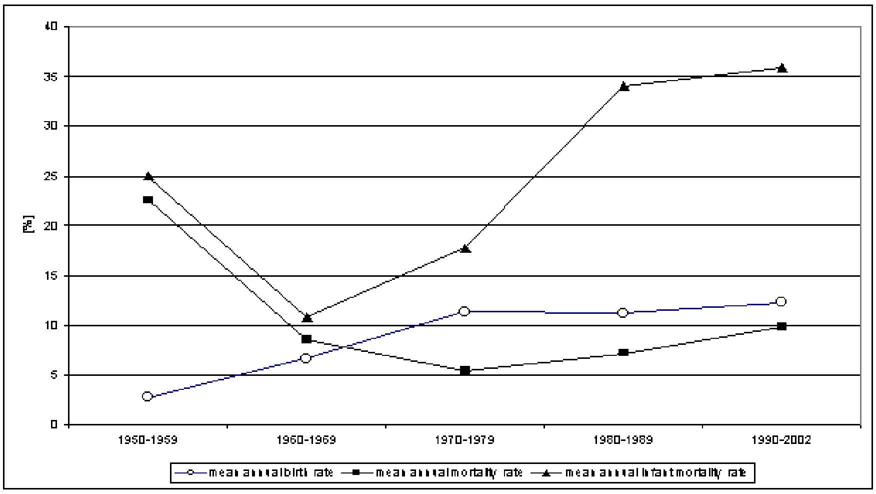

Figure 4: Mean annual birth, mortality and infant mortality rates in the European lion-tailed macaques for five decades.

Although the percentage of females reproducing increased to about 61% in F1, each contributed only 2.4 surviving infants. On an average, a female beyond the age of five years contributes only 0.3 offspring per year (Kaumanns and Rohrhuber 1995). Since F2 to F4 generation females can still be expected to contribute to reproduction, their rates cannot be compared with F0 and F1 as yet. However, the critical fact is that a large number of females fail to reproduce at all each generation, thereby, the genetic diversity is considerably reduced. Since a typical breeding group consisted of several females and only one male, it is obvious that the number of males which reproduced is much smaller (Table 2). Since the difference in the number of breeding males and females, and the variance in reproduction among females are the factors that account for the 'effective breeding size', these values being high indicate that the effective breeding size in the European lion-tailed macaque population is far below the size of the population. In other words, only a small proportion of the population contributes to breeding.

Table 1: Reproductive output per generation/females

	Number of females	Number of reproducing females	Reproducing females [%]	Number of offspring (surviving/dns)	Mean number of surviving infants per female	Mean number of surviving infants per reproducing female
F0	56	22	39.3	112 (97/15)	1.7	4.2 (range 1-10)
F1	46	28	60.9	97 (67/30)	1.5	2.4 (range 1-5)
F2	45	30	66.7	128 (84/44)	1.9	2.8 (range 1-8)
F3	42	18	42.9	44 (28/16)	0.6	1.8 (range 1-5)
F4	14	4	28.6	15 (6/9)	0.4	1.5 (range 1-3)
Σ	**203**	**102**	**50.2**	**396 (282/114)**	**1.4**	**2.8 (range 1-10)**

Table 2: Reproductive output per generation/males

	Number of males	Number of reproducing females	Reproducing males[%]	Number of offspring (surviving/dns)	Mean number of surviving infants per male	Mean number of surviving infants per reproducing male
F0	47	15	31.9	119 (98/21)	2.1	6.5 (range 1-21)
F1	44	15	34.1	85 (56/29)	0.8	4.0 (range 1-12)
F2	21	10	47.6	40 (23/17)	1.1	2.3 (range 1-6)
F3	14	2	14.3	2 (1/1)	0.1	0.5
Σ	**126**	**42**	**33.3**	**246 (176/88)**	**1.4**	**4.3 (range 1-12)**

Figure 5 presents the mean annual population growth rate (lambda) per decade. It shows that, since imports of wild-born individuals had been controlled strictly, captive population growth rates decreased over decades.

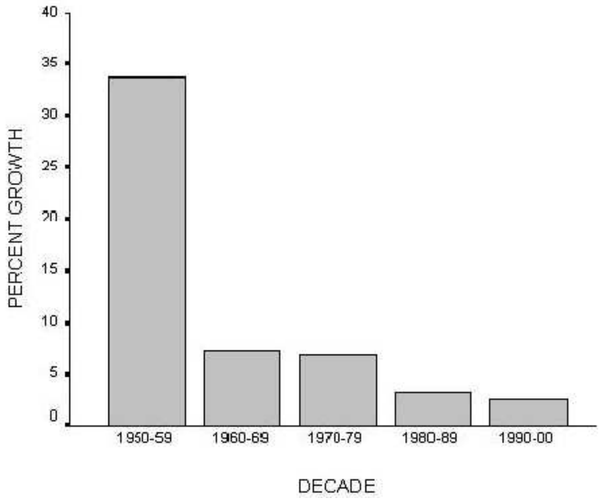

Figure 5: Percent growth of population of lion-tailed macaques per decade for five decades.

In summary, it may be stated that though the population is still growing at a slow rate. The other problems mentioned above indicate that the population is vulnerable with a little scope of viability.

Future population developments

The possible future development of the European lion-tailed macaque population is projected by using DEMOg (Bingaman and Ballou 1997). The instantaneous rate of change (r) as well as expected lambda (Euler results) and the net reproductive rate Ro point, especially in the females, to a slow population growth over the next 20 years (Table 3). With reference to sex, expected lambda values for the next 20 years suggest that the number of males will increase considerably, whereas the increase in the number of females will be more moderate (Figures 6 and 7). It seems to be realistic to aim for a population size of about 400 individuals in order to 'maintain' a number of about 60 adult females. On the basis of available data, the DEMOg-analysis reveals that a European population of 400 lion-tailed macaques would be achieved in about 20 years.

Table 3: Euler results for the European lion-tailed macaque population projections **R** = instantaneous rate of change in the population (values greater than 0 indicate growth; values less than 0 indicate a decline) **T** = generation time (the average length of time between the birth of a parent and the birth of its offspring = average age at which an animal produces offspring) **lambda** = proportion of annual change in population size $\mathbf{R_0}$ = Net reproductive rate or the proportional change in a population per generation (lambda, Ro: values greater than 1.0 indicate growth; values less than 1.0 indicate a decline)

	females	**males**
R	0.012	0.040
Lambda	1.012	1.041
T	10.86	14.15
$\mathbf{R_0}$	1.14	1.77

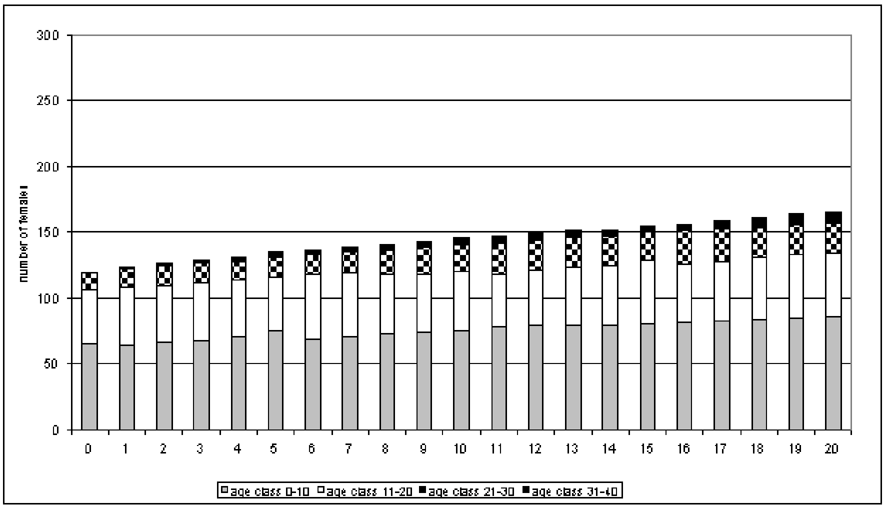

Figure 6: Projected increase in the number of females of different age classes during the next twenty years.

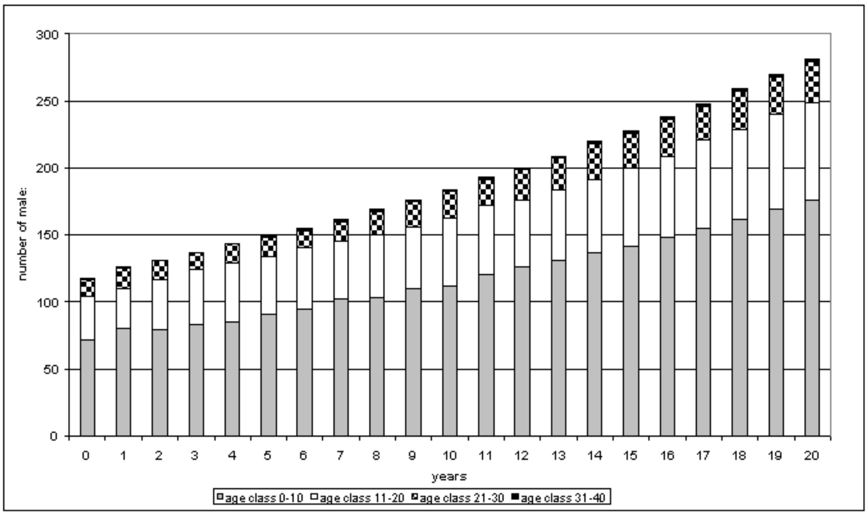

Figure 7: Projected increase in the number of males of different age classes during the next twenty years.

Implications for long-term viability and management

The main problems that have remained consistent throughout are:

- low number of births, with large fluctuations between the years
- high infant mortality
- significant proportion of adult females which do not breed
- slow population growth (with the risk of loosing genetic diversity)

Since no veterinary or nutritional explanations were evident for the above problems, it was considered that the possible causes could be related to demography, behaviour and keeping systems.

During the recent years, the field studies have contributed significantly to our knowledge regarding the ecology and biology of the lion-tailed macaques. It is, therefore, appropriate at this stage to compare some of the features in the captive populations to those till now known in the wild habitats. We assume that the major deviations from wild in captivity may have created the conditions that led to the problems described above. This analysis may help us develop a better perspective for their management.

The mean group size in captivity has been 5.24 individuals as against the modal group size of 13.17 individuals in the wild. The captive groups usually have one adult male whereas there could be more than one adult male at times in the wild groups. Subadult males are often observed in natural groups whereas in captivity, they are invariably removed. In large forest complexes, inter-troop encounters are common which totally lack in captivity. The adult male tenures in the wild groups are relatively short, and male migrations among groups are a routine feature. Such a situation provides an opportunity for the females for mate choice. Males in captivity have relatively long tenures, and females have little mate choice. Little is known about the fission of existing groups or the formation of new groups in the wild. However, two observations (a) that the lion-tailed macaque females form subgroups along matrilines within a group, and (b) that the groups in other macaque species split along matrilines, may suggest that the new groups in lion-tailed macaques are formed by a group of related females. The females in the wild groups remain in their natal groups. However, till EEP began, females in captive groups were often moved between groups, thereby disturbing the social structure in natal groups and in those in which they were introduced. A group of wild lion-tailed macaques spends a large part of the day in foraging. In captivity, even if the food is provided several times during the day, the time spent on food search is little. A wild group consists of individuals of all age-sex classes which provides the best opportunity for immature individuals for socialization. Even subadult males often play with the juveniles. The lack of representation of all age-sex classes in captivity results in limited social environment for infant socialization which might result in lack of development of social competence. Female harassment during mating is a common behaviour of lion-tailed macaques. In the wild habitats, a consort pair is often observed to move away from the rest of the group. However, the space limitations in captivity do not permit such isolation, thereby, probably resulting in high frequency of mating interference.

The deviations described above have been prevalent throughout the history of the population and there are no individuals who would have grown in total species-typical social and physical environment. Attempts have been made in the past, especially after the initiation of EEP, to improve the social and physical environment with considerable success. However, these attempts need to be intensified and made more comprehensive. It is in this context that we propose the following husbandry and management guidelines.

Other captive populations

Lion-tailed macaques have also been maintained in several other countries (Figure 1), with special emphasis on breeding in some places. The earliest attempt to coordinated breeding of lion-tailed macaque, considering its endangered status, was under the Species Survival Plan (SSP) in North America (Gledhill 1996). The population growth patterns and the procedures for captive management in the North American population have been well documented (Lindburg et al. 1989). This population also initially depended on heavy imports, but since 1970s, all individuals have been captive born. Interestingly, the problems encountered in the North American population are more or less the same as in the European population. The infant mortality rate was high in the beginning, though it declined after improvements in husbandry and management. Over a third of the sexually mature females failed to reproduce at all (Lindburg et al. 1989), a problem similar to that in the European population. The sex ratio at birth has been male-biased, which led to the problem of management of 'surplus' males. In 1986, there were 175 animals in North America. As a part of the management plan, some males which were genetically over-represented were vasectomized, and females during their fertility days were shifted to be paired with SSP-designated male partners (Fitch-Snyder 2002). Females were also kept with vasectomized males for longer periods as a conscious attempt at birth control. These strategies resulted in significantly reduced growth of the population, and the population in 2002 stood at 109 animals in 22 institutions with additional 29 animals that were neutered or females older than 25 years (Fitch-Snyder 2002).

A coordinated breeding program for lion-tailed macaques has been recently initiated in India with Vandalur Zoo at Chennai, Mysore Zoo and Trivandrum Zoo as participants. The present total captive population of 65 animals with only a few breeding females spread in several institutions may require replenishment for it to become a potentially viable population.

Husbandry

The captive management must take into consideration management at two levels:

a. Single group management, and

b. Population level management in which each group is considered a part of a metapopulation.

Single group management

Enclosure: The lion-tailed macaques are almost wholly arboreal. They are generally seen at a height between 10 and 30 meters and move horizontally through contiguous middle and upper canopy levels of the forest. A group of wild lion-tailed macaques has home range of several square kilometers. Travel distance per day could be as much as three kilometers. Large inter-individual distances are maintained while foraging. Even while resting, small clusters of individuals engaged in social interactions still remain at considerable distance from each other. An enclosure must provide conditions to realize such patterns to the extent possible. The outdoor enclosure must be designed such that it allows differentiated use of space both horizontally and vertically from ground to the top. The enclosure size should be minimum 200 square meters of usable ground space for a group of up to 10 animals. This size of an enclosure—together with an appropriate equipment (see below)—has been found to allow to realize an essentiell proportion of the typical activity patterns of the species and obviously is one of the preconditions to prevent behavioural disturbances and breeding problems. However, this assumption is only based on personal experiences and qualitative observations; quantitative studies are missing. To be on the safer side it seems to be reasonable to go for larger enclosure sizes when ever possible. At the time of building an enclosure, undulating ground, if possible with a small pool of water inside, should be selected. Depending upon the local situation, the outdoor enclosure could be an open system or a cage like system. In an open system, the central place surrounded by a dry or a water moat, should have trees or functionally similar vertical structures made out of wood. It is advisable that the ground cover consists of natural soil and vegetation such as bushes that are not particularly attractive to the monkeys as they are likely to overuse and destroy them. Such bushes etc. could also be 'protected' using aversive plants such as nettles or heavy stones that could not be moved by the animals. However, large areas are required for such enclosures since the usable central space becomes limited as it has to be kept far from the outer wall or fence to avoid escape. The cage-like system has a roof so that the animals could not escape from vertical places. The height of such enclosure should be at least four meters. There should be high up places for male for monitoring. Such places should have more than one connection so that other animals could escape. The monkeys are likely to destroy many structures over a period of time. The design, therefore, should be such that these structures are easily replaceable, if necessary, with the use of machinery. Large doors for such an access are required. The lion-tailed macaques, especially the males, are very sensitive to disturbance such as feeding and teasing by people, and they become extremely reactive to such situations. Enclosures should be situated such that there is only a moderate exposure of animals to the visitors and the animals have a place to retreat. In order to avoid encircling of animals, the visitors should not be able to access more than 50% of space around the enclosure to watch the animals. In addition to the main enclosure, there should be several other units. These could be at least two adjacent rooms/enclosures which at times could be managed such that animals could be separated with or without visual contact. Each of these units could have independent door to the main enclosure. Each unit should have a space of about 30 cubic meters. If at times it becomes necessary to keep the entire group in these units for longer periods, the two units could serve as one single large unit. In colder countries, these rooms should be inside a solid house where temperature should be maintained at about 20°C during the day and about 15° C at night during winters. Further, additional lights should be used during winter months to resemble the day length being equal to the tropical southern India where day length is about 13 hours and 11 hours in June and December respectively, so that the daily rhythms of activity are not restricted by the local daylight hours. The use of ultraviolet light is also recommended for short periods in winter to trigger physiological activities related to sunshine. The floor in such rooms should be asphalted or made with epoxy for easy cleaning and disinfection. Floor could also be made into a soft bed with materials such as chipped tree bark or wood that could be replaced once a month. Sliding should be such that the animals are visible to keepers but the keeper is far away from the animals. The openings between the keeping units should measure at least 40×70 cm, and these should be at least two meters above the ground. All units must also have doors for keepers to enter. In case a zoo plans to have two groups of lion-tailed macaques (two breeding groups or one breeding group and one all-male group), the enclosures could be situated adjacent such that the animals of two groups have a visual and vocal contact.

Feeding and foraging:

Development of feeding schedule for primates is dependent not only on the nutritional aspects of the diet but also on a number of other factors such as age-sex class, behaviour involved in obtaining food, social environment regulating access to food, and quality, quantity and distribution of food (Kaumanns et al. 2000). We intend to incorporate these factors while recommending feeding schedules for the lion-tailed macaque.

The lion-tailed macaques in their natural habitats spend about 44.25 percent of their time in feeding/foraging every day. Their food consists of 77.78% of floral and 22.22% of faunal items (Sushma 2004). There are feeding peaks during the day, and depending upon food availability, there are seasonal variations in feeding on different food items. For example, during Monsoon, there is a high dependence on fruits, whereas flowers are consumed with a relatively high frequency during post-monsoon season (Sushma 2004). However, availability rather than food selection accounts for such seasonal variations in nature. Group members maintain long inter-individual distances while foraging. Many of their food items require processing such as tedious plucking, opening, rubbing etc., as in the case of *Cullenia* fruits.

Although the natural diet of lion-tailed macaques contains a high amount of 'fruits', a captive diet providing a similar proportion of fruit may not be appropriate. Cultivated fruits usually contain less protein and fiber but more sugar in comparison to wild fruits. High proportion of cultivated fruits, therefore, may lead to obesity and teeth problem. Since lion-tailed macaques in their natural habitats spend considerable amount of time feeding on invertebrates and small vertebrates, it is necessary that such items are offered in captivity. These could be offered as live invertebrates (grasshopper, locust, crickets) or vertebrates (cooked meat, cooked chicken or 1-day old chicken). Another way to offer animal protein is feeding curd (cottage cheese) as a form of 'porridge'. As far as possible, the enclosure and its surroundings should have vegetation that would attract natural prey such as insects and small vertebrates.

Comprehensive studies with quantitative analysis of the diet of captive lion-tailed macaques are not available. However, Hampe (1999) carried out a survey of the diets from five European zoos with regard to nutrients, energy and supplements. All diets were mainly based on fruits and vegetables (Fig. 8) the proportion of which differed strongly among the institutions.

The diet proposed below (see Diet-5 in figure 8) for the lion-tailed macaques is based on a long experience of maintaining the species at the german Primate Center, gottingen, and at Cologne Zoo under the supervision of the EEP Coordinator for lion-tailed macaques. The animals at these institutions had no health problems and have been breeding over the years. We, therefore, take this diet as a model. However, depending on the local conditions, differences in particular items could always be considered without affecting the nutrient and caloric composition.

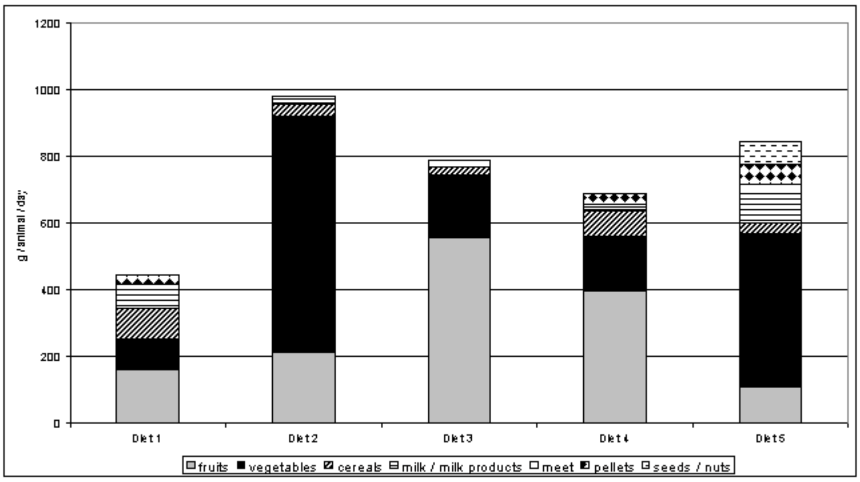

Figure 8: Amount of different items in the daily food of lion-tailed macaques in five institutions. (Adapted from Hampe, 1999).

Table 4: Amount of different food items(g) to be offered per animal per day

Time		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
08:00	**porridge**	porridge 100	porridge 100	porridge 100	porridge 100	porridge 100	porridge 100	porridge 100
11:00	**Vegetables**	Red pepper 150	Aubergine 150	Lettuce 150	carrots 150	Tomatoes 150	Leek 150	Tomatoes 150
14:00	**Seeds or insects**	Seeds of sunflower	Seeds of pumpkin	Soyabeans	Maize	Raisins	Commercial food(pellets)	Locusts
16:00	**Vegetables fruits and others**	Tomatoes 100	Beans 50	Radish 100	Sprouds 100	Kohirabi 100	Beans 50	Cucumber 100
		Lettuce 100	Cucumber 100	Artichoke 50	Leek 100	Red pepper 200	Carrots 50	Kohi rabi 50
		Kohirabi 50	Leek 50	Beans 50	Celery 100	Maize 50	Radish 100	Lettuce 100
		Artichoke 50	Carrots 50	Leek 50	Zucchini 50	Salsify 50	Celery 50	Red pepper 100
			Celery 50	Tomatoes 50	Onion 50		Zucchini 100	
		Pears 100	Apple 100	Pears 100	Apple 100	Apple 100	Pears 100	Apple 100
		Melon 100	Kiwi 50	Melon 100	Tangerine 50	Grapes 50	Coconut 50	Peach 50
		Cheese 50	Bread 20	Meat (cooked) 50	Bread 20	Chicken (cooked) 50	Potatoes 70	Fish 25

Table 4 provides the amount of different food items to be offered per animal per day. An adult animal is offered about 800g of food per day. Vegetables constitute the bulk of the lion-tailed food in captivity. About half of an adult monkey's food must be added if an immature individual between the age of three to six months is present in the group. The feeding schedule for the week is provided in Table 4. The items mentioned against particular days in the chart could be shifted to other days during different weeks without affecting the schedule of feeding.

A preliminary nutritional analysis has been carried out for the above mentioned food (Appendix 1a-g). The additional items such as leaves, buds and flowers etc. are not included in this analysis. It must be stated that depending upon the availability and seasonality of the food items, variations in the diet are possible. However, the proportions of nutrients in the diet should not considerably vary from the model stated above. It is also recommended that the food is weighed from time to time in order to have a better control over the amounts. The nutrient analysis for the items not included in the above schedules can be carried out using a software named ZOOTRITION.

As mentioned earlier, the lion-tailed macaques spend more time on foraging than any other activity. This is because the food items in their habitats are widely distributed. The group members maintain long inter-individual distances while foraging. It is necessary that a similar kind of feeding situation is provided in captivity so that feeding behaviour of the kind observed in nature is elicited. The first step in this direction is to distribute the food as widely as possible throughout the enclosure. This may achieve wide dispersal of individuals. Second, an attempt should be made to 'hide' the food items behind bushes, sticks, stones etc., and also to use both ground and vertical structures to place food. This may induce 'search' activities in the animals, and may also keep them busy foraging for longer periods. Third, the food should be offered several times (minimum 3 times) in a day with small quantities each time so that the animals are not fully satiated after a meal. Further, high energy food items should not be offered in a concentrated way but distributed several times during the day. Some fruits and nuts may require breaking, opening, rubbing etc. Such items should be given in full so that the animals 'process' them before being able to eat. In order to keep the animals busy as well as to provide extra fiber, fresh branches with leaves, buds and flowers etc. should be provided on daily basis *ad libitum*. One of the problems in provisioning captive lion-tailed macaques seems to be that males, because of their larger size, are able to monopolize food especially in small enclosures. As a consequence, many of the captive adult males become obese over time. The solution for this problem is not to separate sexes for feeding, as it would make the males more stressed and disturbed, but to offer the food in a much dispersed way.

Demographic and social management

In all macaque species, individuals of a social unit have personalized social relationships which influence their interactions probably throughout their lives. The core of a group is often constituted by relatives. Groups often encounter other groups in the vicinity that may be viewed as competitors for food resources, however they are partners in reproduction in the long run. Lion-tailed macaques in their natural habitats live in small groups. Females are philopatric and males migrate among groups. Adult males probably spend a large part of their lives as solitary individuals or as peripheral members of a group. All-male groups in lion-tailed macaques are not seen in nature so far. The modal structure of a group is usually one adult male, five to six adult females, and several immature individuals. Within a social group, females form clusters of related individuals. Females are not particularly xenophobic to the presence of new adult males and actually appear to prefer migratory males over long-term resident males in their social interactions. Wherever groups have overlapping home ranges, inter-group encounters are quite common. In captivity, group size and demographic composition must be maintained such that it resembles that in nature. A new group should be established by related females which could be mother and daughter or full or half sisters. If such females are not available, it is preferred that the number of females is even so that they could form subgroups or clusters. Introduction of a new female to an already established group, if inevitable, should be a gradual process where the new female is visually exposed to the group for several weeks or months. The introduction of a juvenile female may require even longer periods to ensure that at least one female from the group develops a special interest in the new female before her release into the group. Since the formation of new groups or the introduction of new members to already established groups is still an experimental process, it is recommended that an experienced person, preferably a scientist, maintains complete records of the process, behaviour of animals, and success/failure achieved so that the other institutions could learn from these experiences. If a zoo can afford to maintain two groups, which in any case is an ideal situation to promote resemblance of inter-group encounters, these groups should be kept in vocal and visual contact with each other. The tenure of an adult male in a group is one of the most critical aspects of captive management. The adult male should be periodically replaced. It is difficult to say at this stage how long should be the tenure of a male, but it could be a maximum period of about five years or the time when his daughters start cycling. The introduction of a new adult male should be done only when all infants are weaned as there is a risk of infanticide by the new male. If a zoo is maintaining two groups with a visual contact between them, adult males could be transferred between the groups. The juvenile or subadult males need to be taken out of a social group. It is desirable that an all-male group of only (half-)brothers or father and sons is established. As far as possible, an established group of adult females should never be split. However, if it is inevitable for some unavoidable reasons, it should be done along matrilines.

Veterinary care

The group living animals, especially primates, sometimes indulge in fights over food, mates, hierarchical position etc., and as a result, scratches or even small wounds are seen in animals. Such situations should not become a matter of worry for a veterinary intervention. The animals, as a matter of fact, should be allowed to regulate their social tensions to the maximum extent by themselves. However, if veterinary intervention is inevitable in certain cases, invasive individual treatment should be avoided. The treatment period should be as short as possible because the group members may become xenophobic if the isolated animal is reintroduced after a long gap. If possible, the animal under treatment should be kept in visual contact with the group. A greater emphasis should be laid on preventive medicine rather than treatment. Too much medication should be avoided as it weakens the immune system of the animals. The medicines should be administered in the morning hours when the animal is hungry. The animal must be handled with great care and precautions since primates may often carry bacteria etc. that could be dangerous to humans.

Hand rearing

Hand rearing of infants should be avoided as far as possible. If it is inevitable, the infant should be placed in a movable cage not bigger than the size of an adult female. The cage should be in parts transparent, preferably made out of wood and soft wire mesh. The infant should be provided with a surrogate, preferably a woolen towel fixed in an upright position, for it to cling. Clinging to the keeper should be strictly avoided. The infant could be fed milk up to the age of three months. It should be brought into a visual contact with the group at the age of 4-5 weeks. The contact duration should increase as the infant grows older. During such contacts, the keeper should be invisible for the group as his/her presence might excite some animals. However, an unobtrusive watch should be kept in order to see if any particular female evinces keen interest in the infant. If possible, such an adult female could be separated from the group for short durations and allowed a physical contact with the infant. It should be done under controlled conditions in which it should be feasible to take out the infant if necessary. The actual introduction of the infant to the social group should take place at the age of about six months.

Metapopulation and long-term management

Each captive group should be regarded as a part of a large metapopulation made up of several captive groups distributed over a large geographic region. It has been observed in lion-tailed macaques that because of high inter-individual variability in the reproductive output of females (some females even failing to reproduce at all), and an increasing difference in the number of adult males and females contributing to a metapopulation, even a relatively large founder population eventually turns into a population with a small effective breeding size. Such a situation has long term genetic consequences for the population and its viability as such (see above).

Daily data logger

A Zoo must maintain a daily data logger for the keepers to fill in. This logger could be in form of several inventories. Some inventories need to be filled when any major event such as birth, death, immigration, emigration or sickness occurs. Other inventory should have daily records on mating, calls, swelling in the female, occurrence of social interactions between male and female etc. The authors of the present paper can be contacted for model inventories.

Research

Research in zoos should be encouraged and made an integral part of management. It must be kept in mind that such research may not only help better management in the zoos, but may also help understand several aspects of biology of the species that are not easy or feasible to be studied in natural habitats. The data, therefore, may be useful even for the management of the species in their wild habitats. A large proportion of the population of lion-tailed macaques to day inhabits unconnected forest fragments. Many such fragments contain only one group of lion-tailed macaques, and the situation has remained such for several decades. The consequence of such isolation is absence of inter-group encounters, male migration, and suboptimal demography and social structure. These also have been the typical features of groups in captivity. The captive groups of lion-tailed macaques, therefore, can be considered an extreme case of fragmentation, and they could serve as models for the fragmented forest populations. Systematic data on population growth, social behaviour, physiological processes such as hormonal cycles etc. from captive groups may help understand what might happen or could be happening in groups inhabiting forest fragments.

It may be noticed that most of our recommendations for captive management are based on the ecology and behavioural biology of the species understood from studies in its natural habitats. The recent field studies have brought out baseline data on several aspects of lion-tailed macaque distribution, ecology, social and reproductive systems and identification of factors responsible for the threatened status of the species (Singh et al. 2002, 2001).

However, there still remain large gaps in the information concerning actual population status and dynamics, genetic status, habitat utilization, reproductive biology, and social dynamics.

A cooperation between scientists working on captive lion-tailed macaques and those working in natural habitats, and an issue-based coordinated approach is necessary for the development of comprehensive *in situ* and *ex situ* conservation and management plans for this endangered species.

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ZOOTRITION Dietary management software, Version 2.0. Wildlife conservation society, New York, Bronx Zoo, 2001

Appendix-I

(a) Nutritional contents of vegetables

Item	Fed per day(g)	Energy (kcal/g)	Crude protien (g)	Fat (g)	Carbo-hydrate (g)	Curde fiber (g)
Artichoke	31.5	15.4	0.76	0.03	3.0	0.6
Auberine	63.8	13.4	0.77	0.13	2.2	0.9
Beans	50.6	17.4	1.21	0.10	3.0	1.5
Beetroot	20.3	8.3	0.32	0.02	1.7	0.5
Cabbage(red)	44.9	9.4	0.67	0.09	1.4	1.1
Carrots	118.2	31.9	1.30	0.24	6.2	4.0
Celery	37.5	8.3	0.6	0.11	1.2	1.6
Celery(tuber)	125.9	27.7	1.3	0.23	2.4	3.2
Cucumber	83.8	10.8	0.49	0.17	1.8	0.8
Kohl rabi	218.8	54.7	4.38	0.22	9.0	3.1
Salad	186.7	18.7	2.43	0.37	1.7	2.8
Leek	124.3	29.8	2.34	0.49	4.2	2.5
Onions	27.1	8.9	0.4	0.08	1.7	0.8
Peas	5.9	4.1	0.34	0.02	0.6	0.3
Pepper (green)	137.2	27.4	1.65	0.41	4.2	2.7
Radishes	47.2	35.1	0.48	0.07	0.6	0.5
Salsify	77.3	10.8	1.1	0.31	0.9	6.2
Tomatoes	289.9	49.3	2.9	0.58	8.4	5.2
Zucchini	71.9	13.7	1.2	0.29	1.6	0.8
Total	1782.4	395.3	143.31	3.97	55.9	39.3

(b) Nutritional contents of fruits

Item	**Fed per day(g)**	**Energy (kcal/g)**	**Crude protien (g)**	**Fat (g)**	**Carbo-hydrate (g)**	**Curde fiber (g)**
Apples	115.5	57.8	0.23	0.69	12.6	3.5
Dates	4.1	11.2	0.08	0.02	2.70	0.4
Grape	11.0	8.0	0.08	0.03	1.90	0.2
Kiwi	41.0	20.5	0.40	0.25	4.20	0.9
Melon	58.4	30.9	0.35	0.05	7.20	0.6
Peach	23.4	9.1	0.20	0.02	2.00	0.3
Pears	135.5	62.3	0.80	0.54	1.40	4.1
Raisin	32.4	91.0	0.80	0.19	21.40	1.7
Tangerine	17.0	7.7	0.10	0.03	1.70	0.3
Total	438.3	298.5	3.04	1.82	55.1	12.0

(c) Nutritional contents of animal matter

Item	**Fed per day(g)**	**Energy (kcal/g)**	**Crude protien (g)**	**Fat (g)**	**Carbohy-drate(g)**
Cooked fish trout	12.3	12.5	2.40	0.33	
Cooked chicken	23.3	23.1	5.30	0.21	0.05
Cooked beef	56.5	59.3	12.10	0.96	0.62
Cheese (hard)	19.3	70.4	4.90	5.60	
Total	111.4	165.3	24.7	7.1	0.67

(d) Nutritional contents of seeds and pellets

Item	**Fed per day(g)**	**Energy (kcal/g)**	**Crude protien (g)**	**Fat (g)**	**Carbohy-drate(g)**	**Curde fiber (g)**
Coconut	7.2	8.8	0.72	5.80	0.80	1.4
Melon seeds	8.5	0.5	2.00	4.00	*NA*	*NA*
Sunflower seeds	10.3	7.6	2.80	5.05	0.86	0.7
Pellets	59.4	223.0	12.47	3.9	*NA*	1.1
Pumpkin seeds	9.6	0.5	2.30	4.40	*NA*	*NA*
Maize	12.1	13.3	0.39	0.18	2.5	0.2
Wheat	72.5	220.4	8.3	1.45	43.6	7.5
Total	214.6	524.1	28.99	76.73	47.76	10.9

(e) Nutritional contents of breads and potatoes

Item	**Fed per day(g)**	**Energy (kcal/g)**	**Crude protien (g)**	**Fat (g)**	**Carbohy-drate(g)**	**Curde fiber (g)**
Bread	11.4	26.5	0.86	0.17	5.40	0.5
Crisp bread	5.0	15.9	0.50	0.08	3.30	0.7
Potatoes	29.4	20.6	0.60		4.50	0.7
Total	45.8	62.9	6.46	0.25	13.2	0.19

(f) Nutritional contents of porridge

Item	**Fed per day(g)**	**Energy (kcal/g)**	**Crude protien (g)**	**Fat (g)**	**Carbohy-drate(g)**	**Curde fiber (g)**
Banana	ca. 70	56.7	0.77	0.14	13.2	2.1
Curd cheese	ca. 50	36.5	0.68	0.15	2.0	—
Egg	ca. 15	23.9	1.94	1.78	0.1	—
Bran	ca. 10	14.5	1.60	0.50	1.0	5.3
Yogurt	ca. 300	183.0	9.90	10.50	12.0	—

Commercial baby mash	ca. 150	540.0	15.8	3.30	—	9.8
Lemon juice	small proportion					
Vitamins	small proportion					
Wheat germ oil	small proportion					
Total	Ca. 610	855	30.8	16.3	28	16.8

(g) Nutrients and vitamins [Analysis: Software program ZOOTRITION Dietary management software, version 1.0 / Wildlife conservation Society, New York, Bronx Zoo, 1999]

Energy	575	Vitamin A	6.08 mg
Crude protein	7.0%	vitamin B1	0.52 mg
Crude Fat	1.6%	vitamin B2	0.42 mg
Carbohydrate	6.3%	Niacin	1.93 mg
Fiber	2.5%	vitamin B6	0.40 mg
		vitamin C	43.4 mg
Na^{+}	0.130%	vitamin E	2.50 mg
K^{+}	0.240%		
Ca^{2+}	0.050%		
Mg^{2+}	0.030%		
Fe^{2+}	0.003%		
Phospor	0.070%		