AN ABSTRACT OF THE THESIS OF

Ramesh S. Krishnamurthy for the degree of Master of Science in Wildlife Science presented on February 25, 1994. Title: Analysis of Lion-tailed Macaque Habitat Fragmentation Using Satellite Imagery.

Abstract approved: Redacted for Privacy
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Deforestation and forest fragmentation are the primary threats to the habitat of endangered lion-tailed macaques, *Macaca silenus*, in Karnataka, India. Landsat satellite images of northwest Karnataka, India, from 1977 and 1990 were analyzed. Two study sites, measuring 16.35 x 19.14 km (31,213 ha) and 14.34 x 21.44 km (30,561 ha), respectively, were selected for analysis.

Based on a group home range estimate of 131 ha, contiguous habitat fragments large enough to support two or more groups of lion-tails remained available in the study area in 1990. A single contiguous patch of 14,718 ha in Site 1 and two contiguous patches in Site 2, 4,276 ha and 9,097 ha respectively, were available for reintroduction of captive lion-tailed macaque populations. Loss of habitat has primarily been occurring in and around previously disturbed regions. Although the study identified potential unfragmented sites, there is still a need for ground-truthing.

Analysis of Lion-tailed Macaque Habitat Fragmentation Using Satellite Imagery

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of the

requirements for the degree of

Master of Science

Completed February 25, 1994

Commencement June 1994

Approved:

Redacted for Privacy

Professor of Wildlife In Charge of Major

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Date thesis is presented: February 25, 1994

Typed by: Ramesh Krishnamurthy

to my wife Gowri Ramanathan

and to my parents S.K. Leelavathy and S.R. Krishnamurthy

ACKNOWLEDGEMENTS

I am greatful for the guidance and support of Drs. Bruce Coblentz, Ross Kiester, Daniel Edge, and Paul Simonds. My sincere appreciation to Drs. Warren Cohen, David Wallin of Forest Science Laboratory, US Department of Agriculture, for providing the facilities for satellite image analysis, Mr. Tom Mairspringer and Ms. Maria Fiorella for their assistance during the data analysis, Mr. Clifford Mead of Special Collections, Kerr Library, the Department of Fisheries and Wildlife for providing office space and Dr. Kamaljit Bawa of University of Massachusetts, Boston, for providing 1990 Landsat TM data tapes. Finally, I would like to express my deep appreciation to my beloved wife, Gowri Ramanathan and to my parents, whose encouragement and support made this endeavor possible.

This project was partially supported by the International Trade and Leadership Fellowship, Oregon State System of Higher Education and Oregon State University Bookstore Scholarship.

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Introduction

"Hot-spots" (Myers, 1988), are areas of exceptionally rich species diversity and include 3.5 percent of the remaining primary forests in the world, containing about 34,000 endemic plant and 700,000 endemic animal species. Among the world's "hot spots", are the evergreen forests of Western Ghats of south India (Myers, 1988; 1990). The Western Ghats comprise a total area of 160,000 km^2 containing eight national parks and 39 wildlife sanctuaries in six states: Goa, Gujarat, Karnataka, Kerala, Maharastra and Tamil Nadu (Collins et al. 1990; Kendrick 1989; World Conservation Monitoring Centre 1988). This region possesses rich species diversity and is one of the most threatened regions of south Asia (Myers 1988). Two-thirds of the species found in the Western Ghats are endemic to this region (Kendrick 1989; Lal et al. 1991; World Conservation Monitoring Center 1988), including the endangered lion-tailed macaque, *Macaca silenus*, (Holloway 1976).

Deforestation and habitat fragmentation of tropical evergreen forests in Western Ghats is a major cause of loss of biodiversity. While about one-third of forest lands are still covered by natural plant communities, much is being disturbed by agricultural development, fuelwood consumption, grazing, and hydroelectric projects, (Collins 1990; Karanth 1992; Lal et al. 1991; Marcot 1992), by an expanding human population.

In Karnataka, tropical evergreen forests occur in a 400 x 15-20 km north-south band along the eastern and western slopes of the Western Ghats (Proctor 1986). The south-west monsoon brings an average of 5,000-8,000 mm rainfall and the tallest trees may be 50 m tall (Proctor 1986). Karnataka's Forest Department controls approximately 80% of the evergreen forests encompassing three national parks and 12 wildlife sanctuaries (Lal et al. 1991; Proctor 1986).

Among many primate species living in the Western Ghats of Karnataka, lion-tailed macaques can be considered an indicator species. These macaques are mainly arboreal and are obligate evergreen forest species, feeding predominately on fruits and insects (Green & Minkowski 1977; Kurup & Kumar 1993). The social structure of lion-tails constitutes multimale groups, female philopatry, promiscuous mating and male emigration (Pearl 1992). In Karnataka, habitat of this species is threatened by human-caused disturbance and forest fragmentations and the lion-tailed macaque population declined (Karanth 1992).

Large areas of Karnataka are yet to be surveyed for the distribution of lion-tailed macaques; however, the species has been sighted or censused in the Anshighat, Jog Falls, Siddapur, Hulekal, Gersoppa forest ranges and Mastimane Ghat of Northwestern Karnataka (Ali 1985; Bhat & Sreenivasan 1977; Daniel & Kannan 1967; see Figure 1). Population surveys of lion-tails are limited in Karnataka. Various estimates of the population of this species have been made previously (Bhat 1983; Karanth 1984, Kumar 1988). The most recent estimate by Karanth (1992) projects the population of this species in Karnataka to be 1,000-2,000 individuals.

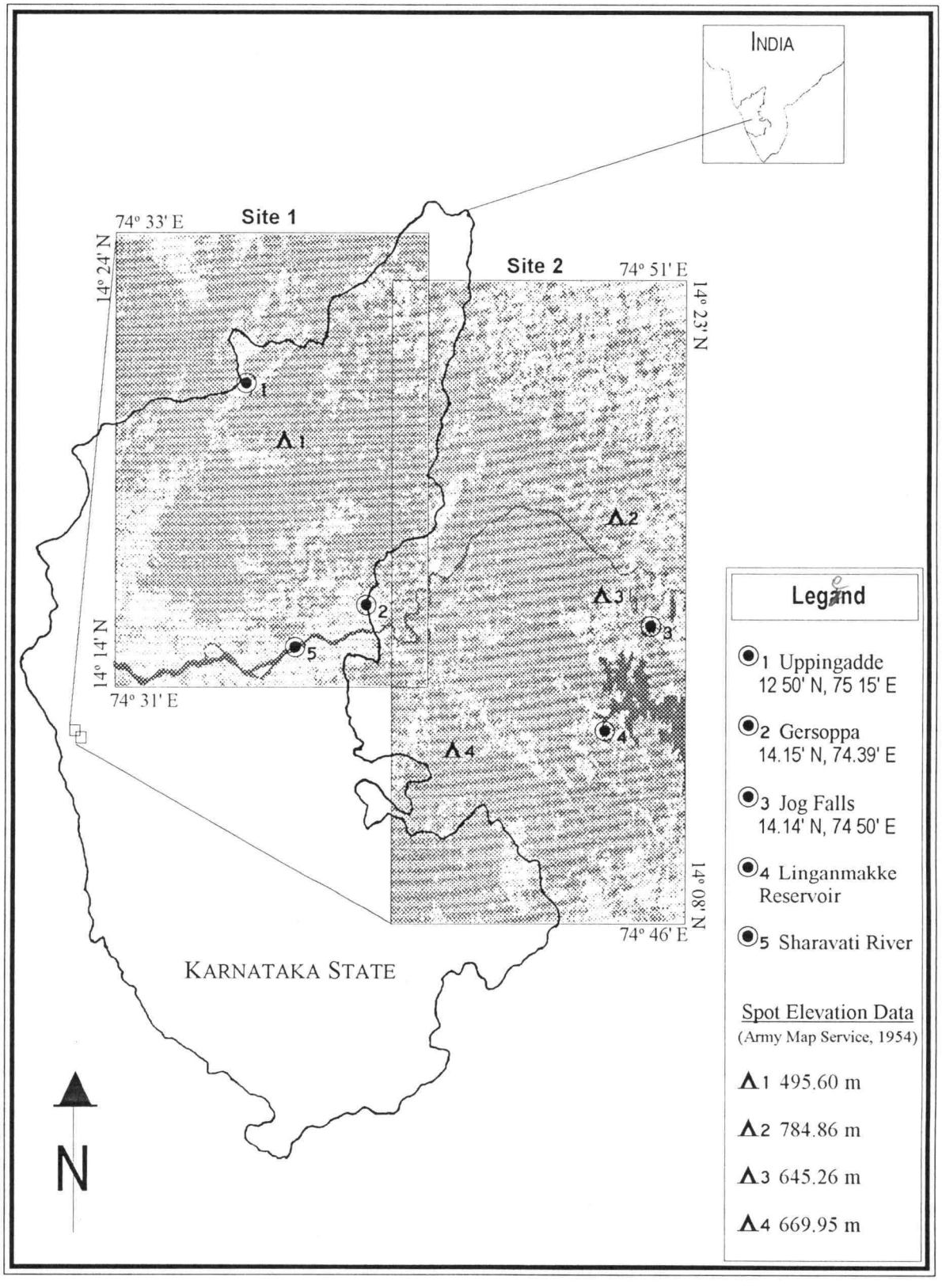

FIGURE 1 STUDY SITES OF LION-TAILED MACAQUE IN NORTHWESTERN KARNATAKA, INDIA

Habitat of lion-tails includes major plant species such as *Dipterocarpus* sp., *Diospyros* sp., *Holigorna* sp., and *Persea* sp. (Pascal 1982); however, the major portion of the population occurs in the forests dominated by *Dipterocarpus* sp. (Karanth 1992).

Lion-tails range primarily through mature forests; any gap in the canopy of over 0.5 km^2 may block their path (Collins 1990; Green 1983; Groombridge 1984). Various group home range estimates of this species are available; 0.76 km^2 (Kumar & Kurup 1985), 5 km^2 (Green & Minkowski 1977), and 100 ha for high-density habitat to 15-20 km^2 in low-density habitat (Kurup 1988). In Western Ghats, over 50 percent of the lion-tailed macaque population is distributed in habitat fragments less than 20 km^2 (Kumar 1985).

During 1990, at the Third International Symposium on Lion-tailed Macaque in San Diego, an action plan for the species was developed. One aspect of that action plan was to develop social groups of lion-tailed macaques in captivity for reintroduction to their native habitat (Chivers 1990). To partially accomplish the action plan for lion-tails, two zoos - The San Diego Zoo and the Bronx Zoo, are preparing social groups for reintroduction (Lindburg & Gledhill 1992). Successful reintroduction will depend on many factors. A review of these factors and guidelines for reintroduction of captive-bred animals are provided in Kleiman (1989). Efforts to reintroduce the monkey are dependent upon determining patterns and rates of deforestation and finding large and contiguous patches for reintroduction. Reintroduction should be carried out only where macaques are absent. Capturing and exchanging individuals among isolated patches to prevent inbreeding (Collins 1990)

would also contribute significantly to the continued survival of the species. Should reintroduction be attempted, released individuals should have a veterinary examination, and then monitored for some extended, post-reintroduction period (Griffith et al. 1989; Harcourt 1987).

The goal of this research is to identify the large and contiguous forest patches in the two study sites available for reintroduction of the endangered lion-tailed macaques from captive populations. The specific objectives were to: (a) determine habitat loss due to fragmentation, and sizes of remaining contiguous habitat fragments in the evergreen forests of northwestern Karnataka through analysis of Landsat images; and (b) identify habitat fragments of sufficient size to support viable populations of lion-tailed macaque.

METHODS

The study was carried out using two cloud free satellite images of the Western Ghats of Karnataka, India (1973 Landsat MSS image acquired on 13 January 1977 - Path 157, Row 50, and 1990 Landsat TM image acquired on 22 January 1990 - quardrat IV, Path 146, Row 50). Based on previous field studies (Bhat & Sreenivasan 1979; Daniel & Kannan 1967), two study sites; Site 1 and Site 2, were chosen from each year, measuring 16.35 x 19.14 km (31,213 ha) and 14.34 x 21.44 km (30,561 ha), respectively. As the path of the satellite was angular, these sites have an overlap of approximately 6.5 km^2 (Figure 1). The study areas were chosen because of known sightings of lion-tailed macaques and also because it was one of the least studied areas of Sharavati Wildlife Sanctuary.

Landsat images were analyzed using a Sun Sparc II Workstation and ERDAS image analysis software (version 7.5). A primary vegetation map by Pascal (1982) and a reference map by Army Map Service (1954) were used to identify lion-tailed macaque habitat. Image rectification was accomplished using 17 ground control points (GCPs). The selection of GCPs was established from the 1990 image to the 1977 image (RMS error = 0.71), using points such as bridges, roads, and mountain peaks. At first, using a sequential clustering method (unsupervised classification), a broad primary classification of the image was made. This classification contained over fifty categories. Later, with the aid of the vegetation map, the preliminary

classification was reduced to two broad categories - potential habitat of lion-tailed macaques and non-habitat. The potential habitat category included the evergreen and semi-evergreen forests and the non-habitat category included deciduous forests, plantations, cultivated lands, urban areas, rivers and others. Visual interpretation of Landsat images for the presence of lion-tails habitat was made by comparing the base and reference maps, and by the texture and patterns of the image. Figure 2 illustrates the flow chart of the methodology used.

I chose the group home range estimate of Kurup and Kumar (1993) of 131 ha/year for 31 individuals due to the considerable variation in the reported group home ranges for lion-tails and because of the similarity in habitats between their study sites and mine. Also, important aspects of lion-tailed macaque biology or ecology were unavailable (for example, the lack of minimum viable population estimates, and a detailed distribution of this species in the study area).

In light of proposals to reintroduce captive groups of lion-tails into their native habitat by two zoos - San Diego Zoo and Bronx Zoo (Lindburg & Gledhill 1992), and for the purpose of this project, I assumed that an area larger than 262 ha is necessary (an area required for two groups of macaques; calculated using Kurup and Kumar's estimates) to reintroduce the macaques from captivity. Habitat fragments smaller than 262 hectares were removed. Because the latest imagery used in this study was approximately four years old, I assumed that additional habitat conversion and fragmentation had occurred. Thus, I developed a buffer strip around forest patches that might approximate recent habitat loss. A buffer width of 645.74 m (23

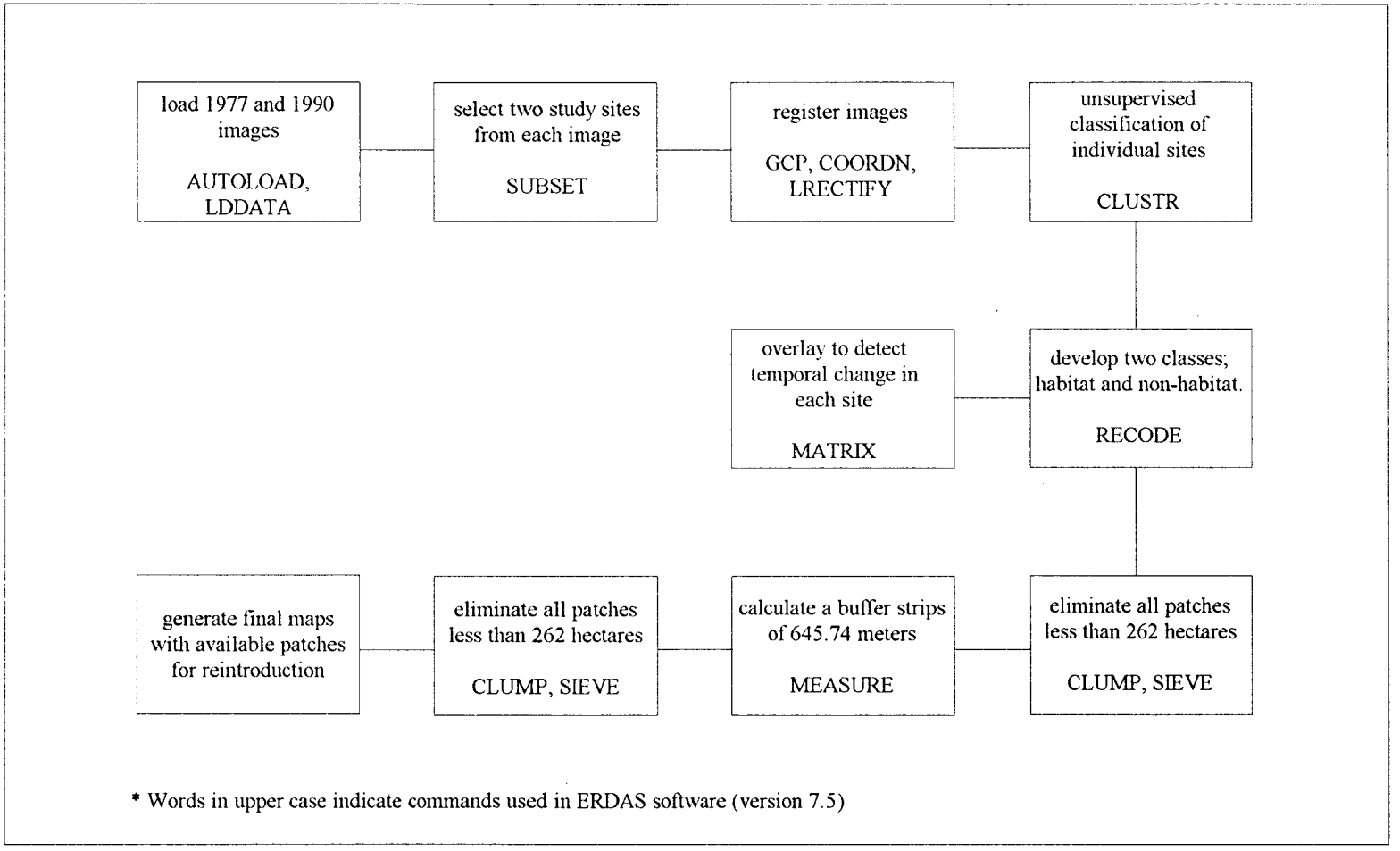

FIGURE 2 FLOW-DIAGRAM OF THE METHODOLOGY

pixels), based on the radius of Kurup and Kumar's (1993) group home range estimate, was mapped on all potential habitat fragments. The final contiguous patches were derived by removing habitat patches that were reduced to less than 262 ha when the buffer strips were delineated.

RESULTS

The analysis revealed various patterns of habitat fragments such as linear strips, semicircular, and large irregular polygons. Forest fragmentation was generally concentrated around areas where previous disturbance had occurred. Disturbed areas were also evident in many previously undisturbed areas. The presence of several small human habitations within lion-tailed macaque habitat also poses additional threats of fragmentation. Three potential habitat patches of lion-tailed macaque remained available in 1990; a single contiguous patch of 14,718 ha in Site 1 and two contiguous patches in Site 2, 4,276 ha and 9,097 ha respectively.

Changes in habitat in Site 1 are more noticeable in the northwest, east, southwest, and south central regions (Figure 3). In Site 2, habitat fragmentation is evident in the north eastern and west central regions (Figure 6). Habitat available to lion-tailed macaques decreased between 1977 and 1990 by 6.36% in Site 1 and 2.83% in Site 2 (Table 1). When accounting for temporal change between 1977-1990, in both sites, there is considerably less activity in the habitat-intact region than in the region where habitat was originally absent or surrounding the towns (Figures 3 and 6; Table 2). The core area in Figure 4 shows various degrees of fragmentation, especially in the regions where small towns are present. Figures 5 and 8 represent the actual habitat patches available (excluding the buffer) for reintroduction of lion-tailed macaques. The buffer, that represents presumed habitat loss, was then

removed from the existing habitat; habitat remaining after this removal is shown in Table 3.

Table 1. Habitat suitable for lion-tailed macaques before removal of fragments less than 262 ha

Category	Site 1	Site 2
Habitat in 1977	22,796 ha	22,322 ha
Habitat in 1990	20,810 ha	21,457 ha
Decrease in Habitat	1,986 ha (6.36%)	865 ha (2.83%)

Table 2. Temporal change in lion-tail macaque habitat between 1977 and 1990 as determined by overlaying imagery from those years

Category	Site 1	Site 2
Change in Habitat	4,980 ha	7,494 ha
Unchanged Habitat	19,659 ha	18,376 ha

Table 3. Habitat of lion-tailed macaques after removing fragments smaller than 262 ha

Category	Site 1	Site 2
Buffer	4,203	5,300
Core Area	15,600	15,378

Contiguous forest fragments large enough to support lion-tailed macaques remain available in the study area. After the buffer strip was delineated, any resulting habitat patches consisting of less than 262 ha were removed. At this point, three patches of potential lion-tailed macaque habitat remained available; a single

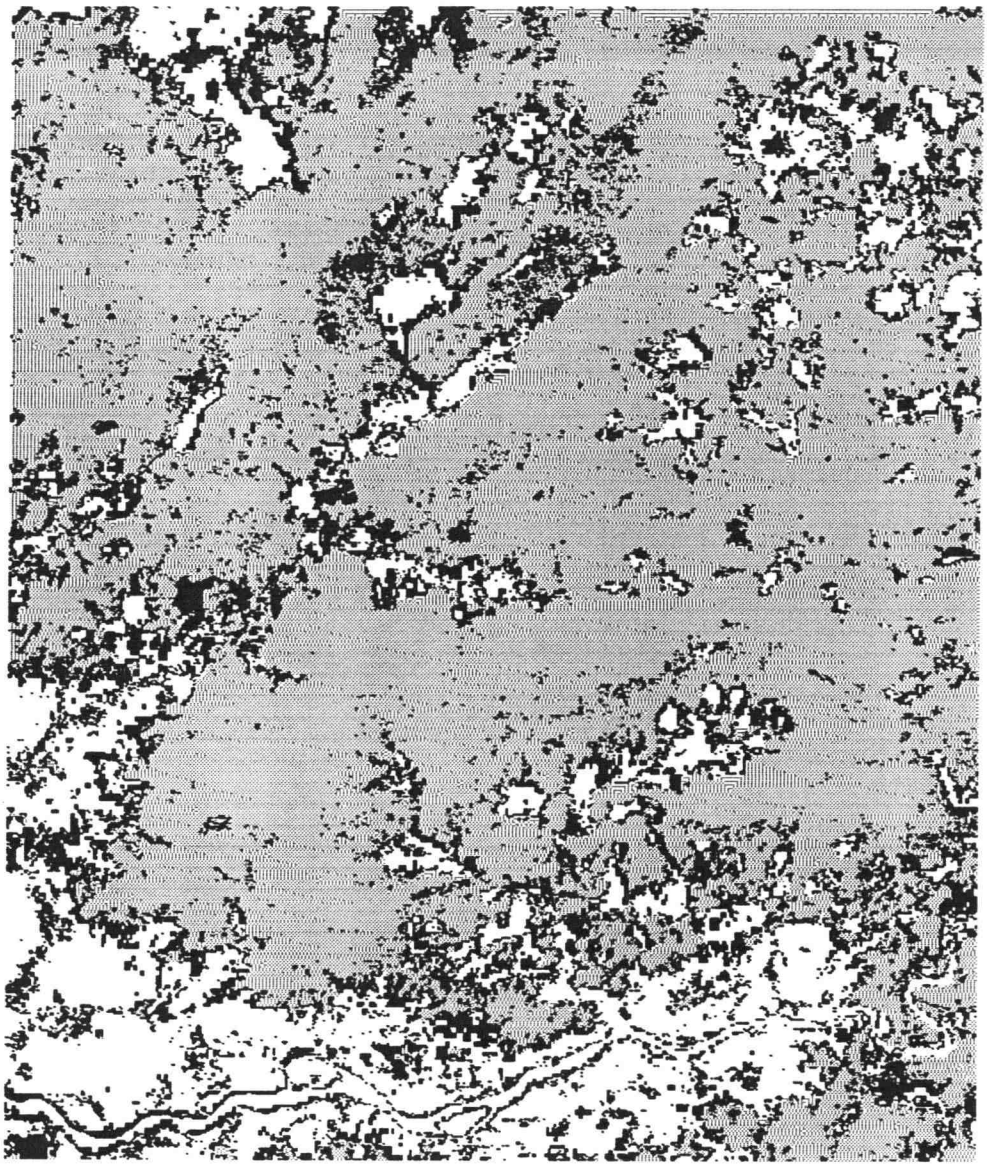

FIGURE 3. TEMPORAL CHANGE IN LION-TAILED MACAQUE HABITAT (Site 1)
(after overlaying of 1977 and 1990 sites)

0 miles 2

GREY = Unchanged habitat (19,659 ha) BLACK = Change in Habitat (4,980 ha)

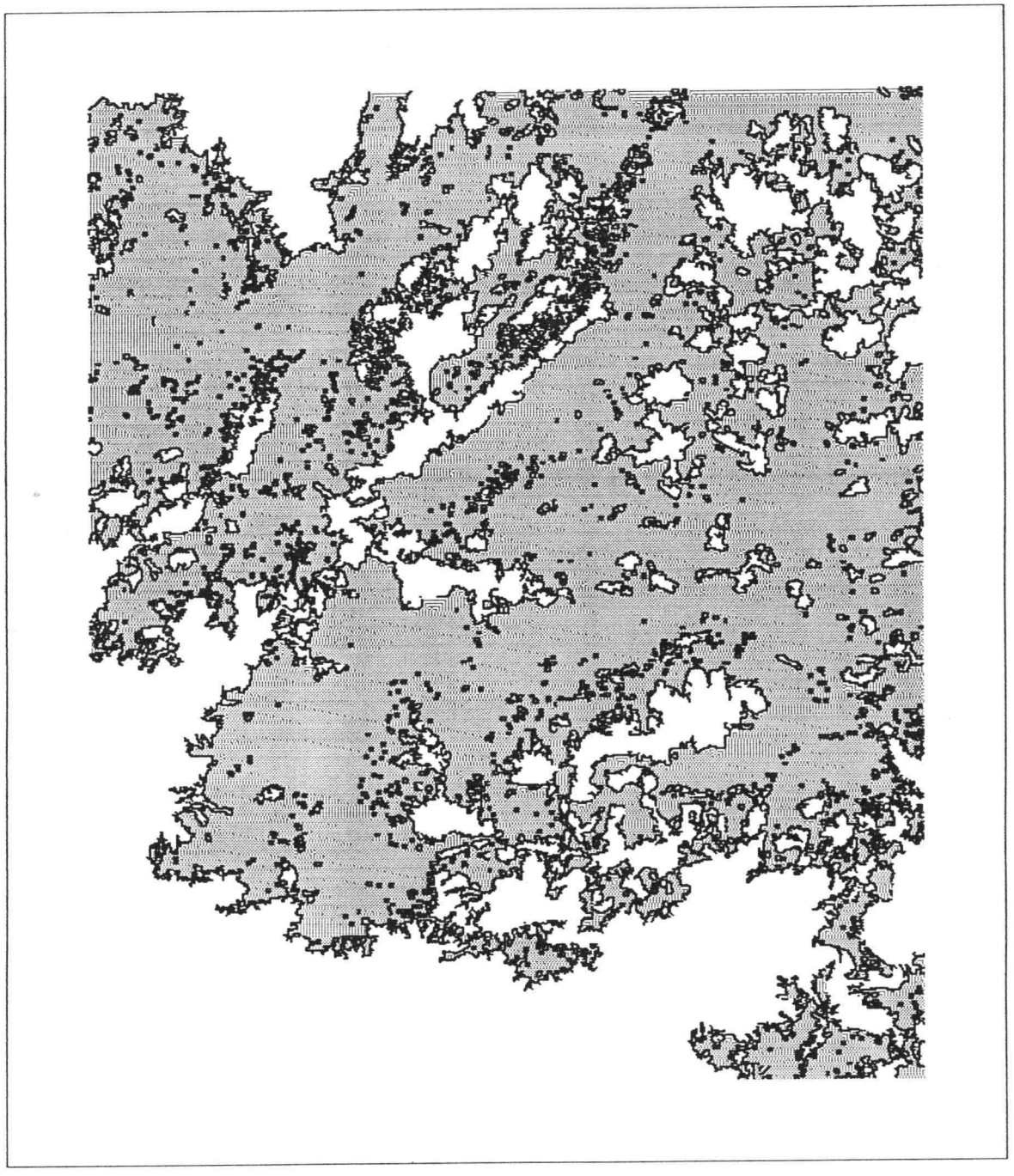

FIGURE 4. HABITAT OF LION-TAILED MACAQUES (SITE 1)
(after the removal of fragments smaller than 262 hectares and
calculating a buffer width of 645.74 meters)

0 miles 2

GREY = Core Area (15,600 ha) BLACK = Buffer (4,980 ha)

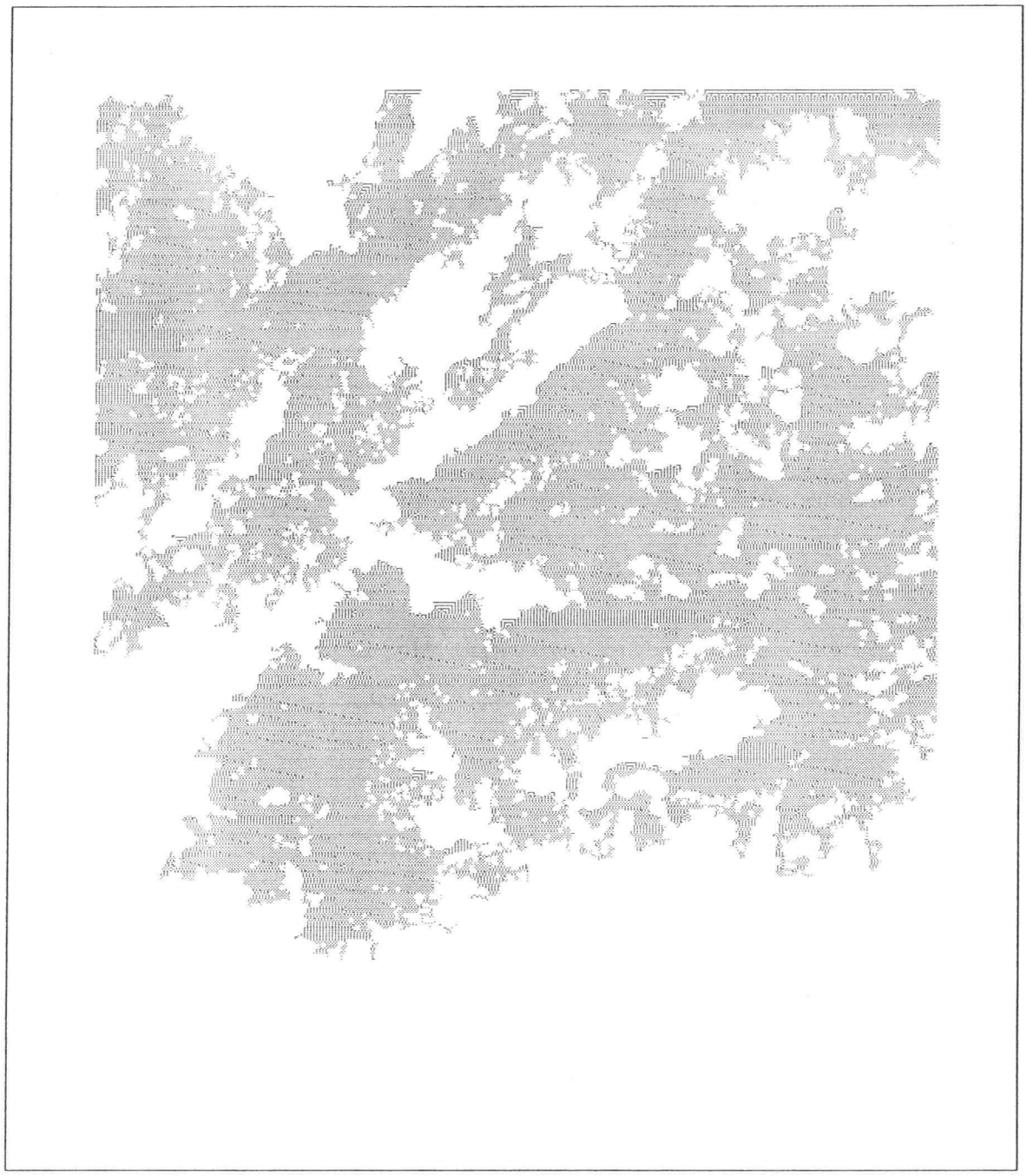

FIGURE 5 HABITAT PATCHES AVAILABLE FOR REINTRODUCTION OF LION-TAILED MACAQUES (SITE 1)

0 miles 2

GREY = Contiguous Patch 1 (14,718 ha)

FIGURE 6. TEMPORAL CHANGE IN HABITAT (SITE 2)
(after overlaying of 1977 and 1990 sites)

0 miles 2

GREY = Unchanged habitat (18,376 ha) BLACK = Change in Habitat (7,494 ha)

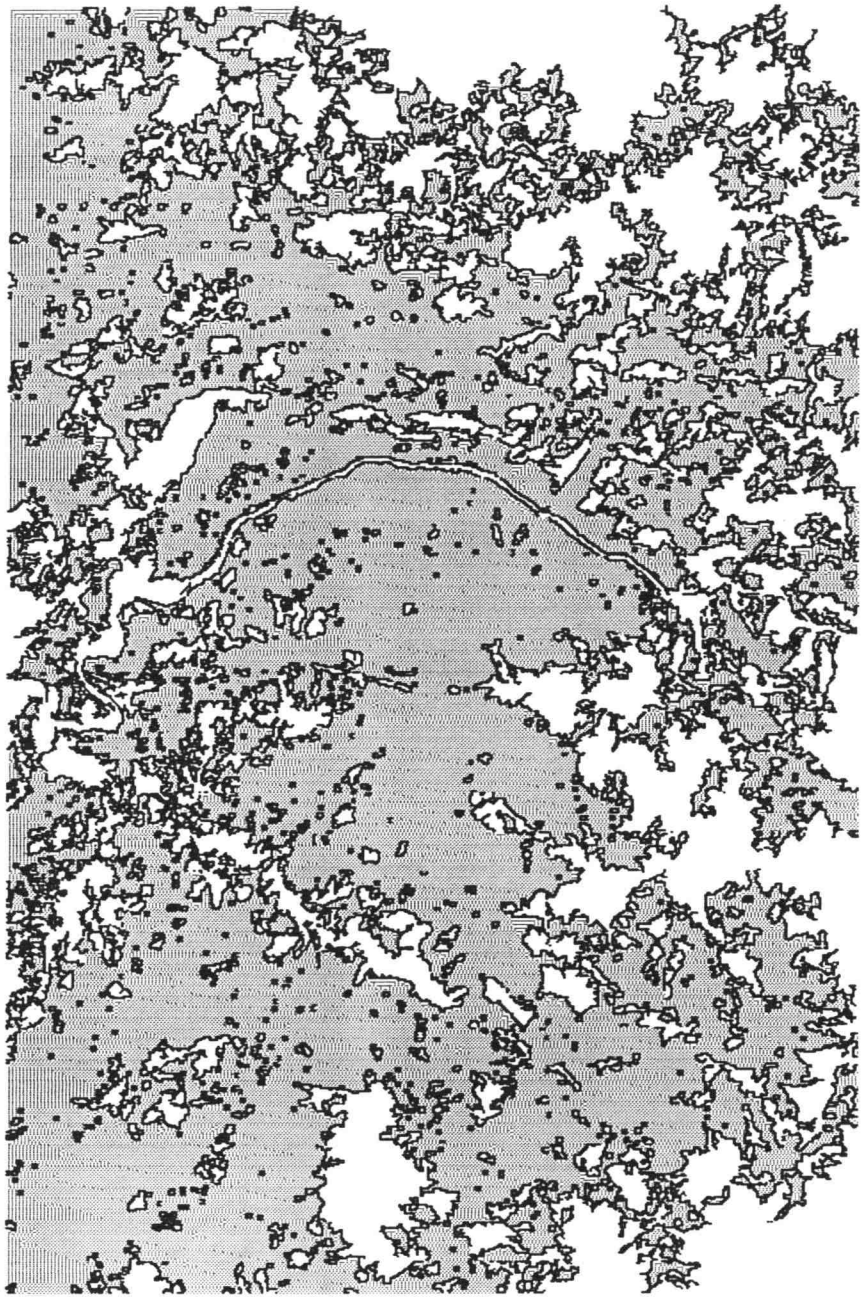

FIGURE 7. HABITAT OF LION-TAILED MACAQUES (SITE 2)
(after the removal of fragments smaller than 262 hectares and calculating a buffer width of 645.74 meters)

0 miles 2

GREY = Core Area (15,378 ha) BLACK = Buffer (5,300 ha)

FIGURE 8. HABITAT PATCHES AVAILABLE FOR REINTRODUCTION (SITE 2)

0 miles 2

GREY = Contiguous Patch 1 (4,267 ha) BLACK = Contiguous Patch 2 (9,087 ha)

contiguous patch of 14,718 ha in Site 1 (Figure 5) and two contiguous patches, separated by the Sharavati river, in Site 2 (Figure 8), 4,276 ha and 9,097 ha respectively. These were considered large enough for reintroduction of lion-tailed macaques (Table 4). Although large contiguous forests were present in 1990, the connectivity width in some areas was fairly narrow (< 0.5 km), making it susceptible to further fragmentation.

Table 4. Habitat available for reintroduction of lion-tailed macaques after removing fragments smaller than 262 ha

Category	Site 1	Site 2
Total Study Area	31,213 ha	30,561 ha
Number of Patches Available	1	2
Patch Size	Patch 1 = 14,718	Patch 1 = 4,267 Patch 2 = 9,087

DISCUSSION

By all accounts, lion-tailed macaques are obligate forest animals. As such, large scale deforestation and forest fragmentation are major threats to their continued survival. Conservation of this species may largely depend on the successful reintroduction of captive populations and the protection of existing habitat. However, before any reintroduction programs can be carried out, considerable attention must be given to (a) developing a detailed survey of the available habitat, (b) developing a detailed survey of lion-tailed macaque distribution, (c) estimating minimum viable population size, (d) the genetic considerations prior to reintroduction of captive populations, and (e) identifying the potential sites and cost of reintroduction.

Like many other regions of the Western Ghats, developing a detailed survey of both habitat and distribution of lion-tailed macaques in the study sites would be difficult to accomplish. Due to steep terrain, some regions of the habitat of lion-tailed macaques are poorly accessible. In Karnataka, the habitat of lion-tailed macaques, including most parts of the study area, are now within the Reserved Forests (Karanth 1992; Proctor 1986), thereby providing habitat protection for the species and thus making large-scale shrinkage of habitat less likely. Attempts should be made to include in the forest reserves those areas that are outside the reserves and yet contain lion-tail habitat.

According to Karanth (1992), hunting of this species above 13°N has not been a threat. As the study sites are well above this latitude, it is safe to assume that the only other pressure could be human activities that clear or inundate forest habitats. Karanth (1992) attributes the general deterioration and fragmentation of forest habitat in this region to the Sharavati project but also indicated the presence of substantial portions of large-scale areas that were free of habitat loss. Conversely, Karanth (1992) warned of the expanding human population nearby which might cause the disturbance of the lion-tail habitat. My results support his observations.

Minimum viable population (MVP), "the minimum conditions for the long-term persistence and adaptation of a species or population in a given place," (Soulé 1987:1), is an essential component of the conservation and management of lion-tailed macaques. To determine the viable population of a given species, numerous biotic and abiotic factors are essential (Koenig 1988; Soulé 1987). However, at present, knowledge of many components under the three fields of the population vulnerability analysis, as described by Gilpin and Soulé (1986:22) (population phenotype (PP), environment (E), and population structure and fitness (PSF)), are not available for lion-tailed macaques. Components such as dispersal and migration under PP, habitat quality under E, and Metapopulation structure and fragmentation and Saturation density under PSF likewise are not available for lion-tailed macaques. Therefore, it would be difficult to judge whether introduction of two groups of captive lion-tails sufficiently satisfy the conditions of MVP. However, it is important to note that a small number (such as reintroduction of two groups of lion-tails) may still play a

critical role in future conservation efforts (Soulé 1987). An earlier estimate by Frankel and Soulé (1981) suggested that at least 50 breeding individuals are necessary to avert inbreeding depression and loss of species during a short period of time. However, Hunter (1990:244) stated that "For population X to have a 95% probability of persisting for 200 years, it must have an effective population size of at least 675 individuals." Clearly these estimates differ substantially.

Preliminary research by Jolly and King (1985) suggests that the relatively high genetic variability of lion-tails is very similar to that of other macaque species. Gilpin and Soulé (1986:21) suggest that "captive populations must be kept above the MVP that assures retention of genetic variation and fitness." The worldwide captive population of lion-tailed macaques was estimated to be 341 in 1987 (IPPL 1991) and space for the captive population in zoos has decreased considerably in the recent years (Lindburg & Gledhill 1992).

Among other issues that Melnick (1990) raised in the action plan is the suitability of potential sites where conservation efforts would be focused. Although this issue requires detailed field study to assess the habitat quality, the results presented here demonstrate the prospects for conservation of lion-tail habitat and a pattern of fragmentation that infers that shrinkage of large patches is related to nearby human occupation. This relationship should be subjected to further verification by field studies. The remote mountainous locations present in the study sites (see spot elevation data in Figure 1) can act as safe havens for the reintroduction of the species. These areas are not easily accessible by the local

people, hence, it is assumed that these areas will act as natural preserves by the virtue of their topography.

The cost of reintroduction is an important factor in determining the success of any reintroduction project. Reintroducing lion-tails from outside the country (such as introducing from zoos in the United States) can be elaborate and expensive. According to Karanth (1992), it would cost about $30,000 to employ 50 guards to protect a 250-km^2 area containing lion-tails. The cost of a reintroduction program can be expensive, but so too is maintenance of large numbers of lion-tails in zoos (Conway 1986; Pearl 1992).

Although my results suggests the presence of large and contiguous habitat in both study sites, it is important to recognize that certain sections of the study sites are susceptible to further fragmentation through very narrow corridors, which I refer to as pinch points. These pinch points are areas where connectivity is very narrow. Habitat loss at these pinch points could potentially lead to significant reduction in the size of identified habitat patches and could jeopardize long-term survival of lion-tailed macaques. In Site 1 (Figure 5), the northeastern portion has a number of pinch points; in Site 2 (Figure 8), several pinch points can seen in south, southeast and central part of Patch 2. Also, it is important to note, in Site 2, the presence of Jog Falls. It is a premier tourist center and the highest waterfall in India, and may exert human pressure, including fuelwood extraction from lion-tails habitat.

The total study area of this research represents a small fragment of the Sharavathi Wildlife Sanctuary which is presently 431 km^2 and proposed to expand by

another 210 km^2 in the future. This is the least studied region of Karnataka, and contains many endemic flora and fauna. Apart from lion-tails, the region also has many known endangered mammalian and bird species. Although, the research presented in this paper is focused on the endangered lion-tailed macaques, the research could be used for assessing the habitat of other species.

The results of this study can be considered a first step toward the process of reintroducing captive populations of lion-tailed macaques to the northwestern rainforests of Karnataka, India. Before reintroduction, careful consideration should be given to various aspects of lion-tailed macaque ecology (such as population sizes, distribution and home range, habitat preferences, and disease resistance). Assuming that these conditions are met, I recommend, in Site 1, future reintroduction be made in the mid and south western region, centered around approximately 74°34′E 14°17′N, where the topography is rugged and the habitat not easily accessible by humans. It is also the least disturbed large habitat fragment. These areas are large and contiguous and can accommodate at least two groups (as has been planned for reintroduction from The San Diego Zoo and the Bronx Zoo). In Site 2, I recommend the reintroduction be made in the northern part of Patch 2, centered around approximately 74°45′E 14°16′N, where higher altitude and slope naturally protect macaques. These areas are safe and generally protected by virtue of steep slopes and an average elevation of 500 meters.

The above recommendations are based on factors such as the maximum distance from nearby villages, roads, high elevation, slope and aspect of the

topography and considering the fact that because the contemporary image used for this study is from 1990, there might have been further loss of habitat by the expanding human population in the region. The study sites selected in this research are potential sites for proposed reintroduction by zoos.

CONCLUSION

My lion-tailed macaque habitat fragmentation analysis using Landsat images suggests the continued presence of large and contiguous patches of habitat in the northwestern rainforests of Karnataka. The study also suggests that shrinkage of habitat has been occurring in and around the previously disturbed regions. Three potential sites; one in Site 1 and two in Site 2, are available for reintroduction of captive lion-tailed macaque populations. Although the study reveals potentially unfragmented sites, there is still a need to ground-truth (habitat verification) the area to further verify that these habitats remain suitable.

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