Status and Ecology of the Nilgiri Tahr in the Mukurthi National Park, South India

by

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(ABSTRACT)

The Nilgiri tahr (*Hemitragus hylocrius*) is an endangered mountain ungulate endemic to the Western Ghats in South India. I studied the status and ecology of the Nilgiri tahr in the Mukurthi National Park, from January 1993 to December 1995. To determine the status of this tahr population, I conducted foot surveys, total counts, and a three-day census and estimated that this population contained about 150 tahr. Tahr were more numerous in the north sector than the south sector of the park. Age-specific mortality rates in this population were higher than in other tahr populations. I conducted deterministic computer simulations to determine the persistence of this population. I estimated that under current conditions, this population will persist for 22 years. When the adult mortality was reduced from 0.40 to 0.17, the modeled population persisted for more than 200 years. Tahr used grasslands that were close to cliffs ($p < 0.0001$), far from roads ($p < 0.0001$), far from shola forests ($p < 0.01$), and far from commercial forestry plantations ($p < 0.001$). Based on these criteria I mapped the suitability of tahr habitat using a GIS and estimated that only 20% of the park area had >50% chance of being used by tahr. I used the GIS to simulate several management options to improve the quality of tahr habitat. Suitable habitat for tahr increased two-fold when roads within the park were closed to vehicular access. Similarly, removal of commercial forestry plantations also resulted in a two-fold increase of suitable habitat, and finally when both road access was restricted and commercial forests were removed, suitable tahr habitat increased three-fold. I used micro-histological analysis on tahr fecal pellets to determine food habits. Grasses constituted 64.2% of their diet. Five plant species (*Eulalia phaeothrix*, *Chrysopogon zeylanicus*, *Ischaemum rugosum*, *Andropogon* sp., and *Carex* sp.) accounted for 84.6% of the tahrs' diet. These species were found in higher densities in the grasslands of the north sector than the south sector of the park ($p < 0.001$). Predators such as leopard (*Panthera pardus*) and tiger (*Panthera tigris*), killed and consumed tahr.   Tahr constituted 56% of the leopards' diet and 6% of the tigers' diet. I estimated that leopards and tigers in the park killed and consumed 30 to 60 tahr per year, and this accounted for 19% to 38% of the tahr population. The tahr population in the park has undergone a decline, possible causes for this decline includes high mortality from predation and poaching and loss of habitat.

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INTRODUCTION

The Indian subcontinent is an area of rich diversity. Habitats include tropical lowlands, deserts, rainforests, and wetlands. Physiographic features range from flat plains, rolling plateaus, and ocean coastlines to the world's highest mountains. This range of habitats is home to a diversity of plant and animal species. India has about 7.6% of the world's known mammal species, 12.6% of known bird species, 6.2% of known reptile species and 4.4% of known amphibians (WCMC 1992). This natural faunal diversity and an even greater but unknown floral diversity, is superimposed on a rich diversity of ethnic groups, cultures, religions, and political parties. This human presence and the resulting pressures of economic development, present unique challenges to land-managers seeking to maintain this biological diversity.

One area of particularly high biodiversity in India is the Western Ghats (Table 1). The Western Ghats is a chain of highlands that extend from Bombay to the southern tip of India. It covers about 159,000 km^2 and has one of the last major tropical evergreen forests in India (Rodgers and Panwar 1988). There are seven national parks in the Western Ghats totaling 2,073 km^2 (1.3% of the region) and 39 wildlife sanctuaries covering about 13,862 km^2 (8.1% of the region, WCMC 1992). About 90 % of the area is under little or no protection from human exploitation. This region also is characterized by a high degree of endemism, and is recognized as a "hotspot" of biodiversity (Myers 1972).

The Nilgiri tahr (*Hemitragus hylocrius*) is endemic to the Western Ghats of South India. Tahr were once numerous on the Nilgiri Plateau (Davidar 1978) but have recently become restricted to its western edge. One sub-population in the Nilgiris (Glen Morgan, Fig. 1) was lost as recently as 1978 (Davidar 1978). Rice (1984) reported 17 tahr populations in South India (Fig. 2). Subsequently, additional populations were reported (Daniels 1987, Zachariah, Kerala Forest Department, pers. commun.).

To protect and increase tahr populations, the species' last stronghold in the Nilgiris was declared a sanctuary in 1982 under the Wildlife Protection Act of 1972 (Government Order. No. 240, Forests and Fisheries Dept., Dt. 8.3.1982). This area, Mukurthi National Park, located at the western border of the Nilgiri district, was believed to support about 450 tahr in the late 1960’s and 1970’s (Schaller 1971, Davidar 1978). From 1988 to 1991, The Nilgiri Wildlife and Environment Association surveyed the Park and reported a decline in tahr sightings (Fig. 3).

The reasons for the general decline in the Nilgiris and the more recent decline within Mukurthi National Park are unknown; however, habitat alteration and poaching were seen as possible causes. The goal of this study was to learn enough about the distribution, abundance, ecology, and factors that led to the decline of the tahr to develop an effective conservation program. My objectives were:

1) To determine the present population status, structure, distribution and future of the Nilgiri tahr in the Nilgiris

2) To determine the habitat used by Nilgiri tahr

3) To determine food preferences of the Nilgiri tahr

4) To quantify the impact of predators on the Nilgiri tahr population

STUDY AREA

Mukurthi National Park is located between 76° 20'E and 76° 37' E, and 11° 5'N and 11° 30' N in the Nilgiri District of Tamil Nadu, South India. It is in the Kundha Range in the southwest corner of the Nilgiri plateau (Fig. 1). The Kundha Range, which is part of the Western Ghats, rises steeply to an elevation of 2000 m from the Silent Valley, Nilambur Valley and the Octerlony Valley, creating an unbroken escarpment, except for the Sispara pass in the south.

The average elevation of the park is about 2400 m; the highest peak is Kollaribetta (2630 m). Other major peaks include Mukurthi Peak (2556 m) and Nilgiri Peak (2477 m). Steep escarpments, rocky outcrops, and sheet rock are common. Rocks primarily are granite. The dominant soil is red laterite soil, Region II, Ootacamund series (Neelakantan 1988).

Several small streams drain the area and the general slope of the area is towards the east and south. Mukurthi, Porthimund, and Upper Bhavani hydro-power reservoirs abut the park. There also is an intricate network of tunnels within the park that move water from catchment areas to these reservoirs.

Temperatures range from 0° C to 20° C. Annual rainfall on Mukurthi ridge averages 6330 mm (Lengerke 1977) but rainfall varies substantially seasonally and geographically (Fig. 4).

The monsoon dominates the annual weather cycle in Mukurthi. Commencing in June, southwest winds bring moist warm air from the Indian Ocean. This commonly is called the Southwest monsoon. Gale-force winds and dense mist accompany this monsoon and often restrict visibility to a few meters. The Southwest monsoon provides the park with 90% of its annual rainfall and continues until August. This season is followed by a season of light rainfall called the Northeast or receding monsoon. This season is followed by winter, which lasts from December to February. During winter, the temperatures drop to 0°C, and ground frost is common. Visibility is excellent due to the clear skies and dry atmosphere. Winter marks the beginning of the dry season when the park receives no rain. Summer or pre-monsoon extends from March to May. During this season, the park begins to receive scattered rainfall, as atmospheric moisture increases. Visibility begins to deteriorate, especially in the afternoons, when mist invades the park from the western edge.

Large mammals in the park include Nilgiri tahr, sambur (*Cervus unicolor*), barking deer (*Muntiacus muntjak*), wild boar (*Sus scrofa*), feral buffalo (*Bubalus* sp.), Asiatic elephant (*Elephas maximus*), tiger (*Panthera tigris*), leopard (*Panthera pardus*), Asiatic wild dog (*Cuon alpinus*), jackal (*Canis aureus*), jungle cat (*Felis chaus*), stripe-necked mongoose (*Herpestes viticollis*), otter (*Lutra* sp.), Nilgiri langur (*Presbytis johnii*), and bonnet macaque (*Macaca radiata*). During this study, I made the first known sighting of a sloth bear (*Melursus ursinus*) in Western Catchment I and gaur (*Bos gaurus*) in Bangitappal in October 1994. These individuals of both species were resighted on several occasions for about two months afterwards and then disappeared.

The natural vegetation in the park consists of vast stretches of rolling grasslands, interspersed with shola forests that occupy the depressions and valleys. Sholas are "Southern Montane wet temperate forest, Sub group II A/I; Type II A/C 1" (Champion 1936). Shola trees generally are < 10 m high and have dense, rounded crowns that form a continuous canopy. There is no marked differentiation into canopy layers (Shetty and Vivekananthan 1971). Species present include *Actinodaphne bourdillonii*, *Elaeocarpus recurvatus*, *Ilex denticulata*, *Ligustrum perrottetti*, *Litsea wightiana*, *Michelia nilgirica*, *Microtropis ramiflora*, *Pithecellobium subcoriaceum*, *Pittosporum tetraspermum*, *Shefflera racemosa*, *Symplocos pendula*, and *Syzygium arnottianum* (Shetty and Vivekananthan 1971). Trunks are covered with lichens, ferns, bryophytes, and orchids. Most sholas contain a stream; hence they are confined to sites with good drainage and persistent moisture. On the basis of species composition and structure, Homji (1969) described the mixed tree and shrub transition zone at the margins of the sholas as a separate physiognomic type. Species present in this zone include *Eurya nitida*, *Photina notoniana*, *Rhododendron nilgaricum*, *Rhodomyrtus tomentosa*, *Ternstroemia japonica*, *Turpina cochinchinensis*, *Berberis tinctoria*, *Gaultheria fragrantissima*, *Heydotis stylosa*, *Leucas suffruticosa*, and *Smithia blanda*. The transition from shola to grassland is usually abrupt.

The origin of the shola - grassland system is a matter of debate. Some argue that Pleistocene glaciation was responsible for pushing the Himalayan flora southward (Burkill 1924, Hora 1949, Vishnu-Mittre 1970, and Homji 1972). However, Blasco (1970, 1971) argued that intermountain migration was not due to direct contact between the various high peaks, but was caused by independent long-distance dispersal.

Vishnu-Mittre (1970) and Vasanthy (1988) conducted pollen studies in the Nilgiris. Vishnu-Mittre (1970) suggested that shola forests originated through gradual invasion of grasslands by woody plants starting about 35,000 years ago, at the time of last glaciation in the north. He suggested that the modern distribution of these forests in patches between folds of mountains is largely due to anthropogenic activity, such as fires. An opposing view was suggested by Vasanthy (1988), again based on pollen analytical studies. She argued that there was no evidence to suggest that grassland formations were a secondary development following sholas being degraded by anthropogenic activity, and that montane grasslands persisted in the Nilgiris since ca. 30,000 yr. B.P. Her study supported Ranganathan's (1938) view that the grasslands represent a climatic climax of the frost zone, while sholas represent a second climatic climax of the frost zone and these persist as relic communities.

Humans have had profound effects on the park. The Todas, an endemic hill tribe of the Nilgiris, used the area to graze their buffaloes. Dilapidated "munds" or corrals bear mute testimony to the former occupation by the Todas. These nomads moved into this area during the post-southwest monsoon months of August-September. To provide grass for their herds, they burned parts of the grasslands during the dry season. A record dating to 1117 A.D. contained the earliest mention of the Todas setting fires in the grasslands (Noble 1967).

When the British came to the Nilgiris in the early 1800's, they brought with them an avid interest in outdoor activities such as hunting and fishing. This interest resulted in the founding of the Nilgiri Game Association in 1877. In addition, the penchant for consumption of wildlife led to introductions of exotics such as the Rainbow trout (*Oncorhynchus mykiss*) and to bounties on predators such as dholes and otters. Species hunted included Nilgiri tahr, sambur, wild boar, leopard, and tiger. The Nilgiri Game Association issued licenses and monitored harvest levels. In addition, it hired an army of fish and game watchers to patrol the area for illegal activities. Hunting of Nilgiri tahr was restricted to saddlebacks (adult males). Tahr was a coveted game species.

In the late 1950's, construction of dams inundated several hundred hectares of grasslands, and the presence of hundreds of laborers may have disturbed the tahr. In the 1960's, much of the grassland was exploited by commercial forestry operations. Plantations of wattle (*Acacia decurrens*), pine (*Pinus pattula*), and blue gum (*Eucalyptus grandis*) took over substantial portions of the grasslands. In due course, most of these plantations, especially along the escarpment and cliffs, died out, probably due to gale-force winds, frost, and fire. The prescriptions for the park area varied over time, but often, since the early 1970's, included establishing plantations (Table 2).

STUDY ANIMAL

Nilgiri tahr belongs to the Family Bovidae and Subfamily Caprinae. This Subfamily includes 4 tribes: Sangini, Rupicaprini, Ovibovini and Caprini. Sangini includes the genera *Pantholops* and *Saiga*; Rupicaprini includes the genera *Nemorhaedus*, *Capricornis, Oreamnos* and *Rupricapra*; Ovibovini includes the genera *Ovibos* and *Budorcas*; Caprini includes the genera *Ammotragus, Pseudois, Hemitragus, Capra* and *Ovis*. Thus, the Nilgiri tahr is in the same tribe as aoudad, bharal, goats, and sheep. The genus *Hemitragus* includes three species, the Himalayan tahr (*H. jemlahicus*), Arabian tahr (*H. jayakeri*) and the Nilgiri tahr (*H. hylocrius*).

The Himalayan tahr inhabits a narrow strip along the southern flank of the Himalayas. The western limit of its distribution lies about 40 km west of Banihal pass in Pir Panjal (Stockey 1936). The eastern extent of its distribution is in Bhutan (White 1910, Fig. 5). Within this area, the tahr once had a continuous distribution, but it has become disrupted by human settlers (Schaller 1982). The Arabian tahr exists as a small population in the dry desert mountains of Oman (Fig. 5). The Nilgiri population is the northernmost of the Nilgiri tahr range, while the Thiruvannnamali population is the southern limit of its distribution (Fig. 2). The Nilgiri tahr is the world's southernmost population of naturally occurring caprids, and the closest to the equator.

The Nilgiri tahr was first named *Kemas hylocrius* by Ogilby in 1838 (Lydekker 1913). In 1842, Gray changed its name to *Capra warryatto,* thus including it with goats such as ibex (*Capra ibex*) and markhor (*Capra falconeri*). Warryatto is the English rendition of the local Tamil name of the Nilgiri tahr “Varai adu”. “Varai” in the local language of Tamil refers to cliffs, and “adu” refers to a goat, thus the Nilgiri tahr was referred to as the cliff goat. Subsequently, in 1852, Gray changed its genus to *Kemas* and reassigned it the name *Kemas warryato*. In 1859, Blyth included the Nilgiri tahr in the genus *Hemitragus*, naming it *Hemitragus hylocrius* (Lydekker 1913), the name that persists to date.

Fully-grown male Nilgiri tahr stand 100 cm at the shoulder and weigh 100 kg (Schaller 1971). These are known as saddlebacks. Saddlebacks are deep chocolate brown in color, and almost black on front of fore and hind legs, shoulder, side of the abdomen, side of the face and front of the muzzle (Rice 1984). They also possess a white facial stripe which starts from the forehead and continues towards the corner of the mouth, just anterior to the eyes, white carpal patches on the front and outside of the forelegs, and a prominent silver saddle. Females, on the other hand, are shorter and lighter than the males. They stand 80 cm at the shoulder and weigh 50 kg. The females are almost uniformly gray, and their carpal patch is black. Facial marks are present, but are faint (Rice 1984). Both sexes possess horns that curve uniformly back, and have no twist. Horns in males are heavier than in females and reach a length of 40 cm, while horns in females reach a maximum length of 26 cm. Horns are covered with numerous fine crenulations. Between the crenulations are more evident annual rings.

CHAPTER 1: POPULATION STATUS AND COMPOSITION

INTRODUCTION

The International Union for the Conservation of Nature and Natural Resources classified the Nilgiri tahr as vulnerable (Goodwin and Holloway 1972) and the Wildlife Act of India (1972) classified it as a Schedule I species, a category meaning that the species is under the imminent threat of extinction. Nineteen populations of the Nilgiri tahr have been identified in the Western Ghats (Rice 1984, Daniels 1987, Zachariah pers. commun., Fig. 2). The Mukurthi population is the northernmost population.

Mukurthi National Park is the last stronghold of the tahr in the Nilgiris. It was estimated to contain 450 individuals in the 1970's (Schaller 1971, Davidar 1976, Rice 1984). In the late 1980's, visitors to the park began to notice a decline in sightings of tahr and suspected that the population had declined. My primary goal was to determine the current population size of the Nilgiri tahr in the Mukurthi National Park and the dynamics of this population.

METHODS

Historical Abundance and Distribution

To determine the historical abundance and distribution of Nilgiri tahr on the western edge of the Nilgiri plateau, I reviewed published papers, reports of surveys, and hunter accounts. In addition I interviewed naturalists, hunters, and shikaris (game watchers) who frequented this area since the 1960's.

Present Abundance and Distribution

To determine the present status of Nilgiri tahr in the Mukurthi National Park, I conducted foot surveys, oral interviews, a three-day census and total counts. When I sighted tahr, I classified them into sex and age classes based on body size, pelage color, and horn size. I used the six classes described by Schaller (1971), with modifications and details from Rice (1984, Table 3). In the young age class, I included all tahr that I sighted that were less than a year old. The actual number of young sighted was used in estimating the population size. However, because I probably failed to detect animals that died in the first month of life, while computing the mortality rate for the young age class, I estimated the number of young by assuming that 90% of the adult females gave birth each year (Schaller 1977, Rice 1988).

Foot Surveys

I used foot surveys primarily to obtain the best estimate of the population size. For the foot survey, I divided the 78 km^2 park into 5 sectors (Fig. 6). The first sector included Pandiar top, Nilgiri Peak, and Devabetta. The second sector included Peechakal bettu, Peechal bettu, Chinna Mukurthi and, Mukurthi Peak. The third sector included Western Catchment III (WC III), Western Catchment II (WC II), and Chattipara. The fourth sector included Western Catchment I (WC I) and Bangitappal. The fifth sector included Nadugani, Sispara, and Kinkerhundi. I traversed the area within a sector during the day, walking along ridge tops and scanning the grasslands for tahr using 10x50 binoculars and a 60 mm spotting scope. In addition, I established 16 observation points near cliffs and observed tahr foraging areas (Fig. 7). Observation points were manned from dawn to dusk, and tahr could be observed without disturbing their normal activity.

I plotted all visual locations of tahr on 1:15,000 scale Survey of India topographic maps. Group composition (sex- and age-structure) was recorded when possible. To estimate the population size, I used the highest number of tahr sighted as a single group in an area. This group also had to have all individuals aged and sexed to be included in the count. The sampling effort in the five sectors was not constant due to variations in accessibility and weather conditions. I attempted to visit each sector once every two months, however.

Oral Interviews

During the first year of the study, I asked Tamil Nadu Forest Department personnel and other frequent visitors to the park, such as fuelwood extraction laborers, tourist guides, and naturalists, to report all sightings of tahr. I made follow-up visits to locations mentioned by the respondents to check their sightings.

Three-day Census

I conducted a three-day census to estimate the population size of the Mukurthi population. The three-day census covered all parts of the park simultaneously on 1 to 3 October 1993. I divided the park and its surrounding areas into 16 sectors (Fig. 7). Crews of three to four members, including a forest department employee who was familiar with the area, surveyed each sector. All participants of the census (enumerators) were trained to use compass and map, to identify mammals, and were taught the census method. Enumerators were to follow a pre-determined route. The routes were placed so they would not overlap and enumerators walked along ridge tops to maximize the area scanned. The census was conducted from 6:00 a.m. to 6:00 p.m. on the first two days and from 6:00 a.m. to 12:00 noon on the third day. Enumerators were asked to remain stationary on sighting a tahr and to wait until the animal passed out of sight. Age, sex and locations of the tahr were recorded on data sheets and maps. The habitat types where tahr were spotted also were recorded. Data on the number of tahr sighted each day were summarized and analyzed using the outer-bound method (Robson and Whitlock 1968).

Total Count

I replicated Davidar’s (1976) method in order to compare my results with his. I divided the park into five sectors (Fig. 6), identical to the sectors used in the foot surveys. Each sector was searched simultaneously by two groups of observers. Each group consisted of three observers. One group searched the western edge while the other walked along the eastern edge of the park. To avoid observer bias, the groups were interchanged the next day. I conducted this count for two successive years, from 17 March to 2 April 1994 and from 20 April to 9 May 1995. Each sector was enumerated on two successive days. Survey effort (time period) in each sector was similar to the time spent by Davidar (1976) in each sector. In larger sectors, a third group was used to survey the area between the eastern and western edges of the park. The total count involved six observers who had served as technicians on this study and had previous experience searching for tahr.

I recorded all tahr sightings during the survey period. I eliminated sightings where I suspected a possibility of double counting. These included multiple sightings of tahr in the same area or with the same group composition.

Productivity and Mortality

To determine the population structure of tahr in the park, I used data from my foot surveys conducted in 1994 and 1995. I did not use the data from 1993, since I feel that in

1993 I did not locate all groups of tahr. However, I substituted the number of young sighted during the foot surveys with the estimated number of births, where I assumed that 90% of the adult females gave birth each year (Schaller 1977, Rice 1988). I estimated mortality during the first year of life by comparing the number of yearlings counted in 1995, with the assumed number of kids born in 1994 based on this natality rate. I estimated the yearling mortality rate by comparing the number of yearlings sighted in 1994 with the estimated number of 2-3 year-old light brown males.

To estimate adult mortality, I examined the difference in average numbers between light brown and dark brown males. However, light brown males contain two age classes: animals 2-3 years old, 3-4 years old. Because I did not know the actual numbers in these two age classes, I estimated adult mortality interactively, starting with the assumption that the numbers in the two age classes were identical, and subsequently applying the estimated mortality to adjust the estimated numbers in each age class, until the mortality rate estimates stabilized (Appendix A).

Rate of Change

I calculated the instantaneous rate of change (r) and annual finite rate of change (λ) using the algebraic form of the exponential growth equation ($N_t = N_o e^{rt}$), and $\lambda = e^r$. The initial population size (N_o) was derived from Davidar's 1975 population estimate, and N_t was the number of tahr sighted during the total count conducted in 1994. The time interval (t) was the time elapsed between the two population estimates i.e., 19 years.

Projected Abundance

I used several models and scenarios to simulate the persistence of the Nilgiri tahr population in the Mukurthi National Park. In the first model, I used the estimated instantaneous rate of change that was calculated based on the change in number of tahr sighted by Davidar in 1975 and the number of tahr sighted during the foot survey I conducted in 1994. Using the estimated instantaneous rate of change, I calculated the time until the population size was zero or time to likely extinction.

In the second model, I calculated the population trajectory based on the estimated age-specific natality and mortality schedule. It was, therefore, possible to alter these rates to simulate the effect of changes in age-specific mortality or natality rates project the outcome of that management strategy on the population. Several scenarios were produced.

This program was based on several assumptions:

(i) Tahr are seasonal breeders.

(ii) All mortality occurs outside the breeding season (only the young that are weaned are counted for the first age class). This eliminates those individuals that die in the uterus or early in life.

(iii) Mortality rates for males and females are similar.

(iv) Mortality rates are constant for adults.

(v) Mortality and reproductive rates do not change significantly over time.

I used this deterministic model to simulate 4 different scenarios. In the first scenario, I simulated the fate of the Mukurthi population under the current conditions, assuming that 90% of the females produced young, and using my estimates of the current mortality rates for the young age class and adult age class. In the second scenario, I retained all parameters similar to the first scenario but reduced the mortality rate in the young age class to match the mortality experienced in the Eravikulam population which is thought to be increasing (Zachariah, Kerala Forest Department, pers. commun.). In the third scenario, I only reduced the mortality rate for the adult age class to equal that of the Eravikulam population. In the fourth scenario, I used the initial population sizes of the Mukurthi population but used mortality rates that were observed in the Eravikulam population for both the young and adult age class.

RESULTS

Historical Abundance and Distribution

Davidar surveyed the entire park and sighted a total of 292 tahr in 1963 (Davidar 1963) and 334 tahr in 1975 (Davidar 1976, Table 4). Schaller (1971) only surveyed the Mukurthi Peak area and Bangitappal in 1969. In these areas he sighted 176 tahr. Based on their sightings, Schaller (1971) and Davidar (1976) both estimated the population of tahr within the park at 450 individuals, arbitrarily accounting for the unseen tahr.

Davidar, in both his surveys of 1963 and 1975 did not record any tahr in the Nilgiri Peak area. Davidar in 1963 sighted 79 tahr in the Mukurthi sector (27% of sightings);

Schaller (1971) also reported similar numbers from this area (Table 4). However, when Davidar resurveyed the Mukurthi area in 1975, he saw only 45 tahr, which accounted for only 13% of the tahr seen in park (Fig. 8). In the other sectors, Davidar observed fewer tahr in 1975 than in 1963, except for the Nadugani sector (Table 4). In Nadugani, Davidar saw 65 tahr in 1963, accounting for 22% of the population, but in 1975, he saw 207 tahr accounting for 62% of sightings (Fig. 8). Radcliffe (pers. commun.) also observed a greater abundance of tahr in the Nadugani area in the 1970's than in other areas of the park. Shikaris (game watchers), who frequented the park in the late 1960's and 1970's reported that large groups of tahr (60-70 individuals) were sighted in the Chattipara and Nadugani areas (Fig. 6). They also reported that small groups of 5-10 tahr often were sighted in the Peechakal bettu area (behind Mukurthi fishing hut) and Upper Bhavani area (Fig. 6).

Elsewhere in the Nilgiris, tahr were reported from Glen Morgan, on the northeastern edge of the Nilgiri plateau, about 20 km from the Mukurthi National Park (Fig. 1). Davidar recorded this population in 1963. Local Shikaris claim that this population remained until the late 1960's and contained about 20 animals. Subsequent surveys by Davidar in 1975 and the Nilgiri Wildlife and Environment Association in 1984 and 1987, found no tahr in this area (Radcliffe pers. commun.). Local tribals, the Todas, claimed sightings of tahr as recent as 1995. My surveys of this area, both in 1994 and 1995, did not reveal the presence of tahr, despite spending 318 observer-hours conducting these surveys. I found that in both of these cases local people had apparently misidentified barking deer as tahr. When I showed local people in these areas pictures of several ungulates including barking deer and tahr, they consistently misidentified barking deer as tahr (n = 5).

Present Abundance and Distribution

Foot Surveys

Using foot survey data from 1995, I estimated the population of tahr within the park to be about 154, with a density of 1.95 tahr/km^2. I counted 52 tahr in the Nilgiri Peak sector in 1995 and they represented 33.5% of the population. In the Mukurthi Peak sector I counted 21 tahr (14 % of the population). In the Western Catchment sector I counted 58 tahr (37.3% of the population). Within the southern sectors of Bangitappal and Nadugani, I counted 9 and 14 tahr that accounted for 6% and 9% of the population respectively. The population in these areas was considerably lower than the records of Davidar (1963, 1976) and Schaller (1971) (Table 4).

Three-day Census

A three-day census was carried out with 53 observers. We enumerated 119 tahr on the first day, 64 tahr on the second day and 19 tahr on the third day (Table 5). Using the outer- bound method (Robson and Whitlock 1964), I estimated that the park and its surrounding areas contained between 174 to 1164 tahr by placing 95% confidence intervals.

Total Count

Total counts were conducted from 17 March to 2 April 1994 and were repeated again in 1995 between 20 April and 9 May.

In 1994, my assistants and I spent 597 observer-hours conducting the total count and sighted 102 tahr or 0.17 tahr/observer-hour. The highest sighting average was in the Pandiar sector, where we spent 159 observer-hours and sighted 53 animals or 0.33 tahr/observer-hour (Table 6). In the Bangitappal sector we sighted a single tahr after spending 60 observer-hours or 0.016 tahr/observer-hour, which was the lowest sighting average (Table 6).

In 1995, we spent 580 observer-hours conducting the total count and sighted 76 tahr with a sighting average of 0.13 tahr/observer-hour (Table 6). Pandiar sector continued to have the largest concentration of tahr, where we sighted 35 tahr in 125 observer-hours or 0.28 tahr/observer-hour. In the Nadugani sector we spent 86 observer-hours and sighted 10 tahr (0.11 tahr/observer-hour). This last sector was the least productive in 1995 (Table 6).

Using data from foot surveys conducted in 1995, I estimated that young accounted for 16%; yearlings, 16%; adult females, 40%; light brown males, 18%; dark brown males, 2%; and saddlebacks, 8% of the population (Fig. 9). The ratio of young per hundred females (100F) in Mukurthi was fairy constant among years, varying from 42.2 to 47.3 between 1993 and 1995 (Table 7). In this study, I was unable to document live births of tahr. I estimated that the tahr counted in the young age class represented animals that were over three months and below one year of age. The ratio of yearlings to 100F, also was fairly constant over the study period, varying between 38.5 to 42 (Table 7).

The young :100 female ratio in the Nilgiris, Eravikulam National Park and Grass Hills showed great variability over the years (Table 7). It ranged from 31.7 to 88.5 in the Eravikulam National Park, where the population is thought to be increasing and in Mukurthi it ranged from 34.4 to 75.5 (Table 7). Rice (1988) reported that between 1978 and 1980 in Eravikulam National Park, the average ratio of young: 100 females was 42.1.

Productivity and Mortality

The number of young in 1994 was estimated based on the assumption that 90% of the adult females gave birth. Thus, I estimated that the Mukurthi population contained 50 young in 1994. In 1995, I counted 22 yearlings during the foot surveys, a decrease of 56% in this cohort. Thus a mortality rate of 0.56 or 56% is estimated for the young age class. I also estimated a mortality rate of 0.04 or 4% (Table 8) for the yearling age class, and a mortality rate of 0.40 or 40% for the light brown male age class (Table 8), which I assumed represented the average adult mortality.

Rate of Change

I determined the instantaneous rate of change for the tahr population in the Nilgiris to be -0.038. The initial population size (N_0) was: 334 tahr sighted by Davidar (1976) and N_t was the number of tahr I sighted during the total count in 1994 (102 tahr). I also determined the annual finite rate of increase (l) as 0.94.

Projected Abundance

Based on the instantaneous rate of increase, I estimated that it would take this population 76 years to reach a population size of zero or extinction. Using deterministic models I estimated that under current conditions, when the mortality rate for the young age class is 0.56 and the adult mortality is 0.40, the modeled Mukurthi population persisted for 22 years (Fig. 10). In the second scenario, when the mortality rate for the young age class in Mukurthi was reduced to match the mortality rate of the young age class in the Eravikulam population of 0.37, I estimated that the Mukurthi population would persist for 27 years (Fig. 11). In the third scenario, I altered the adult mortality rate to equal the mortality rate experienced by the Eravikulam population (0.17), while keeping the mortality rate for the young age class at 0.56. In this model I found that the population of tahr did not reach extinction in the next 200 years (Fig. 12). In the final scenario, I used the mortality rates of 0.37 and 0.17 for the young and adult age class, respectively, experienced by the Eravikulam population and found that the population experienced exponential growth (Fig. 13).

DISCUSSION

Present Abundance and Distribution

I used several census methods to estimate the current population size of the Nilgiri tahr in the Mukurthi National Park. I think the foot surveys conducted in 1995, when I estimated the population size as 154 individuals, was the most reliable estimate of this population. I spent 2,128 hours in 1995 conducting these surveys and was also able to obtain detailed group composition counts. Because I repeatedly obtained the same sex and age composition of each groups in the various areas, I feel confident that I had seen all or most animals.

I also conducted total counts in 1994 and 1995. These counts followed methods that were similar to those used by Davidar in 1975. In this method, my technicians and I walked the entire park spending two days in each of the five sectors for a total of 10 survey days. The time we spent searching for tahr in each of these sectors was similar to the time spent by Davidar in each sector. I used the total counts to compare my results with those of Davidar. In 1995, the total count was conducted a month later than Davidar's 1975 counts. In addition, the early onset of the monsoon reduced visibility and hampered field work, thereby reducing our chances of seeing and counting all tahr. This may explain our sightings of only 76 tahr during the total count of 1995. However in 1994, when the total count was conducted in March, the visibility was good (< 2 km), and I feel that the good visibility improved our chances of seeing and counting all tahr. During the 1994 total count we sighted 102 tahr. The shorter duration (17 days) and intensity (597 observer-hours) resulted in a lower total than the more intensive foot surveys.

A three-day census was conducted in 1993 and involved 53 observers. This was part of an annual survey conducted cooperatively by the Forest Department and NWEA. The observers were not trained biologists, but were instead volunteers from the NWEA and local college students. This census was conducted over a period of three days. On the first day, 119 tahr were sighted, and on the second day, 64 tahr, and on the third day, 19 tahr were sighted. This dramatic decline in sightings on successive days suggests that the large number of people in the survey crew may have been driving the tahr into hiding. During my observations on the tahr in this study, I observed that tahr were skittish and abandoned areas where humans were present. In view of this, I feel that the tahr in the park may have abandoned the census sectors and moved away from the grasslands. Based on my observations of tahr subsequent to the census operation, I feel that the tahr may have descended the escarpment on the western edge of the park, and sought refuge under rock overhangs. Under these rock overhangs and in crevices, the tahr are not visible to observers on the grasslands above and probably would have been missed by census participants.

I used the outer-bound method of Robson and Whitlock (1968) to estimate the population size using data from the three-day census. This procedure uses the two highest counts to estimate the population, accounting for the fact that some animals are missed during each count. If the second highest count was artificially depressed by disturbance, it would have led to an overestimate of the population size and inflation of the confidence interval. Thus I feel that the outer-bound estimate of between 174 and 1164 tahr is probably higher than the true population.

The fact that all three census methods provided estimates in the 100-200 range supports the idea that the population size is in this order of magnitude. It appears that the population of tahr in the park has declined from 334 tahr actually seen by Davidar in his total count conducted in 1975.

There has been a change in the distribution of tahr within the park. In 1975, when Davidar conducted his survey he found 74% of the tahr population in the south sectors of the park, but during this study I found that the south sectors contained only 16% of the population. The large concentration of 207 tahr in the Nadugani and Sispara sector reported by Davidar (1976) may have moved in from other areas of the park due to a large fire that had promoted fresh growth of grasses there (Davidar 1976).   I observed a similar response to fire during this study. In 1993, the area above Kallhundi halla (Yella malai) had not burned, and I did not record any tahr using this area. However, I recorded tahr closer to Nilgiri Peak, 2 km to the west, that same year. During the summers of 1994 and 1995, fires burned the Kallhundi halla area and after the first rains in March 1994, I found a concentration of 35 tahr in this area. Since I was unable to identify individual tahr, I am not sure from where these tahr colonized this area. However, I found the number of tahr using Mukurthi Peak, which was about 3 km away, dropped from 38 tahr in 1993 to 26 tahr in 1994. Thus I suspect that the fire at Kallhundi halla, and the subsequent flush of grass may have enticed the tahr to move in from the Mukurthi Peak area. During 1994, the area east of King Dhar in Western Catchment III also had extensive fires, but I did not observe the King Dahr tahr herd to move into this freshly burned area. This burned area, though it may have provided good forage, had no cliffs in its vicinity, and hence, may not have been used by tahr. Escape cover is important for mountain ungulates (Schaller 1977, McQuivey 1978, Tilton and Willard 1982, Van Dyke et al. 1983, Fairbanks et al. 1987). Tahr in my study area stayed within a mean distance of 145 m from cliffs (see Chapter 2: Habitat Use).

Rate of Change

Davidar sighted 334 tahr during his survey in 1975, but added an arbitrary number of tahr to account for the tahr that he might have missed. In order to compare my results with his, I used the results from the total count I conducted in 1994. It appears that there has been a 67% decline in the population since 1975. In addition, I used these total count data to determine the annual finite rate of increase (λ) as 0.94 and the instantaneous rate of increase as -0.038, which suggests that the population declined between 1975 and 1994.

The tahr population in the Nilgiris may have experienced low population levels in the past. As early as 1954 (and again in 1958, 1962 and 1969) the Nilgiri Game Association, which issued game licenses and monitored harvest levels, closed the hunting season on tahr (Fig. 14) since they perceived that the tahr population was dangerously low. There is no record for population estimates for these years, however.

Productivity and Mortality

Assuming a 90% birth rate (Schaller 1977 and Rice 1988) for tahr, I estimated a mortality rate of 0.56 for the young age class in Mukurthi. Rice (1988) estimated a mortality rate of 0.37 for an increasing population of Nilgiri tahr in the Eravikulam National Park (Table 8). For the Himalayan tahr in New Zealand, Caughley (1970) reported several mortality rates in different populations. In an increasing population, he estimated mortality rates for the young age class as 0.37, while in a stationary population, the mortality rate was 0.53 and in a declining population the mortality rate was 0.59 (Table 8).

I estimated a yearling mortality rate of 0.04 in Mukurthi. Previous studies on Nilgiri tahr by Schaller (1977) and Rice (1988) reported that mortality was the highest in the yearling age class. I used Rice's (1988) estimate of the age structure in the Vaguvarai sub-population to recalculate mortality rates in his study area and estimated a mortality rate of 0.41 for the yearling age class in the Vaguvarai sub-population in the Eravikulam National Park. Caughley (1970) reported a yearling mortality rate of 0.029 in an increasing population of Himalayan tahr, and a yearling mortality rate of 0.024 in a stationary population (Table 8). The mortality rates observed in this study are comparable to Caughley's 1970 estimates, but unlike the rates observed by Rice (1988). However, the Himalayan tahr in New Zealand are in a predator-free environment and may therefore have lower mortality rates than both the Eravikulam and Mukurthi population.

Adult mortality in Mukurthi National Park is high, with an estimated average rate of 0.40, compared to 0.17 in Eravikulam (Rice 1988). Caughley (1970) reported an adult mortality rate of 0.10 in an increasing population and 0.20 in a stationary population of Himalayan tahr. Thus, overall, the Nilgiri tahr population in Mukurthi appears to exhibit high mortality in the young and adult age classes. The mortality rates that I estimated for the different age class are a rough estimate at best, more accurate estimates of the mortality rates are necessary to better understand the dynamics of this tahr population.

Projected Abundance

Deterministic modeling based on my estimates of age-specific mortality rates and on the assumption of 90% natality rates suggested that, if no management actions are taken, the Mukurthi population will be extinct in 22 years. In this aspect of the study, I did not attempt to incorporate the influence of habitat restoration, environmental stochasticity or genetic influences. In another aspect of this study (Chapter 2: Habitat Use), I have shown that specific management actions could improve the quality of tahr habitat. This habitat improvement may increase the persistence of the Mukurthi tahr population.

The mortality rate experienced by the young and adult age classes in Mukurthi is higher than in other populations of the Nilgiri tahr. Of the age-specific mortality rates, I found that the adult mortality rates were higher than in other populations of tahr.

Therefore, a management strategy to reduce adult mortality is of primary importance. In another aspect of this study (see Chapter 4: Predation Rates), I found that predators such as the leopard and tiger could alone account for most or all of the mortality experienced by this population of tahr. Furthermore, humans normally target adult animals to be poached. Based on my interviews with the local people, it appears that in the early 1980's, when the area was declared as a National Park, poaching was rampant due to infrequent patrolling by the Forest Department personnel. Also during my surveys in the Varagapallam area in 1994 and 1995, I encountered several signs of poaching, such as snares, spear-heads and gun shots. Interviews with local people suggested that poachers from the Pudur and Attapadi villages in the Attapadi range (Fig. 1) ascend to the plateau during the dry season and burn some portions of the grassland. The flush of fresh grass in these burned areas entices herbivores including tahr to move into these areas were they are poached. A similar mode of poaching also was recorded by Davidar (pers. commun.) in the Nadugani area during the 1970's.

The Mukurthi tahr population is an isolated population with no corridors linking it to other populations, thus preventing immigration of tahr. Further, the existing habitat within the park is highly fragmented, with patches of suitable tahr habitat isolated from other patches by shola forests and commercial forestry plantations (see Chapter 2: Habitat Use). This isolation of the tahr herds in Mukurthi could have undesirable genetic consequences, further reducing the chances of long term persistence of this population. Moreover, fragmentation of the grasslands by commercial forests may have brought the predators closer to the tahr, resulting in more frequent encounters between tahr, and leopards and tigers, increasing the predation rate.

CHAPTER 2: HABITAT USE

INTRODUCTION

It is important that wildlife managers understand the habitat requirements of the Nilgiri tahr, which has reduced its distribution in the Nilgiris and is now restricted to the western edge of the Nilgiri plateau. Habitat requirements of the Nilgiri tahr are not well understood. General characteristics of tahr habitat were qualitatively described by Willet (1969), Schaller (1971), Davidar (1978) and, Rice (1984). They emphasized the importance to tahr of high altitude open grasslands and cliffs.

My objectives were 1) to describe quantitatively the habitat used by tahr, 2) to develop a model that described habitat use by tahr, 3) to incorporate the model into a geographic information system (GIS) of the park to distinguish preferred habitat from avoided habitats and to map potential tahr habitats and, 4) to assess the impact of management options on the suitability of tahr habitat.

METHODS

To assess habitat selection, I compared habitat at used points with habitat at points not known to be used by tahr. I randomly selected points in the park by placing a grid over a 1:25,000 scale map. I randomly selected X and Y coordinates of the grid. The intersection of these coordinates on the grid denoted a random point to be sampled. I spent a total of 6,823 hours, from January 1993 to December 1995, searching for and observing tahr, and on only 19 occasions did I witness a tahr crossing a shola or commercial plantation. In addition, my technicians and I searched 12 sholas and five plantations thoroughly and found no sign of tahr use in these. Therefore, I excluded random points that were located in sholas and commercial plantations. At each of the selected points, I laid a 10-m radius circular plot. I designated the plot as used or not known to be used (hereinafter called unused) by tahr based on the presence or absence of tahr fecal pellets within this plot. I assumed that tahr defecated at random.

Identification of Tahr Fecal Pellets

Because tahr and sambur use similar areas in the park, I had to differentiate between tahr and sambur fecal pellets in the field. I tested two methods to be able to correctly identify the origin of the fecal pellets. The first method relied on pellet morphology, and the second on smell. I collected fecal pellets from tahr and sambur that were seen defecating. I collected pellet groups of all age and sex classes. I transferred the pellet groups into plastic bags, and recorded the species, age, sex, and location of collection on the bags. I removed a random sample of five pellets from each group and measured them following the procedure adopted by Maccraken and Van Ballenberghe (1987). I measured each pellet in the sample for maximum length (L), maximum width (W_1), and width at 90° rotation from W_1 (W_2). I estimated pellet volume as L x W_1 x W_2, and calculated the ratios L:W_1, L:W_2, W_1:W_2. All measurements were made to the nearest 0.01 mm using vernier calipers. I derived descriptive statistics for each variable.

The second method for distinguishing tahr from sambur fecal pellets relied on smell. I smelled each pellet group to familiarize myself with the odor of the fecal pellets, since I observed that tahr fecal pellets had a characteristic musky odor. Later I conducted blind tests to determine if I could consistently distinguish pellets of the two species based on their odor.

Characteristics of Used and Unused Plots

I measured a series of habitat variables at each plot (Table 10). I determined elevation using an altimeter calibrated at known ground locations. I made distance measurements by pacing. Actual observation of an animal or the presence of dung or scat within each 10-m radius plot determined presence of herbivores or carnivores. I used non-parametric tests to analyze these data. I used the Wilcoxon rank sum test (SAS Institute 1989) to test for differences between used and unused plots for each variable individually. I also tested for differences in tahr habitat use during the dry and wet seasons, using the Wilcoxon rank sum test (SAS Institute 1989).

Logistic Regression Models

I developed two models to predict the probability of tahr use in a plot. In the first model I investigated the effects of 12 habitat variables on tahr use (Table 10). In the second model, I used only five variables which were all distance measurements (Table 10). These variables were selected since they could easily be incorporated into a GIS database. I used multiple stepwise logistic regression procedures (SAS Institute 1989) to develop the models to predict the probability of tahr use in a plot within the park.

Landcover Mapping

Satellite Image

To develop a landcover map for the current conditions in the park, I used satellite imagery. I acquired a scene from the Indian Remote Sensing (IRS 1B) series satellite, LISS II scanner (26/61), corresponding to the Survey of India Topographic Sheet A11/58, in digital format. This image was acquired on 20 March 1995 and had a pixel resolution of 25 m. Since the scene covered a larger area than my area of interest, I extracted a sub-scene using the subset routine in the ERDAS IMAGINE 8.2 (ERDAS Inc. 1996) image processing software.

I used unsupervised and supervised classification procedures to delineate the landcover types in the image. For the unsupervised classification routine, I used 20 classes and 200 iterations. I used a supervised classification routine, and delineated training sets based on the visual interpretation of the unsupervised classification output, aerial photographs, and field notes.

I developed a minimum of 10 spectral signatures for each landcover class, using a region growing approach (Bucheim and Lillesand 1989). I examined these spectral signatures for normality, separability (Appendix B), and partitioning of the spectral space (Fig. 15). If a spectral signature for a landcover class contained information similar to other spectral signatures, these signatures were merged into a single spectral signature in ERDAS IMAGINE 8.2 (ERDAS Inc. 1996). The distinct signatures for each landcover class were used to perform a supervised classification using the maximum likelihood decision rule, which assigned each pixel to its most likely landcover class. I used all four bands of the satellite image for classification, including blue (0.43-0.51 mm), green (0.52-0.59 mm), red (0.62-0.68 mm) and near infrared (0.77-0.86 mm). I did not conduct an accuracy assessment of the classified image since I was unable to visit the study area after the completion of the field study. However, based on visual assessment of the classified image, which is based on three years of field work in the area, I feel confident that the classified image is a good representation of the landcover.

Separate coverages for shola forests and commercial plantations were developed from the supervised classification image of the park and its surroundings. I recoded these images by changing the pixel values for shola forest and commercial plantations to one and all other pixel values to zero. I conducted proximity analysis on these recoded coverages, setting the search distance to 254 pixels. This analytical procedure assigns numerical values to all the pixels in the coverage. The new pixel values correspond to the distance from a particular pixel to the nearest shola forest or commercial plantation.

ARC/INFO Coverages

I digitized cliffs, roads, the park boundary, and water bodies including streams as coverages in PC ARC/INFO 3.4.2b (Environmental Systems Research Institute 1994). I used 1:50,000 scale Survey of India Topographic Sheets as the base maps. I projected the coverages to India Lambert Grid, which is a Lambert Conical Orthomorphic projection (Table 11), since the 1:50,000 scale Survey of India Topographic maps were in this projection system.

I converted these vector coverages into raster coverages. I recoded the rasterized coverages by assigning pixels that denoted cliffs and roads a value of one and the remaining pixels a value of zero.

The satellite image also had to be rectified to the same projection as the ARC/INFO coverages so that they could be overlaid. To accomplish this, I selected 28 ground control points on the vector coverages and the raster image that could be readily recognized on the ground and in both coverages. I determined the geographical coordinates of these points and then rectified the image, via a first-order transformation. The transformation matrix was calculated using least squares regression in ERDAS IMAGINE 8.2.

GIS Models

I used four separate coverages for the four variables that entered into the logistic regression model. These included coverages of 1) distance to cliffs, 2) distance to roads, 3) distance to shola forests, and 4) distance to commercial plantations.

I conducted proximity analysis on the four recoded coverages. In this process, each pixel in the coverage is assigned a pixel value which corresponds to the distance of a pixel from the feature of interest. These distance coverages were then multiplied by their coefficients from the logistic regression model and were entered into the logistic regression equation using the model maker module in ERDAS IMAGINE 8.2.

In the resulting output coverage, each pixel was assigned a value that corresponded to q in the logistic regression equation, where

$$q = 1/\{1 + \exp[-(b_0 + \sum_{j=1}^{k} b_j x_{ij})]\} \qquad i = 1,2,\ldots, n.$$

The dependent variable, q, is a rough estimate of the probability of each map pixel area being used by tahr. I used a 5x5 scan majority filter, which scans an area of 25 pixels and assigns the pixel in the center a value that represents the majority of the class values in the window of 25 pixels, thereby smoothing the image. This procedure was also used to mask rainforests and hydroelectric reservoirs in the final output of the model, thus assigning rainforests and hydroelectric reservoirs zero probability of use by tahr. I used a 5x5 kernel instead of the conventional 3x3 kernel, since the 3x3 kernel proved insufficient to eliminate isolated unclassified pixels.

I tested the classification accuracy of the model by overlaying a coverage that contained visual locations of tahr. This data set had not been used to create the logistic regression model. If a visual location was located in a pixel with a probability of use greater than 0.5, I considered the pixel correctly classified.

To assess the impact of different management strategies on the quality of tahr habitat, I simulated three possible scenarios using the GIS database. In the first scenario, I simulated the effect of hypothetically removing the commercial forestry plantations in and near the park and assessed the effect of removal on the suitability of tahr habitat. To accomplish this, I created a new coverage from the commercial plantation coverage. In this new coverage, I recoded every pixel to represent a distance of 3000 m from the nearest plantation, thus assigning each pixel in the commercial plantation coverage a pixel value of 120 (i.e., 3000 divided by the pixel width of 25 m). I used 3000 m because this was the farthest distance a randomly-sampled plot was located from a commercial plantation. This new coverage was then used instead of the original commercial plantation coverage, and was incorporated into the logistic regression model, using the Model Maker module of ERDAS IMAGINE 8.2.

In the second scenario, I modeled the effect of hypothetical closure of roads. Closing roads will prevent human access to critical tahr areas. I created a coverage in which every pixel was 3000 m from the closest road, thus assigning each pixel a value of 120 (i.e., 3000 divided by the pixel width of 25 m). I used 3000 m, as this was the farthest distance a randomly sampled plot was located from a road. The roads coverage was substituted by this new coverage and incorporated into the logistic regression model.

In the third scenario, I examined the combined effect of hypothetically removing commercial plantations and also of closing roads. I substituted the roads and commercial forestry plantations coverage with the new coverages and incorporated these into the logistic regression equation.

To provide a better understanding of the effect of these management options, I calculated the amount of habitat at different probability of use levels that would be available to the tahr under each of these options. I color-coded the final maps to show, in one color all pixels with the same range of probability values.

To assess the impacts of these management scenarios on habitat fragmentation, I estimated the mean sizes of potential habitat patches and their mean inter-patch distance using FRAGSTATS, a spatial pattern analysis program (McGarigal and Marks 1995). I used the output coverages from the three management scenarios and the current habitat map of the park. The potential habitat patches were clumped using the clumping routine in ERDAS IMAGINE 8.2. I eliminated habitat patches that were less than five hectares in area using the sieving routine in ERDAS IMAGINE 8.2. The sieved coverages were exported to FRAGSTATS, and descriptive statistics, such as patch density, patch size and inter-patch distances, were calculated for each coverage

RESULTS

I sampled 657 plots and classified 338 as used by tahr, based on the presence of tahr pellets in the 10-m radius plot.

Identification of Tahr Fecal Pellets

Analysis of pellet sizes of tahr and sambur pellets indicated that there is overlap in the size ranges of pellets of tahr and sambur (Table 12). However, the smell test proved to be the most effective method of differentiating the pellets. Tahr pellets have a characteristic musky odor. In blind tests I could correctly differentiate between tahr and sambur pellets on all occasions ($n = 23$). Thus I used olfaction to distinguish tahr fecal pellets in the field.

Characteristics of Used and Unused plots

The mean elevation of plots used by tahr was higher than the mean elevation of unused plots (Wilcoxon rank sum test: $S = 40102.0$, $n1 = 207$, $n2 = 230$, $p = 0.0001$,

Table 13). Used plots were farther than unused plots from water (Wilcoxon rank sum test: S = 98802.5, n_1 = 319, n_2 = 338, p = 0.0114), roads (Wilcoxon rank sum test: S = 85633.0, n_1 = 319, n_2 = 338, p = 0.0001), and from commercial plantations (Wilcoxon rank sum test: S = 97837.5, n_1 = 319, n_2 = 338, p = 0.002). Used plots were closer to cliffs than unused plots (Wilcoxon rank sum test: S = 137397, n_1 = 319, n_2 = 338, p = 0.0001). Used plots also had less vegetation cover on the ground than unused plots (Wilcoxon rank sum test: S = 120078, n_1 = 319, n_2 = 337, p = 0.0001), and the substrate of used plots was either sheet rock or large boulders. I found evidence of herbivores, such as sambur and wild boar, and carnivores, such as leopard and tiger, significantly more often in used plots than in unused plots (c^2 = , n_1 = 275, n_2 = 338, p = 0.0001) (Table 14).

Seasonal Differences

Of the 338 plots that were classified as used by tahr, 128 plots were sampled during the dry season, and 210 during the wet season. The mean elevation of areas used by tahr in the dry season was lower than those used during the wet season (Wilcoxon rank sum test: S = 10060.0, n_1 = 107, n_2 = 123, p = 0.0001, Table 15). Vegetation cover on the ground was greater in the wet season (Wilcoxon rank sum test: S = 17650.5, n_1 = 127, n_2 = 210, p = 0.0001) than in the dry season. Compared to areas used during the wet season, areas that tahr used during the dry season were closer to water (Wilcoxon rank sum test: S = 16354.0, n_1 = 128, n_2 = 210, p = 0.0001), and closer to roads (Wilcoxon rank sum test: S = 17838.0, n_1= 128, n_2 = 210, p = 0.0001), but were farther away from escape cover (Wilcoxon rank sum test: S = 24137, n_1 = 128, n_2 = 210, p = 0.0051), farther from shola forests (Wilcoxon rank sum test: S = 19636.5, n_1 = 127, n_2 = 210, p = 0.03), and commercial plantations (Wilcoxon rank sum test: S = 25745.0, n_1 = 127, n_2 = 210, p = 0.0001) (Table 15). Also during the dry season tahr used areas where there were more herbivores (c^2 =, n_1 = 107, n_2 = 208, p = 0.02) than during the wet season (Table 16).

Logistic Regression Model

The first logistic regression model incorporated all 12 habitat variables measured at the plots. Of these variables, vegetation cover, aspect, slope, distance to cliffs, roads, commercial plantations, and shola forests were used to determine tahr use in a plot (Table 17). The logistic regression model containing these variables produced a model that correctly classified plots as used or unused by tahr 77.6 % of the time. This logistic regression model suggested that, compared to unused areas, tahr used areas that were closer to cliffs, farther from roads, commercial plantations, and sholas and had less vegetation cover, steeper slopes and were less frequently on north-facing slopes (Table 17).

The second model incorporated only distance measurements (Table 18). This model suggested that tahr used areas that were closer to cliffs, and farther from roads, commercial plantations, and sholas, than unused areas. The logistic regression model containing these variables produced a model that correctly classified plots as used or not known to be used by tahr 76% of the time.

Landcover Mapping

I classified the sub-scene that represented most of the park into six land-cover classes using the maximum likelihood decision rule in a supervised classification (Fig. 16). Grasslands accounted for 27.1% of the land area covered by the image, and commercial forests and sholas accounted for 11.1% and 20.3% of the land area, respectively (Table 19). Fewer than 5% of the pixels in the image were unclassified (Table 19).

GIS Models

Under current habitat conditions in the park, the area with high predicted probability of tahr use is largely restricted to the western edge of the park along the cliff line (Fig. 17 A). The area with the highest probability of tahr use (0.86 - 1.0) represents about 226.0 ha. (Fig. 17 A) which is < 3 % of the total area; however 1599.9 ha or 20.9% of the area has a probability > 0.5 of being used by tahr (Table 20). The existing habitat also is highly fragmented. I estimated that under current conditions there were 25 habitat patches, with a patch density of 1.5 patches / 100 ha (Table 21). The mean distance between the patches of suitable habitat was 425 meters (Table 21).

I overlaid a coverage that contained visual locations of tahr on the final output coverage of the current conditions of the park to provide a visual fit for the data (Fig. 17 B). Forty-five visual locations (52%) were located in areas that had a predicted probability of tahr use above 0.5 (Table 22). However, if the visual locations were randomly distributed in the park, only 20 observations (23%) would be located in areas with a probability of tahr use above 0.5 (Table 22).

In the first management option, I simulated a scenario in which the roads within the park were hypothetically closed to vehicular traffic. In this case, the area with the highest probability of tahr use (0.86 - 1.0) represented 836.4 ha (9.4% of the total area, Fig. 18), a three-fold increase over current conditions. 3478.4 ha (29.8% of the area) had a probability > 0.5 of being used by tahr (Table 20). There were 11 patches of potential tahr habitat and the mean inter-patch distance was 340 meters (Table 21).

In the second management option, I examined the effect of harvesting all commercial plantations within the park and restoring the harvested area to grasslands. In this scenario 1799.7 ha (20.3% of the area) had the highest probability of tahr use (0.86 - 1.0, Fig. 19), a six-fold increase over current conditions. In addition 4066.3 ha or 46% of the total area had >0.5 probability of tahr use (Table 20). In this management scenario, there were ten habitat patches, and the mean inter-patch distance was 349 meters (Table 21).

In the final scenario, I examined the combined effect of closing roads and removing all commercial plantations on the tahr habitat. This model suggested that 3713.1 ha (38% of the total area) would have probabilities between 0.86 and 1.0 of tahr use (Fig. 20), this represents a twelve-fold increase over current conditions. In addition 6019.5 ha (60.9% of the area) would have a probability > 0.5 of tahr use (Table 20). In this scenario there were six large patches of potential tahr habitat and the mean inter-patch distance was 145 meters (Table 21).

DISCUSSION

Characteristics of Used and Unused Plots

My results suggested that tahr used areas that were close to cliffs. The importance of escape cover is a common to other mountain ungulates has been emphasized (Schaller 1977, McQuivey 1978, Tilton and Willard 1982, Van Dyke et al. 1983, Gionfriddo and Krausman 1986, and Fairbanks et al. 1987). Geist (1971) suggested that proximity to escape cover is part of the evolved predator-evasion strategy in mountain ungulates.

My results also indicated that tahr avoid areas that are prone to human disturbance. Human disturbance in Mukurthi was restricted to areas along roads. Etchberger et al. (1989) found that bighorn sheep in Arizona used areas that were twice as far from human disturbance as unused areas. They further felt that distance from human disturbance was the most important factor in determining habitat use.

The greatest source of disturbance to tahr during the study within the park was from movie makers. During the dry season of 1995, there was an average of three movie crews per week within the park (personal observation). Their use was concentrated in the area between WC III and WC II. This area afforded the most spectacular view of the cliffs. Filming commenced early in the morning and continued late into the evening along the cliff line, almost always accompanied by loud music for the song and dance sequences. I observed a group of tahr to desert the area when filming commenced and to return to the same area only two days after the filming was completed. Leslie and Douglas (1980), Campbell and Remington (1981) and King 1985, observed that bighorn sheep altered their behavior patterns in response to construction activities and fed less and acted more wary than undisturbed sheep.

Tourists to the park were very few since access to the park is restricted, and there are no amenities for tourists. These tourists enter the park without valid permits but their activity is restricted to the roads. Tourists seldom venture into the grasslands to cause any substantial disturbance to the tahr. Hicks and Elder (1979) demonstrated that mountain sheep were tolerant of controlled human visitation. However, Purdy (1981) reported that backcountry recreationists posed a greater threat to mountain sheep (*Ovis* spp.) than recreationists restricted to roads and campsites.

Commercial plantations have a profound effect on tahr habitat use. The mean distance from a commercial plantation to a used plot was 720.1 m. Unused plots were closer to commercial plantations with a mean distance of 573.8 m from them. During my field observations, I never observed tahr to venture into dense commercial plantations.

Most plantations within the park area are wattle plantations. These, unlike Eucalyptus plantations, are extremely dense, and have well-used game trails. These game trails are substantially used by other wildlife; however I have not encountered tahr on these game trails. Tahr also avoid shola forests. However, tahr will enter strip sholas, to move from one patch of grassland to another. When they do, they are extremely cautious and spend several minutes scanning the surroundings (Davidar 1976, Rice 1982, and personal observation). This reluctance to enter sholas and plantations is likely a predator avoidance strategy, since leopards and tigers use shola forests and commercial plantations for cover.

Tahrs' reluctance to venture into and cross commercial plantations can have detrimental effects on the population. These commercial plantations appear to form effective barriers which fragment the population, thereby preventing interbreeding among the groups. Tilton and Willard (1982) observed that dense forests did not provide forage or bedding sites for mountain sheep (*Ovis* spp.) and were avoided. However, Daniels (1987) recorded that tahr in Kanyakumari District of Tamil Nadu ventured deep into shola forests.

In this study, I found that areas used by tahr were farther away from water than unused areas. This may be a predator avoidance strategy, since most streams are surrounded by shola forests. Krausman and Leopold (1989) observed that desert bighorn sheep in Arizona, used areas that were far from free standing water. Leslie and Douglas (1979) made the opposite observation for sheep in the River Mountains of Nevada.

Plots used by tahr are significantly higher in elevation than unused plots. Davidar (1978) observed that tahr are in the habit of looking down for danger and seldom look for danger to approach from above. This observation was confirmed in this study too, and I took advantage of this behavior of tahr to approach resting individuals. During this study, I observed that the tahr that first reacted to my presence was the individual that occupied the highest point above the rest of the herd. Mountain sheep (*Ovis* spp.) preferred areas where they can see for considerable distances, and this usually means choosing the highest point in the terrain (Cowan 1974, Tilton and Willard 1982). Cowan (1974) observed that adult male mountain sheep tended to remain at higher elevations than the other age- and sex-classes. During this study I did not observe this spatial separation between sexes in tahr. However, in Eravikulam, Rice (1982) observed that saddleback males ventured into valleys and bases of cliffs, areas which usually were lower than other parts of the park.

Seasonal Differences

During the dry season, tahr used areas that were further away from cliffs and closer to roads than during the wet season ($p < 0.005$). Preferred forage was in short supply during the dry season (see Chapter 3: Vegetation and Forage Preference), thus it appeared that tahr were willing to venture away from their escape cover in search of areas that provided forage.

In areas used by tahr, there was significantly greater ground vegetation cover in the wet season than during the dry season (Chapter 3: Vegetation and Forage Preference). During the dry season, tahr used areas that also were used by sambur and wild boar, maybe because the amount of available forage was low (Chapter 3: Vegetation and Forage Preference). Thus, tahr and sambur congregated in areas where forage was abundant. However, when forage in the grasslands became abundant during the wet season, tahr and sambur segregate and exhibit spatial differences in habitats used.

Tahr used areas that were closer to water during the dry season than during the wet seasons ($p < 0.0001$). Davidar (1976) suggested that tahr may not have very demanding water requirements. I have not encountered tahr very often at water; however they do drink water as they cross streams.

GIS Models

Incorporating the logistic regression model into a GIS database provided a method to predict and map areas that tahr used. The transferability of this model needs to be tested by applying this model to predict tahr use in other regions in the Western Ghats. The different scenarios I simulated suggested that managers can have a major, positive impact on tahr habitat through the use of conventional management techniques.

In the first scenario, when roads within the park were closed to vehicular traffic, there was two-times more suitable tahr habitat than is now available. The infrastructure such as gates across roads to restrict vehicular traffic within the park exists, but the laws prohibiting travel are not effectively enforced. If the existing laws are effectively enforced, there would be a substantial improvement in the quality and quantity of tahr habitat. In addition the number of habitat patches and the mean inter-patch distance between these habitat patches would be lower than the current conditions.

The scenario that simulated conditions with no commercial plantations produced two-times more suitable tahr habitat than is now available. The first commercial plantings of wattle and blue gum trees in the park were undertaken in the late 1970's. Under the Indian Wildlife Act (1972), no commercial forestry operations can be conducted within a National Park in India. Therefore, these existing plantations have no present financial value. Hence, these plantations could be removed in a one-time habitat improvement measure, generating income to the Forest Department and the local people. Removal of commercial plantations from the park and restoring these harvested areas to grasslands will restore the habitat to a condition similar to that existed in the late 1970's, prior to the censuses conducted by Davidar.

At present only 20% of the park area has >50% chance of being used by tahr (Fig. 21). However, when commercial plantations are removed and the roads closed to vehicular access more than 45% of the park will have >50% chance of being used by tahr (Fig. 21). This management option will result in a 120% increase in availability of habitat. This corresponds to the 125% decline in the tahr population from the 1976 estimates to the current population size. Thus, loss of habitat to the tahr, among other factors, could have caused a decline in tahr numbers.

CHAPTER 3: VEGETATION AND TAHR FORAGE PREFERENCE

INTRODUCTION

The ecology of high-altitude grasslands in the Western Ghats has been poorly studied (Gupte and Rege 1965, Gupte et al. 1967, Shetty and Vivekananthan 1971, Meher-Homji 1982). No attempt had been made to document the vegetation in the Mukurthi National Park.

A previous study on the diet of Nilgiri tahr was based on direct observations of foraging tahr. This study provided a list of plant species consumed, with only general indications of the importance of particular plant species (Rice 1988). There have been no attempts to quantitatively relate Nilgiri tahr diet to vegetation availability.

I used fecal pellet analysis to describe the composition and seasonal variability in the diets of tahr. I also compared the mean proportion of occurrence of plants in tahrs' diet with plant species abundance to assess relative preferences for various forage species. I tested the hypothesis that all plant species occurring in the grasslands of the Mukurthi National Park were consumed in proportion to their occurrence. During this study, I also documented that tahr were more numerous in the north than in the south sector of the park (see Chapter 1: Population Status and Composition). To attempt to understand this observed difference in tahr distribution, I tested the hypothesis that there was no difference in the abundance of preferred forage species between the north and south sector of the park.

METHODS

Vegetation Sampling

I placed 1m square quadrats at random points within the park. Random points were selected by placing a grid over a 1:25,000 scale map of the park. I randomly selected X and Y coordinates of the grid and the intersection of these coordinates denoted a random point to be sampled. I excluded points that were located in sholas and commercial plantations, since only on 19 occasions did I witness tahr using a shola or commercial forestry plantation. Within a quadrat, all plants were counted by species. For clumped grasses, each clump was counted as one plant.

Food Habits

I used the microscopic technique described by Sparks and Malecheck (1968) to determine the food habits of the Nilgiri tahr. I collected tahr fecal pellets from the study area during every month of this study. Only fresh pellets from tahr I saw defecating or those pellet groups that had a mucous coat and were therefore judged to be less than a day old were collected. Pellets were placed in plastic bags, air dried until the pellets lost their moisture and sealed. I recorded date, location and, when possible, sex of each defecating animal.

Botanical composition of fecal pellets was based on microhistological analysis (Sparks and Malecheck 1968, Vavra and Holechek 1980). From each pellet group I randomly selected and weighed one gram of tahr fecal material and soaked it in 10 ml methyl alcohol for about 24 hours to remove the chlorophyll. After soaking, I ground the fecal material in a mortar and sieved it through a 60 mm mesh screen. The filtrate was shaken well to ensure proper mixing and a portion was spread on a microscopic slide. Five such slides were made for each sample, and scanned immediately under a binocular microscope. Twenty microscopic fields were scanned at random in each of the 5 slides, for a total of 100 fields/sample. A field was defined as the area of a microscopic slide, visible under the 80X power magnification. Only those fragments recognized as epidermal tissue other than hairs were recorded as positive evidence for the presence of a plant species in a field. Plant fragments were identified to species using a key which I developed. This key included all plant species found in the grasslands and those plants recorded by Rice (1988) as tahr food plants. Frequency of occurrence (number of fields out of 100 fields in which a species occurred) and number of fragments of each species in the sample were tabulated and the mean proportion of occurrence of a plant was calculated.

Reference Collection

I collected representative specimens of all grasses, sedges, forbs and shrubs occurring in the grassland, and pressed them between blotting paper to dry the plants. These were identified to species by the Botanical Survey of India, Southern Circle. A herbarium was made of all collected plants.

I collected plant parts on which tahr were seen feeding and plants listed as tahr food plants by Rice (1988), and preserved them in FAA (methyl alcohol, 90%; formalin, 5%; and acetic acid, 5%). I ground the preserved plant material in an electric mill to simulate the digestion process, and made permanent slide mounts of this material. In addition, I made permanent slide mounts of leaf and stem cross sections and transverse sections, and epidermal peels. I used histological features such as cell shape, occurrence of special epidermal cells (e.g., cork or silica cells), size and shape of guard and subsidiary cells of the stomata and crystals in epidermal cells to develop a key for identifying food plants in fecal material. Davis (1959), Brusven and Mulkern (1960), and Storr (1961) found that epidermal characteristics of grasses and forbs were variable with different stages of maturity. Hence, I collected plant samples in all seasons. The reference collection for the appropriate season was used when fecal samples for that season were analyzed.

Forage Preference

To determine forage preference, I compared use and availability of different forage plants using the Wilcoxon rank sum test (SAS Institute 1979). I defined use as the mean proportion of occurrence of a plant species in the diet of the tahr. This was determined through microhistological analysis of fecal pellets. I defined availability as the mean proportion of occurrence of plant species in the grasslands. These data were derived from vegetation sampling.

I grouped the results by season and geographic location, and tested for differences between use and availability of each forage species individually using the Wilcoxon 2-sample test (SAS Institute 1989). I identified two seasons based on the rainfall pattern. The dry season extended from January to May and the wet season was from June to December. I also classified pellet groups based on the collection location. The north sector included Pandiar, Nilgiri Peak, Mukurthi Peak, WC III, WC II and Kollaribetta. The south sector included WC I, Bangitappal, Nadugani, Sispara and Bhavani puza (Fig. 7). I used this classification because I observed differences in the abundance of tahr between these areas. I also tested overall forage preference of tahr by combining data for all seasons and areas. I tested the hypotheses that tahrs' use of each plant species is proportional to its relative abundance in the grasslands.

RESULTS

Vegetation Sampling

I sampled vegetation within the park from January 1993 to December 1995, during all seasons. I recorded 16 grass species, 3 sedge species, 45 forb species, and 9 shrub species in the grasslands of the Mukurthi National Park (Appendix B).

When data from all plots (n = 679) were pooled to represent vegetation over the entire study period, *Andropogon oligantha* was the dominant grass in the park, with a density of 13.88 plants/ m^2 (Table 23), followed by *Dicanthium polyptylum* (7.06 plants/m^2). *A. oligantha* is a single-stem grass and was found only during the wet season. *Dicanthium polyptylum* is a bunch grass that was found during all seasons. Other dominant grasses, in order of densities, were *Eulalia phaeothrix* (5.68 plants/m^2), *Andropogon* sp. (5.44 plants/m^2), *Chrysopogon zeylanicus* (3.17 plants/ m^2), and *Ischaemum rugosum* (2.88 plants/m^2; Table 23). Among the forbs, *Taraxacum officinale* was found in the highest density of 8.55 plants/m^2, followed by *Impatiens pocilla* (3.54 plants/m^2) and *Eriocaulon* sp. (3.24 plants/m^2; Table 23). *Leucas suffruticosa* (2.29 plants/m^2) was the dominant shrub (Table 23).

Seasonal Variation

During the dry season grasses accounted for 68.1%, Sedges, 2.0%; forbs, 20.3%; and shrubs, 7.3%; of the vegetation in the grassland (n = 292; Fig. 22). *Dicanthium polyptylum* was the dominant grass with a density of 9.68 plants/m^2, followed by *Eulalia phaeothrix* (6.65 plants/m^2; Table 24). Other dominant grasses included *Andropogon* sp. (6.20 plants/m^2). *Taraxacum officinale* was the dominant forb during the dry season (7.45 plants/m^2; Table 24). Among the shrubs, *Leucas suffruticosa* (2.22 plants/m^2; Table 24) was the dominant shrub during the dry season. Sedges represented by *Carex* sp. accounted for 1.16 plants/m^2 (Table 24).

During the wet season (n = 387), grasses accounted for 49.85% , forbs 42.3%, shrubs 5.05% and sedges 2.8% of the vegetation in the grasslands (Fig. 22). *Andropogon oligantha* was the dominant grass during the wet season and occurred in densities of 24.36 plants/m^2, followed by *Dicanthium polyptylum* (5.09 plants/m^2), *Eulalia phaeothrix* (5.05 plants/m^2), *Andropogon* sp. (4.86 plants/m^2) and *Ischaemum rugosum* (4.01 plants/m^2; Table 24). *Taraxacum officinale* continued to be the dominant forb with 9.39 plants/m^2 (Table 24), followed by *Impatiens pocilla* (6.22 plants/m^2) and *Eriocaulon* sp. (5.57 plants/m^2; Table 24). *Leucas suffruticosa* continued as the dominant shrub with 2.35 plants/m^2 (Table 24). Sedges represented by *Carex* sp. accounted for 2.23 plants/m^2 (Table 24).

Geographical Variation

Eulalia phaeothrix, *Andropogon* sp., *Ischaemum rugosum, Chrysopogon zeylanicus*, *Curculigio* and *Carex* sp. had significantly higher densities in the north sector than the south sector (Table 25). On the other hand, *Dicanthium polyptylum* and *Strobilanthus* were significantly higher in the south than in the north (Table 25).

Food Habits

I analyzed 307 tahr pellet groups collected through the entire study period. Thirty-four species of plants were identified in fecal pellets through microhistological analysis. Grasses dominated the diet of tahr and comprised 64.2%, followed by forbs which accounted for 14.9%, sedges 13.9%, and shrubs 6.9% (Fig. 23).The five most important forage species were *Eulalia phaeothrix* (24%), *Chrysopogon zeylanicus* (22.53%), *Ischaemum rugosum* (12.96%), *Andropogon* sp. (12.62%) and *Carex* sp. (12.5%) (Table 26 and Fig. 24).

Seasonal Variation

During the dry season, five forage species accounted for about 72.3% of the tahrs' diet. These were *Eulalia phaeothrix* (20.1%), *Chrysopogon zeylanicus* (15.3%), *Carex* sp. (14.6%), *Taraxacum officinale* (13.7%) and *Andropogon* sp. (8.6%) (Table 27 and Fig. 24). Grasses comprised 54% of tahrs' diet. During the wet season, the major forage species are similar to the dry season, though their relative contribution to the overall diet of the tahr was different. *Eulalia phaeothrix* accounted for 17.6% of the tahrs' diet followed by *Chrysopogon zeylanicus* (13.4%), *Andropogon* sp. (12.4%) *Ischaemum rugosum* (12.3%), and *Carex* sp. (9.4%) during the wet season (Table 28 and Fig. 24).

Forage Preference

The hypothesis that all plant species were equally preferred by tahr was consistently rejected, indicating that tahr were exhibiting selective feeding. When data from all seasons and areas were combined, *Eulalia phaeothrix* comprised about 24% of the tahrs' diet, and was used in greater proportion than available in the grasslands (Wilcoxon rank sum test: $S = 176051$, $n_1 = 295$, $n_2 = 677$, $p = 0.0001$). *Chrysopogon zeylanicus* comprised 22.53 % of their diet, and was also actively selected for (Wilcoxon rank sum test: $S = 167383$, $n_1 = 295$, $n_2 = 677$, $p = 0.0001$). Other preferred forage species included *Ischaemum rugosum* (Wilcoxon rank sum test: S =166682, n_1 = 295, n_2 = 677, p = 0.0001), *Andropogon* sp. (Wilcoxon rank sum test: S = 157146, n_1 = 295, n_2 = 677, p = 0.0005), *Carex* sp. (Wilcoxon rank sum test: S =183370, n_1 = 295, n_2 = 677, p = 0.0001), *Tripogon bromoides* (Wilcoxon rank sum test: S = 162201, n_1 = 295, n_2 = 677, p = 0.0001), *Strobilanthus* (Wilcoxon rank sum test: S = 123267, n_1 = 295, n_2 = 677, p = 0.0001), *Curculigio* (Wilcoxon rank sum test: S = 167395, n_1 = 295, n_2 = 677, p = 0.001) and *Fimbristylis* (Wilcoxon rank sum test: S = 163322, n_1 = 295, n_2 = 677, p = 0.0001, Table 26). Tahr consumed *Arundinella fuscata* in the same proportion to its availability in the grasslands, thus exhibiting no preference for this species (Wilcoxon rank sum test: S = 143922, n_1 = 295, n_2 = 677, p = 0.8839, Table 26). On the other hand some species that were avoided by tahr included *Taraxacum officinale* (Wilcoxon rank sum test: S = 127363, n_1 = 295, n_2 = 677, p = 0.0001), *Leucas suffruticosa* (Wilcoxon rank sum test: S = 132579, n_1 = 295, n_2 = 677, p = 0.0026), *Impatiens* (Wilcoxon rank sum test: S = 135463, n_1 = 295, n_2 = 677, p = 0.0077), and *Dicanthium polyptylum* (Wilcoxon rank sum test: S = 78088, n_1 = 295, n_2 = 677, p = 0.0001, Table 26). *Dicanthium* had the highest mean proportion of occurrence in the grasslands.

Seasonal Variation

Eulalia phaeothrix constituted a major portion of the tahrs' diet during both the dry and wet seasons and accounted for 20.1% and 17.6% respectively (Table 27 and 28). Though the relative proportions of the forage species consumed varied over seasons, some species consumed in greater proportion than available (preferred) included *Chrysopogon* *zeylanicus, Carex* sp., *Ischaemum rugosum*, and *Tripogon bromoides* (Table 27 and 28). *Andropogon* sp. was actively selected during the wet season (Wilcoxon rank sum test: S = 65736, n_1 = 187, n_2 = 387, p = 0.0001) but was avoided during the dry season (Wilcoxon rank sum test: S =19619, n_1 = 108, n_2 = 290, p = 0.0518). *Taraxacum officinale* was used in proportion to availability during the dry season (Wilcoxon rank sum test: S = 23074.5, n_1 = 108, n_2 = 290, p = 0.1288, Table 27) was avoided during the wet season (Wilcoxon rank sum test: S = 42611, n_1 = 187, n_2 = 387, p = 0.0001, Table 28). *Dicanthium polyptylum* the dominant plant in the grasslands during both seasons and was consistently avoided by the tahr.

Geographical Variation

Considerable variation exists between dietary preferences of tahr in the north and the south sectors of the park. *Eulalia phaeothrix* was the major component of tahrs' diet in the north and accounted for 26.2 % of their diet (Table 29), while in the south accounted for only 7.36 % of their diet (Table 30) and was not actively selected. Forage species that were consistently selected in both the north and south sectors of the park included *Chrysopogon zeylanicus*, *Carex* sp., *Tripogon bromoides, Strobilanthus* and *Fimbristylis* (Tables 29 and 30). *Taraxacum officinale* was a preferred forage species in the south sector and comprised 15.7% of the tahrs' diet (Wilcoxon rank sum test: S = 7963.5, n_1 = 35, n_2 = 318, p = 0.0018, Table 30), but comprised only 7.67% of the tahrs' diet in the north and was avoided (Wilcoxon rank sum test: S = 71371, n_1 = 259, n_2 = 359, p = 0.0001, Table 29). *Andropogon* sp. constituted the major component of the tahrs' diet in the south and was actively selected (Wilcoxon rank sum test: S = 9242.5, n_1 = 35, n_2 = 318, p = 0.0001, Table 30). On the contrary, *Andropogon* sp. was avoided in the north (Wilcoxon rank sum test: S = 81930, n_1 = 259, n_2 = 359, p = 0.4109, Table 29). *Leucas suffruticosa* a shrub, was actively selected in the south (Wilcoxon rank sum test: S = 8298, n_1 = 35, n_2 = 318, p = 0.0001, Table 30), but was avoided in the north (Wilcoxon rank sum test: S = 71542, n_1 = 259, n_2 = 359, p = 0.0001, Table 29).

DISCUSSION

Vegetation Sampling

This study revealed that *Dicanthium polyptylum* was the dominant grass in the park. Dominance in this study was determined by the number of plants in a quadrat. For bunch grasses this was equivalent to the number bunches. Thus, this analysis underestimated *Dicanthium*'s dominance. This observation was consistent with the observations of Gupte and Rege (1965) who were the first to point out that there were two major types of high altitude grasslands in the Nilgiris; one dominated by *Chrysopogon zeylanicus* and the other by *Dicanthium polyptylum*. Previous vegetation surveys (Shankaranarayana 1958, Agrawal et al. 1961) failed to notice the existence of *Dicanthium polyptylum* occurring on an extensive scale along the western edge of the Nilgiri plateau. Gupte et al. 1967 found that *Chrysopogon zeylanicus* which dominated the Wenlock Downs near Ootacamund (Fig. 1) was absent in typical *Dicanthium* *polyptylum* grasslands along the western edge of the Nilgiri plateau. They hypothesized that grasslands dominated by *Dicanthium* were the oldest grasslands in the Nilgiris and the disappearance of this species from vast areas of the Nilgiris could be attributed to biotic factors. They considered *Chrysopogon zeylanicus* to be an invader species that replaced *Dicanthium*. Therefore, what appeared to be two distinct grassland types in the Nilgiris, may in fact be two stages of one type of grassland (Gupte et al. 1967). Similar observations were made by Shetty and Vivekananthan (1971) during their studies on the grasslands of Annaimudi in Eravikulam. They also observed that, in areas where there was little disturbance (fire or grazing), *Dicanthium* was the dominant grass and could reach a height of over one meter. Fires in Mukurthi National Park have been suppressed and elaborate fire lines were made during the dry season to prevent the spread of accidental fires. These fire suppression measures caused certain areas of the grasslands to be choked by *Dicanthium*, and in these areas *Dicanthium*, reached a height of 20 cm.

Some of the other vegetation in the grasslands that was not represented in my sampling included solitary plants of *Gaultheria fragrantissima* and *Rhododendron nilgaricum*. These plants appear stunted in growth on account of the gale force winds on the plateau. Reed bamboo (*Arundinaria* sp.) occurred in small patches near streams, I have not recorded tahr feeding on these. However, reed bamboo was consumed by elephants when they visited the park.

There was marked difference in the vegetation during the dry season and the wet seasons. Major grasses such as *Dicanthium*, *Eulalia*, and *Andropogon* sp. persisted during all seasons. However some grasses such as *Andropogon oligantha*, made their appearance only during the wet season. Other typical wet season plants included *Eriocaulon*, *Impatiens*, and *Cyanotis*.

There were significant differences in plant densities of the major forage plants between the north and south sectors of the park. The north sector had significantly higher densities of major forage species of the tahr, and these species included *Eulalia phaeothrix*, *Chrysopogon zeylanicus*, *Ischaemum rugosum*, *Andropogon* sp., and *Carex* sp. This difference in vegetation composition between the north and the south could explain the greater abundance of tahr in the north than the south. Mackie (1970) reported that the availability of preferred forage species appeared to be the primary determinant in seasonal distributions of elk in the Missouri River Breaks in central Montana. In Utah, habitat selection by elk on a summer range was strongly influenced by forage availability (Collins et al. 1978). Edge et al. (1988) showed that elk used areas where preferred forage species were twice as abundant as those in unused areas.

Food Habits

Dicanthium, though it was the dominant grass within the park, was avoided by tahr and contributed less than 1% to their diet. *Dicanthium* is a coarse grass, and not used by cattle when it is mature and it is usually left ungrazed in the grasslands and on the sides of roads frequented by cattle (Gupte et al. 1967). *Eulalia phaeothrix,* which ranked second in its dominance in the grasslands, was the major component of the tahrs' diet. Other species that contributed more than 10% to tahrs' diet included *Chrysopogon zeylanicus*, *Ischaemum rugosum*, *Andropogon* sp. and, *Carex* sp. (Fig. 24).

Gupte and Rege (1965) analyzed the nutritive value of six grasses for crude protein, ash, crude fiber, and classified *Ischaemum indium* and *Bothriochloa (Andropogon) insculpta* as good fodder grasses; *Arundinella purpurea* and *Themida triandra* as medium fodder grasses; and *Tripogon bromoides* and *Chrysopogon zeylanicus* as poor fodder grasses. *Andropogon* and *Ischaemum* that were described as good forage grasses contribute only about 25% to the tahrs' diet. Interestingly, *Chrysopogon* and *Tripogon*, that were described as poor quality forage, contributed 27% to the tahrs' diet (Fig. 24).

During the wet season tahr consumed twice the amount of *Ischaemum* as they did in the dry season. Similarly, a significantly greater quantity of *Andropogon* sp. also was consumed (Fig. 24). The wet season coincided with the peak rutting and breeding season of the tahr. During this period, protein demand on the female is high for fetal development. These two grasses have the highest protein content (Gupte and Rege 1965), and this may explain the increase in consumption of high protein forage in the wet season compared to the dry season.

During the dry season, when forage availability is poor, I observed tahr feeding on the inflorescence of *Taraxacum*. Rice (1988) reported that tahr in Eravikulam also exhibited such preferences for specific parts of a plant. He recorded that tahr had a preference for leaves of *Gaultheria*. I never saw tahr in Mukurthi feed on *Gaultheria* leaves, nor did I detect significant amounts of this species in their fecal pellets.

Inherent biases exist when using microhistological studies on fecal pellets to determine food habits. Primary among these biases is the problem of differential digestibility of forage plants. The biases of this method have been described by Gill et al. (1983). In an effort to minimize the bias of under representation of hard-to-digest forage and over representation of easily digestible forage, I ground the sample in a mill and sieved it through a mesh to ensure uniform particle size in the filtrate to be sampled.

CHAPTER 4: PREDATION RATES

INTRODUCTION

The impact of predators on Nilgiri tahr populations is poorly understood, yet the predators could have a significant impact on this endangered species. My objectives in this part of the study were 1) to determine the food habits of the tigers and leopards that occur within the Mukurthi National Park, and 2) to assess the magnitude of predation on the Nilgiri tahr population.

METHODS

I collected the scats of leopard and tiger while I walked along roads and trails and when I encountered them on the grasslands while conducting tahr surveys. I distinguished tiger scats from leopard scats using supplementary evidence in the form of tracks at the defecating site, scrapes, and size. Tiger scats are found in scrapes and leopard scats are not. Moreover, tiger scats have a larger diameter than leopard scats. I did not collect jackal scats since jackals are scavengers on tahr (Rice 1986). I placed scats in plastic bags and later allowed them to air dry. I recorded the date, location, and predator on the bags. In the laboratory, I washed and strained the scats in water. I segregated hairs from each scat based on color, length, and thickness. A sample of 5 hairs from each such group was removed and compared with a reference collection of prey hairs under an 80X microscope.   I collected the hair of major prey species which included tahr, sambur, barking deer, feral buffalo, Nilgiri langur, and bonnet macaque from captive and preserved specimens and made a reference collection following the procedure described by Koppikara and Subnis (1976). I used the cuticular architecture of the hairs to provide a positive identification of the prey item consumed (Johnson and Hansen 1978, Kroschgen 1980, Gamberg and Atkinson 1988).

I made paper traces and plaster casts of predator pug-marks when I encountered them in the park. I differentiated individual animals based on the size of the print. I also used sighting data from the tahr censuses to estimate the number of predators within the park. These estimates are rough at best, but do provide some indication of the number of predators in the park. I used census data from the foot surveys conducted in 1995 to estimate tahr biomass.

Reconstruction of Predator Diets

Frequency of occurrence of prey species is a commonly used parameter to reconstruct the diet of a carnivore (Davidar 1976, Johnsingh 1983, and Rice 1984). Floyd et al. (1978) and Ackerman et al. (1984) showed that when prey sizes were highly variable, using frequency of occurrence in scats could considerably distort the relative frequency of different prey types in the diet. Therefore, they suggested estimating relative biomass and numbers of prey species consumed to reconstruct predator diets. I used the method developed by Ackerman et al. (1984) to convert frequency of occurrence of a prey species in the scats to relative biomass and numbers of individuals killed.

Karanth (1993) and Karanth and Sunquist (1995) found that the degree of carcass use by tigers and leopards was comparable to the results of the feeding trials conducted by Ackerman et al. (1984) on cougars. Therefore, I used the regression developed by Ackerman et al. (1984) to relate the weight of a prey item represented in one field collected predator scat (y) to the live weight of prey killed (x). That equation was:

$$y = 1.980 + 0.035x$$

Karanth and Sunquist (1995) found that this method provided unbiased estimates of prey species weights including small prey items and young animals in the predator's scat.

Karanth and Sunquist (1995) found there were age- and sex-related biases in predation and that the average weight of prey taken by leopards was less than the average weight of prey taken by tigers. I used data from Karanth and Sunquist (1995) to determine the average weight of prey species for the tiger and leopard. Average weight of Nilgiri tahr was determined from a captive population at the Minnesota Zoo, Minneapolis, Minnesota, USA. I used polynomial regression analysis to fit a curve to predict the weights of tahr in a given age class using the equation $y = -3.52x^2 + 37.67x + 1.40$ for males and $y = -5.35x^2 + 34.54x + 5.46$ for females; where x = age class (Fig. 25). I used these weights to estimate the biomass of each age class of tahr, by multiplying the average weight for an age or sex class with the number of individuals in the park in a particular age and sex class. The average weight of all tahr in the park was used as the average weight of tahr for computations.

Relative biomass of a prey species consumed, and relative number of prey consumed were calculated using the following formulae developed by Ackerman et al. (1984).

$$X = (A \times C) \,/\, \sum (A \times C)$$

where X = relative biomass of prey species consumed
A = frequency of occurrence in scat
C = correction factor (C = 1.98 + 0.035B)
B = estimated mass of individuals consumed

and

$$Y = (X \div B) \,/\, \sum (X \div B)$$

where Y = relative number of prey consumed
X = relative biomass of prey species consumed
B = estimated mass of individuals consumed.

The annual food requirements for tiger and leopard were derived from Schaller (1972) and Sunquist (1981). The requirements were corrected for the inedible portion of the prey which was 35% (Jackson and Ahlborn 1984).

I used the mortality rates for each age class (see Chapter 1: Population Status and Composition) and calculated the number of tahr lost each year. I compared the estimated number of deaths to the estimated number of tahr that were killed by predators to determine if predation could be a major cause of mortality in this population of tahr.

RESULTS

I analyzed 53 tiger scats and 95 leopard scats. Sambur accounted for 91.8% of the tiger's diet and tahr accounted for 6.7%, and wild boar accounted for 1.5% (Table 31). Tahr made up 56.4% of the leopards' diet and sambur 39.1%. Other prey items consumed by leopard included wild boar, Nilgiri langur, and porcupine (Table 32).

During the three-day census in 1993, two leopards were sighted. However, I could differentiate at least four different pug marks from the plaster casts and paper traces. Therefore, I estimated that there were two to four leopards using the park. Thus, the density of leopards in the park, is 2.53 to 5.06 leopards / 100 km^2. I also estimated that there are two to three tigers using the park or a density of 2.53 - 3.79 tigers / 100 km^2. During the three-day census carried out during 1993, three different tigers were sighted, one in the Pandiar area and two in the Bangitappal area. Later in January 1994, I recorded pug-marks of a tigress and cub near Mukurthi Peak. Leopard and jackal sightings and sign have been recorded from all areas within the park; however, I have encountered leopard sign more often in Pandiar, Mukurthi, and Bhavani puza than other areas of the park.

I estimated the number of tahr within the park to be about 154 individuals which yielded a density of 1.95 tahr / km^2 (see Chapter 1: Population Status and Composition) and total estimated tahr biomass of 8,082 kg or 102.3 kg/km^2 (Table 33). Schaller (1972) estimated that leopards need to kill and consume about 1,000 kg of meat/year. Tahr comprised about 56% of the leopard's diet; therefore, I estimated that each leopard killed about 560 kg of tahr per year or 12 tahr of average weight. Hence, for the estimated number of leopards (2 to 4 leopards), I estimated that they would need to kill and consume 24 to 48 tahr annually.

Sunquist (1981) estimated that tigers required between 5 to 7 kg of meat a day or 2,000 to 2,625 kg per year. The corrected estimates, accounting for the inedible portion of their prey was 2700 to 3550 kg /year. Tahr comprised only 6% of the tigers' diet. I estimated that each tiger consumed 162 to 213 kg or 3 to 4 tahr per year; therefore for the estimated number of tigers (2 to 3 tigers) within the park, I estimated that they would need to kill and consume 6 to 12 tahr per year. Tigers and leopards together should kill and consume 30 to 60 tahr per year or 19% to 38% of the total population of tahr within the park. Based on the assumption that predators (leopards and tigers) killed and consumed tahr in the proportion to the number that are encountered, i.e., there is no preference for a particular age and sex class of tahr, the predators should kill and consume 5 to 10 young tahr, 4 to 9 yearlings, 11 to 22 adult females, 6 to 12 light brown males, 1 to 2 dark brown male and 2 to 5 saddlebacks per year (Table 34). This estimate did not take into account predation by dholes, which are seasonal visitors to the park.

I estimated that 29 tahr in the young age class die each year from all causes of mortality, of these 5 to 10 young are killed by predators (Table 34). In the other sex- and age-classes, nearly all the observed mortality could be accounted for by predators (Table 34).

DISCUSSION

In Mukurthi National Park it appeared that sambur constituted a major portion of the tigers' diet, and tahr accounted for only 6 % of the prey biomass consumed by tigers. Leopards, on the other hand, consumed a large quantity of tahr. Tahr accounted for about 56% of the biomass they consumed. Sambur contributed 39% of the biomass consumed by leopards. Davidar (1976) reported 80% of the leopard scats and 12% of the tiger scats from Mukurthi National Park contained tahr remains. Rice (1984) analyzed 18 tiger scats from Eravikulam and found that none contained tahr remains. I found sambur in 94% of the tiger scats.

Karanth and Sunquist (1995) observed that there were significant differences in the size of sambur killed by leopards and tigers. Leopards tended to kill small sambur. These were primarily females and young. Tigers killed adult males, which were larger. This preference of tigers for larger prey can be considered in the light of hypotheses related to foraging theory (Stephens and Krebs 1987), which suggested that predators may select age and sex classes containing the most profitable prey as measured by the ratio of energy gain to handling time (Scheel 1993). Tigers depend on concealment and ambush to capture their prey and in an open grassland system such as Mukurthi, tigers are at a disadvantage to capture tahr. Tahr used primarily open grasslands, far from the commercial plantations and sholas (see Chapter 2: Habitat Use), that afford the tiger good cover. Sambur, on the other hand, use sholas and plantations, where they are prone to predation by tiger. Rice (1984) observed two interactions between tiger and tahr, and in both cases tahr appeared to show no strong alarm reaction.

Adult mortality of tahr in Mukurthi is high compared to other populations of tahr. I estimated a mortality rate of 0.294 in 1975, based on Davidars' population estimate, and in 1995, I estimated this rate at 0.402. Caughley (1970) reported mortality rates for different age classes between 0.040 and 0.287 in an increasing population and between 0.068 and 0.33 in a stationary population of Himalayan tahr in New Zealand, which were in a predator-free environment. In this study I estimated a mortality rate for the young age class as 0.569, while the mortality rate for the yearling age class is 0.042 and the adult age class was 0.403 (Table 8). Based on these mortality rates, I estimated the number of individuals dying due to all causes each year. It seems possible that most of the mortality experienced by this population of tahr could be accounted for by predation alone (Table 34). This raises the question of why this particular population of tahr faces such high predation rates.   The recent history of the park provides a possible explanation.

The 78-km^2 area that comprises the present day Mukurthi National Park was declared a protected area in 1982 under the Indian Wildlife Act. This act does not permit human settlements within the park boundaries. Therefore, in 1982 the indigenous peoples, the Todas and the Badagas, who were pastoralists, grazing primarily buffaloes and cows, were evicted from the park along with their livestock. It is possible that the presence of these livestock allowed the predator populations to increase above natural levels. When the livestock were removed from the park, the predators had to resort to taking naturally-occurring prey such as tahr and sambur. This may account for the high mortality in the tahr population today.

Another possible scenario relates to the conversion of grasslands into commercial forestry plantations. These plantations provide cover for the leopards and tigers, and I suspect that these plantations, which provide good cover to the predators, may be bringing the predators closer to the tahr in the grasslands, making the tahr more vulnerable to predation.

My estimates of the predator population were based on the total number of predators sighted during the three-day census and plaster casts of their pug-marks collected over the study period. I estimated the density of leopards in the Mukurthi National Park to be between 2.53 to 5.06 leopards / 100 km^2, however in Sri Lanka, Clark (1901) estimated a density of 5 leopards / 100 km^2 and more recently Eisenberg and Lockhart estimated densities of 3.3 leopards / 100 km^2. In view of these density estimates, I feel that my estimates of leopard densities in Mukurthi may be realistic. Tigers on the other hand are found in much higher densities in other parks in India. Karanth (1991) estimated densities ranging from 6.82 to 11.65 tigers / 100 km^2 in tropical and monsoon forests. My density estimate of 2.53 to 3.79 tigers / 100 km^2 in the park is lower than these estimates. This low density of tigers may be in response to the lack of large patches of dense forests preferred by tigers (Karanth 1991).

Dholes and humans are temporary visitors to the park. Dholes appear to visit the park only during certain times of the year and their visits are brief. I encountered dholes in the Upper Bhavani area and the Pandiar - Mukurthi reservoir area. Packs consisted of 8 to 10 dholes. They appeared to concentrate on sambur that are more abundant in the park. I witnessed five kills by dholes and in all cases their victims were sambur young and does. I did not encounter any instances of poaching within the actual boundaries of the park. In eight separate instances, I came across snares that were set on game trails that adjoined the park. These snares were set within wattle plantations and at game crossings through strip sholas. In areas adjacent to the park, I observed three successful snares and their victims in all cases were sambur. I observed snares set along the cliff edge at Aattuparai near East Varagapallam and suspect they were laid for tahr.

CONCLUSIONS

All evidence gathered during this study from repeated surveys, mathematical modeling and computer simulations suggests that the Nilgiri tahr population in the Mukurthi National Park has declined and will continue to do so in the absence of management. I estimated that the park contains 154 individuals, compared to Davidar's 1976 estimate of 450 tahr. In addition to the overall decline of tahr within the park, I found that there was significant change in the distribution of tahr in the park. Historically most of the tahr (74%) were found in the south sector of the park but now this sector contains only 14% of the population. I found that the south sector had significantly lower densities of the major forage species of the tahr than the north sector, where the tahr are now concentrated. It is possible that the tahr depleted their forage in the south sector and have moved to the north where forage is available. Alternatively other factors, such as fire suppression, may have reduced forage in the south resulting in a shift in tahr distribution. In addition, the logistic regression model showed that more suitable tahr habitat (as defined by distance to cliffs, sholas, roads and commercial forestry plantations) is available in the north than the south.

The age-specific mortality experienced by the Mukurthi tahr population is higher than those experienced by other tahr populations. My estimates suggest that predation by leopards and tigers accounts for much of the mortality experienced by this population. I estimated that these predators killed and consumed between 30-60 tahr each year, and this accounts for 39% to 82% of the estimated mortality.

Tahr in the Mukurthi National Park used primarily grasslands and within grasslands, they used areas that were close to cliffs, and far from roads, shola forests, and commercial forestry plantations. Conversion of the grasslands in the park into commercial forestry plantations began in the late 1970's and today occupies 11% of the area. These plantations restrict tahr movements, fragment the grasslands, and provide cover for the leopards and tigers. I suspect that the commercial plantations may be bringing the predators closer to the tahr, making the tahr more prone to predation.

I found through GIS simulations that the quantity of suitable of tahr habitat can be increased if commercial forestry plantations are removed and the area restored to grasslands. Similarly, closing roads or reducing road use substantially can increase the amount of suitable habitat available to the tahr.

I investigated the food habits of the tahr and found that they were primarily grazers and that grasses constituted more than half (64%) their diet. Five plant species (*Eulalia phaeothrix*, *Chrysopogon zeylanicus*, *Ischaemum rugosum*, *Andropogon* sp. , and *Carex* sp.) accounted for 84.6% of their diet.

It appears that high mortality (mostly from predation), the loss of grasslands to commercial forestry plantations, and increased human disturbance are the most likely causes of the tahr decline in the Mukurthi National Park.

MANAGEMENT RECOMMENDATIONS

Enlargement of the Park

(i) The park boundary should be redrawn to include areas that currently are used by tahr.

(ii) A bi-state committee should be set-up to coordinate management of Mukurthi, Attapadi and New Amarambalam areas.

My surveys within the park and the adjoining areas suggested that tahr used areas that were outside the present boundaries of the park. These areas include Pandiar, area east of Western Catchments, and Varagapallam. These areas are under the purview of the Forest Department and are now managed as Reserved Forests. These Reserved Forests are managed under a multiple-use mandate and are subject to commercial exploitation and with little protection to the wildlife these forests contain. Therefore, I recommend that the park be enlarged to afford better protection to the tahr that use these areas. Figure 26 outlines areas that should be included in the park and the new proposed boundary for the Mukurthi National Park.

A bi-state committee consisting of representatives from Tamil Nadu and Kerala should be set up to coordinate management decisions. The Mukurthi, Attapadi, New Amarambalam and Silent Valley areas are of special importance since they form the core area of the Nilgiri Biosphere Reserve, and provide corridors linking protected areas in the states of Kerala, Tamil Nadu, and Karnataka. One of the issues to be addressed by this bi-state committee will be control of poaching, not only on tahr but on other large mammals.

Grassland Management

(i) Commercial forestry plantations of wattle, blue gum and pine within the park should be harvested and the harvested area restored to grasslands.

(ii) Controlled fires should be made along the cliff line on the western edge of the park, prior to the onset of the southwest monsoon.

I found that tahr used primarily grasslands, and within grasslands used areas that are close to cliffs, and far from roads, commercial forestry plantations, and shola forests. It is therefore important to manage for these features to increase suitable tahr habitat. Cliffs and shola forests form a part of the natural landscape. However, commercial plantations could be managed to increase suitable tahr habitat. Using GIS simulations I have shown that, when commercial forestry plantations within and near the park were restored to grasslands, there was a two-fold increase in suitable tahr habitat. The existing commercial forestry plantations have no financial value since no commercial forestry operations are allowed within a National Park in India. However, a one time removal of existing plantations would restore the habitat in the park to its original state and would also generate income and fuel wood for a year to the local people.

I have observed that the subsequent flush of grasses after the grasslands were burned attracted herbivores to these areas. In the past, the nomadic Todas and Badagas set the grasslands on fire to provide grazing grounds for their livestock and this indirectly benefited the tahr and other herbivores.

Human Disturbance

(i) Close roads within the park to vehicular traffic.

(ii) Restrict movie-makers from using the western edge of the park.

Using GIS simulations, I have shown that closing roads within the park, and thus preventing vehicular access within the park could increase the quantity of suitable tahr habitat two-fold. At present there are gates across roads at Pandiar, Western Catchment, and Upper Bhavani to restrict vehicular access to the park. However, these gates are seldom locked.

Movie makers are a source of disturbance to the tahr and the ecosystem today. The movie makers concentrate their activity between WCIII and WCII. In the interests of the tahr, this noisy practice of filming will need to be curtailed in sensitive tahr areas especially along the western edge of the park.

Park infrastructure improvement

(i) Establish a Wildlife Warden with exclusive control over Mukurthi National Park.

(ii) Improve facilities for Forest Guards and Watchers to ensure better patrolling of the park.

The 78 km^2 park with its rugged terrain and inhospitable weather is managed by a Wildlife Warden. The Wildlife Warden is in charge of both the Mudumalai Wildlife Sanctuary and the Mukurthi National Park. The office headquarters for both the parks is situated in Ootacamund which is about 20 km away from the park. There are no facilities for the Forest Guards and Watchers to live or even spend a comfortable night in the park. They are not provided with basic infrastructure such as vehicles or communication facilities or arms.

Wireless communication stations should be located within the park, along with living quarters for the forest personnel to ensure that the area is patrolled daily. Sensitive areas, where the threat of poaching is imminent include Pandiar, where it abuts the Terrace estate and the Moolakad estate, Western Catchment III, where it adjoins the Emerald Valley tea estate, Western Catchment II, in the area adjacent to the villages of Emerald and Avalanche. Other sensitive areas includes Nadugani, adjacent to the cliff line, and the Bison Swamp area.

Research Needed

(i) Continued monitoring of this population size is required.

(ii) A better understanding of the age- and sex-specific mortality rates experienced by this tahr population is essential. One approach would be to use radio-telemetry.

(iii) Further studies into the effect of fire on the flora of the grasslands will be required to effectively manage the grasslands.

Regular monitoring of the population of tahr is required at the minimum on an annual basis. When population sizes drop to such low levels one year of poor productivity due to environmental factors could have undesirable effects. In addition there is a need for a better estimates on the natality and mortality rates of this population. Close observations on the tahr are quite difficult given their skittish nature. One approach would be to use radio-telemetry to be able to obtain better estimates on the mortality and natality rates of this population.

During this study, I have observed that tahr congregate in areas that were burned during the dry season. This congregation of tahr may be explained by the presence of succulent forage. However, they use burned areas that are in the vicinity of cliffs. It is therefore essential to study the impact of fire on the plant community in the grasslands to determine if preferred forage species are found in greater abundance in burned areas than unburned areas.

With the implementation of these management recommendations, the quality of habitat available to tahr could be enhanced, thereby ensuring the continued survival of the rare and endangered Nilgiri tahr in the Mukurthi National Park.

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Table 1. Number of endemic species in the Western Ghats of India and a comparison with the known species in each taxa.

	Western Ghats Endemics	World Total	% of World Total
Freshwater fishes	84	8275[a]	1.0 %
Amphibians	87	4014[b]	2.2 %
Reptiles	89	6547[c]	1.4 %
Birds	13	9672[d]	0.13 %
Mammals	12	4170[e]	0.26 %
Total	285	32678	0.87 %

[a]Freshwater fishes (Cohen 1970)
[b]Amphibians (Frost 1985)
[c]Reptiles (Halliday and Adler 1986)
[d]Birds (Sibley and Monroe 1990)
[e]Mammals (Honacki et. al. 1982)

Table 2. Forest management plans for the Mukurthi park region. The area that includes the present day Mukurthi National Park was formerly part of the Nilgiri forest division and subsequently the Nilgiri (South) forest division. The area has been managed under forest working plans since 1882. Summaries were extracted from Neelakantan (1988).

Gamble's working scheme (1882 - 1914)

This marked the beginning of eucalyptus plantations.
(However, there was no planting in the park area)

Cox's working plans (1910 - 1919 & 1914 - 1928)

Blue gum (Eucalyptus) plantations were worked on a rotation of 15 years under a simple coppice system.

Dyson's working plan (1928 - 1938)

The plan dealt with blue gum plantations, in which rotation was changed to 20 years.

Ranganathan's working plan (1938 - 1948)

This plan was not revised until 1955 and hence work was carried on until 1954, on the lines prescribed by this plan. Blue gums were to be coppiced on a rotation of 18 years. Wattle felling on a rotation of 6 years was prescribed.

Jeyadev's working plan (1954 - 1964)

This plan provided for afforestation of the Kundha's. It was during this planning period that large scale plantations were undertaken in the grasslands of the plateau.

Thigarajan's working plan (1964 - 1974)

Pulpwood plantations were undertaken in the grasslands.

Jeyaraman's working plan (1974 - 1984)

Pulpwood plantations were undertaken in the grasslands

Table 3. Description of age and sex classes based on body size, pelage color, and horn size used in this study.

Young (Yo): Age 0-1 years.

> Gray-brown or light brown coat. Up to about 45 cm at the shoulder. Horns up to about 7 cm in length.

Yearling (Yl): Age 1-2 years.

> Gray brown coat. Intermediate in size between Yo and F's. Horns up to 12 cm.

Adult Female (AF): Age 2+ years.

> Gray brown coat. Carpal patch black. Height 70-80 cm. Horns more slender than those of males, up to 30 cm in length. In frontal view of horns, they appear to be more divergent (V shaped) at the base than males.

Light brown males (Lbm): Age 2-4 years.

> Similar in body size, horn size, and pelage as adult females. In frontal view, horns are parallel at the base. Penis sheath and scrotum provide positive identification. The black carpal patch begins to show a change to white.

Dark brown male (Dbm): Age 5- 6 years.

> Gray brown to dark brown coat. Larger and more robust than F's and Lbm's, larger horns, and more distinct facial markings. Key trait in distinguishing this age class is the distinct white knee patch.

Saddleback male (Sb): Age 6 + years.

> Dark brown to black coat with an area of light brown, white, or silvery hair covering their lower back, rump and/or flanks. The black patch directly above the white knee patch does not differ in coloration markedly from the rest of the front of the foreleg.

Table 4. Distribution of Nilgiri tahr in the various sectors within the Mukurthi National Park South India. Data for 1993-1995 were collected during foot surveys.

			Age class[1]						
Sector	Areas covered	Year	Sb	Dbm	Lbm + AF	Yl	Yo	Total	Sources
I	Nilgiri Peak, Pandiar top,	1963	0	0	0	0	0	0	Davidar (1963)
	Deva betta	1969	ns	ns	ns	ns	ns	ns	Schaller (1971)
		1975	0	0	0	0	0	0	Davidar (1976)
		1993	2	1	17	5	7	32	This study
		1994	1	1	23	11	10	46	This study
		1995	2	0	31	8	11	52	This study
II	Mukurthi Peak, Chinna	1963						79	Davidar (1963)
	Mukurthi, Peechal betta	1969						63	Schaller (1971)
	Peechakal betta	1975	2	3	22	9	9	45	Davidar (1976)
		1993	2	4	21	5	6	38	This study
		1994	3	2	15	3	3	26	This study
		1995	3	1	10	4	3	21	This study
III	WC III, WC II, WC I	1963						66	Davidar (1963)
	Kollaribetta	1969	ns	ns	ns	ns	ns	ns	Schaller (1971)
		1975	2	4	24	6	6	42	Davidar (1976)
		1993	2	4	31	8	6	51	This study
		1994	2	4	28	7	8	49	This study
		1995	4	2	34	9	9	58	This study
IV	Bangitappal, Upper Bhavani	1963						47	Davidar (1963)
		1969						113	Schaller (1971)
		1975	3	3	26	2	6	40	Davidar (1976)
		1993	0	0	0	0	0	0	This study
		1994	0	0	4	0	2	6	This study
		1995	0	0	7	0	2	9	This study

Table 4. continued

			Age class[1]						
Sector	Areas covered	Year	Sb	Dbm	Lbm + AF	Yl	Yo	Total	Source
V	Nadugani, Sispara	1963						65	Davidar (1963)
	Varagapallam	1969	ns	ns	ns	ns	ns	ns	Schaller (1971)
		1975	8	15	130	33	31	207	Davidar (1976)
		1993	0	0	0	0	0	0	This study
		1994	0	0	8	3	3	14	This study
		1995	3	1	8	1	2	15	This study

[1] Symbols for age classes are from Table 3

ns - not surveyed

Table 5. Sightings of Nilgiri tahr, during the three-day census conducted between October 1-3, 1993 at the Mukurthi National Park, South India.

Sector	Day 1	Day 2	Day 3
Pandiar	0	0	0
Nilgiri Peak	0	1	0
Devabetta	3	0	0
Mukurthi hut	28	1	0
W.C. III	8	7	0
W.C.II	48	3	0
Kollaribetta	3	0	0
Bangitappal (N)	6	9	0
Bangitappal (S)	0	2	0
Upper Bhavani	0	0	0
Bison swamp	1	1	0
Nadugani (W)	22	0	0
Nadugani (E)	0	31	12
Sispara (W)	0	0	4
Sispara (E)	0	9	3
Total	**119**	**64**	**19**

Table 6. Nilgiri tahr sightings during total count population surveys conducted from 17 March to 2 April 1994 and 20 April to 9 May 1995 in the Mukurthi National Park, South India.

Sector	Areas Covered	Hours Spent in Survey (Observer-Hours)		Number of Tahr Seen		Tahr/Observer-Hour	
		1994	1995	1994	1995	1994	1995
1	Pandiar top, Nilgiri Peak and Deva betta	159.3	125.1	53	35	0.33	0.28
2	Peechakal bettu, Peechal bettu, Chinna Mukurthi and Mukurthi Peak	111.0	105.0	21	11	0.19	0.1
3	WC III, WC II and Chattipara	159.4	145.0	18	18	0.11	0.12
4	WC I, Bangitappal and Maddipu malai	60.3	118.2	1	2	0.016	0.016
5	Nadugani, Sispara and Kinkerhundi	107.3	86.3	9	10	0.083	0.11
	Total	597.3	579.6	102	76	0.17	0.13

Table 7. Estimated ratios of Nilgiri tahr by sex and age class to 100 females in several populations. Data for 1993-1995 collected during foot surveys.

Location	Year	No. AF	Age Class Ratios[1]					Source
			Sb	Dbm	Lbm	Yl	Yo	
Mukurthi N.P.	1969	56	26.8	12.5	23.2	55.4	75.5	Schaller (1971)
	1975	151	9.9	16.6	33.8	26.5	34.4	Davidar (1976)
	1993	45	13.3	20	53.3	40	42.2	This study
	1994	57	10.5	12.2	36.8	42.1	45.6	This study
	1995	57	21	7	56.1	38.5	47.3	This study
Grass Hills	1971	60	1.7	6.7	21.7	31.7	60	Davidar (1971)
	1980	99	6.1	12.1	48.5	28.3	47.5	Rice (1988)
Eravikulam N.P.	1969	87	33.3	12.6	12.6	51.7	88.5	Schaller (1971)
	1978	142	9.9	23.9	23.9	55.6	31.7	Rice (1988)
	1979	188	9.6	28.2	28.2	21.3	58.5	Rice (1988)
	1980	268	13.8	9.3	30.6	25.7	36.2	Rice (1988)

[1] Age and sex class code from Table 3

Table 8. Comparison of mortality rates in different populations of Nilgiri tahr and Himalayan tahr. Eravikulam and Rangitata represent increasing populations and Godley represents a stationary population.

Age class	Population			
	Mukurthi	Eravikulam	Rangitata[1a]	Godley[1b]
Young	0.56	0.37	0.37	0.59
Yearling	0.04	0.41	0.02	0.02
Adult	0.40	0.17	0.10	0.20

[1] Himalayan tahr introduced in New Zealand
[a] Increasing population of Himalayan tahr
[b] Stationary population of Himalayan tahr

Table 9. Comparison of population estimates of the Nilgiri tahr in the Mukurthi National Park, South India. January 1993 - December 1995, using different census techniques. Data were collected during this study.

Method	Year		
	1993	1994	1995
Foot survey	121	127	154
Three-day census	174	-	-
Total count	-	102	76

Table 10. Habitat characteristics measured at used and unused plots by Nilgiri tahr in the Mukurthi National Park, South India, 1993-1996.

Elevation	: Measured with an altimeter
Slope class	: F = flat(valley bottom) (0-10%), G = gentle slope (11-25%), M = moderate slope (26-45%), S = steep slope (46-100%), C = cliff face, RT = ridge top
Aspect	:
Percent vegetation cover	: Percent vegetation cover on the ground in a 1x1m quadrat (visual estimation)
Substrate class	: 1=bare soil, 2=small rocks, 3=stone, 4=boulders, 5=sheet rock
Distance to water[1]	
Distance to cliffs[1]	
Distance to sholas[1]	
Distance to disturbance[1]	
Distance to plantations[1]	
Presence of carnivores[2]	
Presence of herbivores[2]	

[1] Distance measurements made by pacing
[2] Presence / absence of carnivores and herbivores determined by visual observation of animals or presence of dung/pellets/scat in a ten meter radius circle around the plot

Table 11. Projection parameters for the India Lambert Grid used to project the satellite image and ARC/INFO coverages to real world coordinates.

Spheroid	Everest (a 6 377 301.243 meters, f 1/300.8017)
Scale factor at parallel of origin	0.998 786 408
False Northing	914 398.8 meters
False Easting	2 743 196.4 meters
Zone	IV A
Latitude of origin	12°
Central meridian	8°
Standard parallels	14° 49’ 36" .97408 E
	9° 09’ 46" .39555 N

Table 12. Descriptive statistics for Nilgiri tahr and sambur fecal pellets collected from Mukurthi National Park, South India, during the winter of 1992-93.

	Nilgiri tahr (n=40)			Sambur (n=25)		
Variable	$\bar{x}$	S.E.	Range	$\bar{x}$	S.E.	Range
Max. length (mm)	13.1	0.16	7.9-17.8	16.5	0.35	10.4-17.8
Max. width (mm)	9.0	0.11	4.7-14.0	13.4	0.20	8.7-16.1
Width at 90° (mm)	8.9	0.10	5.0-14.0	12.9	0.19	0.6-1.7
Length / width	1.4	0.01	0.8-2.0	1.2	0.03	0.8-1.9
Length / width at 90°	1.4	0.01	0.9-2.1	1.3	0.03	0.8-1.3
Width / width at 90°	1.0	0.005	0.8-1.2	1.0	0.01	
Volume (mm^3)	1135.0	32.27	205-2940	2876.6	87.38	1438.8-3918.

Table 13. Summary statistics on habitat variables measured at used and unused plots by Nilgiri tahr in the Mukurthi National Park, South India, January 1993 - December 1995.

Characteristic	n	$\bar{x}$	S.E.	Range	p[a]
Elevation (m)					
Tahr use	230	2357.2	8.85	1800 - 2573	
No tahr use	207	2304.1	10.0	2046 - 2555	0.0001
Percent ground cover					
Tahr use	337	74	0.99	20.0 - 80.0	
No tahr use	319	84	0.75	25.0 -75.0	0.0001
Distance to water (m)					
Tahr use	338	163.7	9.77	2 - 900	
No tahr use	319	136.6	8.89	1 - 900	0.01
Distance to cliffs (m)					
Tahr use	338	144.9	14.43	2 - 3000	
No tahr use	319	536.9	31.07	0 - 2000	0.0001
Distance to shola forests (m)					
Tahr use	337	67.2	4.05	2 - 800	
No tahr use	316	69.9	5.72	1 - 1000	0.1
Distance to roads (m)					
Tahr use	338	1083.4	56.57	15 - 5000	
No tahr use	319	605.4	44.26	1 - 4000	0.0001

Table 13. Continued

Characteristic	n	$\bar{x}$	S.E.	Range	p[a]
Distance to plantations (m)					
Tahr use	338	720.1	30.36	0 - 3000	
No tahr use	319	573.8	23.72	0 - 1000	0.002

[a] Probability value determined using Wilcoxon ranked sum test

Table 14. Number of random plots sampled that were used by other herbivores and carnivores during all seasons in the Mukurthi National Park, South India, January 1993 - December 1995.

	n	Present	Absent	p
Herbivores				
Tahr use	338	141	197	
No tahr use	275	49	226	0.0001[a]
Carnivores				
Tahr use	338	65	273	
No tahr use	275	4	271	0.0001[a]

[a] Probability value determined using χ^2 test of independence

Table 15. Summary statistics on habitat variables measured at used plots only by Nilgiri tahr, during the dry and wet seasons in the Mukurthi National Park, South India, January 1993 - December 1995.

Characteristic	n	$\bar{x}$	S.E.	Range	p[a]
Elevation (m)					
Dry	107	2307.1	11.64	1800 - 2527	
Wet	123	2400.7	16.24	2200 - 2573	0.0001
Percent ground cover					
Dry	127	70	1	30 - 95	
Wet	210	77	1.01	20 - 100	0.0001
Distance to water (m)					
Dry	128	113.7	4.34	2 - 600	
Wet	210	194.1	15.88	10 - 900	0.0001
Distance to cliffs (m)					
Dry	128	216.6	44.99	0 - 2000	
Wet	210	101.2	42.53	1 - 900	0.005
Distance to shola forests (m)					
Dry	127	68.9	4.24	2 - 800	
Wet	210	66.1	10.77	10 - 300	0.03
Distance to roads (m)					
Dry	128	717.8	30.98	15 - 4000	
Wet	210	1306.3	80.08	30 - 5000	0.0001

Table 15. continued

Characteristic	n	$\bar{x}$	S.E.	Range	p[a]
Distance to plantations (m)					
Dry	128	815.5	33.36	0 - 2000	
Wet	210	633.0	31.09	25 - 3000	0.0001

[a] Probability value determined using Wilcoxon ranked sum test

Table 16. Number of random plots sampled that were used by tahr and by other herbivores and carnivores during all seasons in the Mukurthi National Park, South India, January 1993 - December 1995.

	n	Present	Absent	p
Herbivores				
Dry	107	57	50	
Wet	210	84	126	0.02
Carnivores				
Dry	107	24	83	
Wet	210	43	167	0.7

[b] Probability value determined using χ^2 test of independence

Table 17. Logistic regression [a] parameter estimates (using all variables from 656 plots) for predicting Nilgiri tahr use in Mukurthi National Park, South India, January 1993-December 1995

	Parameter estimates			
Variable	Beta	S.E.	χ^2	p
Intercept	3.18	0.690	21.21	0.0010
Distance to cliffs	-0.003	0.0004	56.31	0.0001
Distance to disturbance	0.0007	0.0001	29.84	0.0001
Percent vegetation cover	-0.040	0.008	32.53	0.0001
Presence of herbivores	1.44	0.250	32.07	0.0001
Presence of carnivores	2.68	0.590	20.27	0.0001
Distance to plantations	0.0006	0.0002	6.68	0.0090
Slope class (2)	-0.580	0.690	6.19	0.0100
Distance to shola	0.003	0.001	5.63	0.0100

[a] The logistic regression equation is:

$$\theta = 1/\{1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]\} \qquad i = 1,2,\ldots, n$$

where θ is the probability of tahr use, β_0 is the beta value of the intercept, β_j is the beta value of the j^{th} dependent variables and x_{ij}'s are the data values for each of the k independent variables.

Table 18. Logistic regression [a] parameter estimates (using only distance variables from 656 plots) for predicting Nilgiri tahr use in Mukurthi National Park, South India, January 1993-December 1995

	Parameter estimates			
Variable	Beta	S.E.	χ^2	p
Intercept	-0.2258	0.1900	1.28	0.250
Distance to cliffs	-0.0036	0.0003	87.30	0.0001
Distance to disturbance	0.0008	0.0001	44.95	0.0001
Distance to plantation	0.0006	0.0002	10.36	0.0010
Distance to shola	0.0029	0.0010	6.38	0.0100

[a] The logistic regression equation is:

$$\theta = 1/\{1 + \exp[-(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij})]\} \qquad i = 1,2,\ldots, n$$

where θ is the probability of tahr use, β_0 is the beta value of the intercept, β_j is the beta value of the j^{th} dependent variables and x_{ij}'s are the data values for each of the k independent variables.

Table 19. Area in each landcover class as determined from the supervised classification image of an IRS -1B satellite image of the Mukurthi National Park, South India.

Habitat type	Area (ha)	Percentage of total area
Grasslands	8548.6	27.1
Rainforests	7879.3	25.0
Sholas	6398.8	20.3
Commercial plantations	3496.5	11.1
Water	1553.6	4.9
Agriculture	1453.2	4.6
Tea	654.8	2.1
Shadow	217.3	0.7
Unclassified	1337.2	4.2

Table 20. Area of the Mukurthi National Park, South India, in hectares and the numbers in parenthesis indicate the percent of total land area, under different probabilities of tahr use, as determined by management scenario simulation conducted using a GIS.

	Area (ha) under each probability of use value				
	0 - 0.25	0.26 - 0.5	0.51 - 0.75	0.76 - 0.85	0.86 - 1.0
Present	4696 (60%)	1439 (18%)	1105 (14%)	267 (3%)	226 (3%)
No roads	3870 (44%)	1509 (17%)	1684 (19%)	957 (11%)	836 (9%)
No plantations	3469 (39%)	1338 (15%)	1435 (16%)	830 (9%)	1799 (20%)
No roads and plantations	2820 (29%)	1043 (11%)	1410 (14%)	896 (9%)	3713 (37%)

Table 21. Descriptive statistics on the patches of suitable tahr habitat under different management scenarios and current conditions within the Mukurthi National Park, South India.

Management Option	Number of Patches	Patch Density (Number/ 100ha)	Patch Size (ha)		Inter-patch Distance (m)	
			Mean	Range	Mean	Range
Current	25	1.52	65.8	5.5 - 96	425	25 - 1823
No Roads	11	0.31	318.8	5.0 - 1790.5	340	25 - 1353
No Plantations	10	0.24	404.3	5.5 - 2900	349	56 - 619
No Roads and No Plantations	6	0.1	994.4	5.5 - 5752	145	56 - 226

Table 22. Number of visual locations of tahr in different predicted probability values of tahr use in the Mukurthi National Park, South India.

Probability of Use by Tahr	Number of Visual Locations	Percent of Total	Expected Number of Locations[1]
0.0 - 0.5	41	47.7	66
0.51 - 0.75	27	31.4	15
0.76 - 0.85	8	9.3	3
0.86 - 1.0	10	11.6	2

Distribution of observed and expected tahr locations were significantly different when tested using the χ^2 test of independence (χ^2 = 54.9, df =3)

[1] Expected number of locations if visual locations were randomly distributed.

Table 23. Mean number of plants in 679 plots (1 m^2) sampled in the Mukurthi National Park, South India during all seasons of 1993-1995.

Species	Mean number of plants / m^2	S.E.
Grasses		
Andropogon. oligantha	13.88	1.45
Dicanthium polyptylum	7.06	0.33
Eulalia phaeothrix	5.68	0.25
Andropogon sp.	5.44	0.26
Minor grasses	3.33	0.25
Chrysopogon zeylanicus	3.17	0.18
Ischaemum rugosum	2.88	0.21
Tripogon bromoides	0.72	0.10
Arudinella sp.	1.58	0.18
Sedges		
Carex sp.	1.77	0.17
Forbs		
Taraxacum officinale	8.55	0.51
Minor forbs	6.08	0.33
Impatiens pocilla	3.54	0.60

Table 23. Continued

Species	Mean number of plants / m^2	S.E.
Eriocaulon sp.	3.24	0.45
Impatiens sp.	2.78	0.31
Curculigo orchioides	1.11	0.10
Cyanotis sp.	0.18	0.03
Shrubs		
Leucas suffruticosa	2.29	0.13
Knoxia sp.	0.85	0.09
Strobilanthus sp.	0.60	0.18
Minor shrubs	0.91	0.08

Table 24. Density or mean number of plants (1 m^2 plot) of some plants in the dry (n = 292) and wet (n = 387) seasons on the grasslands of the Mukurthi National Park, South India, 1993-1995.

Species	Season	Mean number of plants / m^2	S.E.
Grasses			
Andropogon sp.	Dry	6.20	0.46
	Wet	4.86	0.31
Chrysopogon zeylanicus	Dry	2.76	0.30
	Wet	3.48	0.23
Tripogon bromoides	Dry	0.57	0.14
	Wet	0.82	0.15
Ischaemum rugosum	Dry	1.39	0.20
	Wet	4.01	0.32
Eulalia phaeothrix	Dry	6.52	0.39
	Wet	5.05	0.33
Arudinella sp.	Dry	1.65	0.28
	Wet	1.53	0.23
Dicanthium polyptylum	Dry	9.68	0.64
	Wet	5.09	0.29
Andropogon. oligantha	Dry	0	0
	Wet	24.36	2.41
Minor grasses	Dry	3.78	0.35
	Wet	2.99	0.35
Sedges			
Carex sp.	Dry	1.16	0.21
	Wet	2.23	0.25

Table 24. continued

Species	Season	Mean number of plants / m^2	S.E.
Forbs			
Taraxacum officinale	Dry	7.45	0.80
	Wet	9.39	0.65
Curculigo orchioides	Dry	0.33	0.08
	Wet	1.70	0.17
Eriocaulon sp.	Dry	0.15	0.06
	Wet	5.57	0.77
Cyanotis sp.	Dry	0.11	0.04
	Wet	0.23	0.05
Impatiens sp.	Dry	0.26	0.11
	Wet	4.68	0.52
Impatiens pocilla	Dry	0	0
	Wet	6.22	1.04
Minor forbs	Dry	2.8	0.40
	Wet	8.55	0.45
Shrubs			
Strobilanthus sp.	Dry	0.81	0.27
	Wet	0.45	0.24
Leucas suffruticosa	Dry	2.22	0.19
	Wet	2.35	0.19
Knoxia sp.	Dry	0.43	0.07
	Wet	1.17	0.15

Table 24. continued

Species	Season	Mean number of plants / m^2	S.E.
Minor shrubs	Dry	0.73	0.10
	Wet	1.03	0.13

Table 25. Density or mean number of plants (1 m^2 plot) of some plant species in the grasslands of north (n = 359) and south (n = 318) sectors of the Mukurthi National Park, South India during all seasons of 1993-1995.

Species	Area	Mean number of plants / m^2	p[*]	Selection[a]
Grasses				
Andropogon sp.	North	6.44	0.0001	+
	South	3.4		
Chrysopogon zeylanicus	North	3.75	0.0001	+
	South	2.51		
Tripogon bromoides	North	0.88	0.1	+
	South	0.53		
Ischaemum rugosum	North	3.88	0.0001	+
	South	1.75		
Eulalia phaeothrix	North	6.58	0.0001	+
	South	4.66		
Arudinella sp.	North	1.71	0.8	0
	South	1.43		
Dicanthium polyptylum	North	6.51	0.003	-
	South	7.69		
Andropogon oligantha	North	16.26	0.05	-
	South	11.19		
Minor grasses	North	3.44	0.0001	-
	South	4.77		
Sedges				
Carex sp.	North	2.37	0.0001	+
	South	1.09		

Table 25. continued

Species	Area	Mean number of plants / m^2	p[*]	Selection[a]
Forbs				
Taraxacum officianale	North	9.67	0.7	-
	South	7.29		
Curculigo orchioides	North	1.22	0.002	+
	South	0.99		
Eriocaulon sp.	North	3.2	0.2	-
	South	3.29		
Cyanotis sp.	North	0.23	0.2	-
	South	0.12		
Impatiens sp.	North	3.16	0.009	-
	South	2.34		
Impatiens pocilla	North	4.75	0.01	-
	South	2.17		
Minor forbs	North	4.2	0.0001	-
	South	2.9		
Shrubs				
Strobilanthus sp.	North	0.03	0.0005	+
	South	1.26		
Leucas suffruticosa	North	2.39	0.3	-
	South	2.18		
Knoxia sp.	North	0.97	0.7	-
	South	0.71		
Minor shrubs	North	0.91	0.05	-
	South	0.9		

Table 25. continued

* Based on Wilcoxon 2 sample test

[a] + = Active selection, 0 = No selection, - = Avoidance

Table 26. Mean proportion of occurrence of some forage species in the diet of the Nilgiri tahr (use, n = 295) and in the grasslands (available, n = 677) of the Mukurthi National Park, South India, January 1993 to December 1995.

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Preference				
Eulalia phaeothrix	Use	24	0.0001	+
	Available	10.42		
Chrysopogon zeylanicus	Use	22.53	0.0001	+
	Available	6.85		
Isachemum rugosum	Use	12.96	0.0001	+
	Available	4.2		
Andropogon sp.	Use	12.62	0.0005	+
	Available	8.62		
Carex sp.	Use	12.5	0.0001	+
	Available	2.29		
Tripogon bromoides	Use	4.05	0.0001	+
	Available	1.11		
Strobilanthus sp.	Use	3.88	0.0001	+
	Available	0.88		
Curculigo orchioides	Use	2.04	0.0001	+
	Available	1.4		
Fimbristylis	Use	1.95	0.0001	+
	Available	0.27		

Table 26. continued

Species	Status	Mean proportion of occurrence	p*	Selection[a]
No selection				
Arundinella fuscata	Use	4.1	0.8	0
	Available	2.68		
Avoidance				
Taraxacum officinale	Use	8.59	0.0001	-
	Available	11.82		
Leucas suffruticosa	Use	3.56	0.002	-
	Available	4.11		
Minor grasses	Use	2.38	0.0001	-
	Available	6.73		
Minor forbs	Use	1.84	0.0001	-
	Available	9.19		
Impatiens sp.	Use	1.02	0.007	-
	Available	3.34		
Dicanthium polyptychus	Use	0.51	0.0001	-
	Available	14.22		
Knoxia	Use	0.07	0.0001	-
	Available	1.43		
Minor shrubs	Use	0.02	0.0001	-
	Available	1.95		

* Based on Wilcoxon 2-sample test
[a] + = Active selection, 0 = No selection, - = Avoidance

Table 27. Mean proportion of occurrence of some forage plants in the diet of the Nilgiri tahr (use, n = 109) and the grasslands (available, n = 296) of the Mukurthi National Park, South India during the dry seasons of 1993 to 1995.

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Preference				
Eulalia phaeothrix	Use	20.1	0.0008	+
	Available	13.5		
Chrysopogon zeylanicus	Use	15.3	0.0001	+
	Available	5.6		
Carex sp.	Use	14.6	0.0001	+
	Available	1.8		
Isachemum rugosum	Use	6.7	0.006	+
	Available	2.9		
Curculigo orchioides	Use	2.4	0.0001	+
	Available	0.05		
Tripogon bromoides	Use	2.0	0.005	+
	Available	1.1		
No selection				
Taraxacum officianale	Use	13.7	0.309	0
	Available	12.9		
Avoidance				
Andropogon sp.	Use	8.6	0.01	-
	Available	11.4		
Leucas suffruticosa	Use	3.8	0.006	-
	Available	4.8		

Table 27. continued

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Dicanthium polyptychus	Use	1.2	0.0001	-
	Available	20.2		

* Based on Wilcoxon 2-sample test

[a] + = Active selection, 0 = No selection, - = Avoidance

Table 28. Mean proportion of occurrence of some forage species in diet of the Nilgiri tahr (use, n = 188) and in grasslands (available, n = 387) of the Mukurthi National Park, South India, during the wet seasons of 1993-1995.

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Preference				
Eulalia phaeothrix	Use	17.6	0.0001	+
	Available	6.8		
Chrysopogon zeylanicus	Use	13.4	0.0001	+
	Available	4.1		
Andropogon sp.	Use	12.4	0.0001	+
	Available	5.7		
Isachemum rugosum	Use	12.3	0.0001	+
	Available	4.5		
Carex sp.	Use	9.4	0.0001	+
	Available	2.2		
Tripogon bromoides	Use	4.8	0.0001	+
	Available	0.8		
No selection				
Arundinella fuscata	Use	4.3	0.1	0
	Available	1.8		
Leucas suffruticosa	Use	3.0	0.1	0
	Available	3.2		
Curculigo orchioides	Use	1.5	0.3	0
	Available	1.8		

Table 28. continued

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Avoidance				
Taraxacum officinale	Use	4.4	0.0001	-
	Available	10.0		
Dicanthium polyptychus	Use	0.07	0.0001	-
	Available	8.8		

* Based on Wilcoxon 2 -sample test
[a] + = Active selection, 0 = No selection, - = Avoidance

Table 29. Mean proportion of occurrence of some forage species in the diet of the Nilgiri tahr (use, n = 259) and in the grasslands (available, n = 359) of the north sector of the Mukurthi National Park, South India, January 1993 to December 1995.

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Preference				
Eulalia phaeothrix	Use	26.2	0.0001	+
	Available	11.13		
Chrysopogon zeylanicus	Use	24.17	0.0001	+
	Available	8.39		
Isachemum rugosum	Use	14.06	0.0001	+
	Available	5.15		
Carex sp.	Use	12.68	0.0001	+
	Available	3.1		
Tripogon bromoides	Use	3.82	0.0001	+
	Available	1.05		
Strobilanthus sp.	Use	3.32	0.0001	+
	Available	0.1		
Fimbristylis	Use	1.96	0.0001	+
	Available	0.43		
No Selection				
Andropogon sp.	Use	12.03	0.4	0
	Available	9.64		
Arundinella fuscata	Use	4.45	0.5	0
	Available	3.04		

Table 29. continued

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Avoidance				
Taraxacum officianale	Use	7.67	0.0001	-
	Available	11.92		
Leucas suffruticosa	Use	2.94	0.0001	-
	Available	3.81		
Minor grasses	Use	2.53	0.0001	-
	Available	4.48		
Minor forbs	Use	1.19	0.0001	-
	Available	9.05		
Impatiens sp.	Use	1.08	0.0006	-
	Available	3.89		
Dicanthium polyptychus	Use	0.58	0.0001	-
	Available	11.56		
Knoxia	Use	0.05	0.0001	-
	Available	1.32		
Minor shrubs	Use	0	0.0001	-
	Available	1.62		

* Based on Wilcoxon 2-sample test

[a] + = Active selection, 0 = No selection, - = Avoidance

Table 30. Mean proportion of occurrence of some forage species in the diet of the Nilgiri tahr (use, n = 35) and in the grasslands (available, n = 318) of the south sector of the Mukurthi National Park, South India, January 1993 to December 1995.

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Preference				
Andropogon sp.	Use	17.37	0.0001	+
	Available	7.47		
Taraxacum officianale	Use	15.7	0.001	+
	Available	11.71		
Carex sp.	Use	10.68	0.0001	+
	Available	1.37		
Chrysopogon zeylanicus	Use	9.42	0.001	+
	Available	5.38		
Leucas suffruticosa	Use	8.26	0.0001	+
	Available	4.45		
Strobilanthus sp.	Use	8.13	0.0001	+
	Available	1.76		
Tripogon bromoides	Use	5.81	0.0001	+
	Available	1.18		
Fimbristylis	Use	1.96	0.0001	+
	Available	0.09		
No selection				
Eulalia phaeothrix	Use	7.36	0.08	0
	Available	9.64		

Table 30. continued

Species	Status	Mean proportion of occurrence	p*	Selection[a]
Minor forbs	Use	6.68	0.8	0
	Available	9.36		
Isachemum rugosum	Use	4.15	0.1	0
	Available	3.12		
Arundinella fuscata	Use	1.67	0.06	0
	Available	2.27		
Impatiens sp.	Use	0.63	0.7	0
	Available	2.72		
Avoidance				
Minor grasses	Use	1.29	0.0003	-
	Available	9.26		
Knoxia sp.	Use	0.26	0.01	-
	Available	1.56		
Minor shrubs	Use	0.22	0.001	-
	Available	2.33		
Dicanthium polyptychus	Use	0.06	0.0001	-
	Available	17.24		

* Based on Wilcoxon 2-sample test
[a] + = Active selection, 0 = No selection, - = Avoidance

Table 31. Frequency of occurrence (percentage in parentheses), relative biomass, and relative number of prey consumed by tiger (*Panthera tigris*), as determined by scat analysis (n=53) in the Mukurthi National Park, South India, January 1993-December 1995.

Prey item	Frequency of occurrence (A)	Estimated mass (kg)[a] (B)	Correction factor[b] (kg/scat) (C)	Relative biomass consumed (%)[c] (D)	Relative number consumed (%)[d] (E)
Nilgiri tahr	8 (15.1)	49	3.69	6.71	22.48
Sambur	43 (81.1)	212	9.4	91.77	70.99
Wild boar	2 (3.8)	38	3.31	1.5	5.53

[a] Estimated mean live weight (kg) of individuals consumed
[b] Estimated weight of prey consumed per collectible scat produced
[c] $D = (A \times C) / \sum (A \times C)$
[d] $E = (D \div B) / \sum (D \div B)$

Table 32. Frequency of occurrence (percentage in parentheses), relative biomass, and relative number of prey consumed by leopard (*Panthera pardus*), as determined by scat analysis (n=95) in the Mukurthi National Park, South India, January 1993 - December 1995.

Prey item	Frequency of occurrence (A)	Estimated mass (kg)[a] (B)	Correction factor (kg/scat)[b] (C)	Relative biomass consumed (%)[c](D)	Relative number consumed (%)[d](E)
Nilgiri tahr	55 (57.9)	49	3.69	56.43	53.49
Sambur	34 (35.8)	62	4.15	39.18	29.36
Wild boar	2 (2.1)	37	3.27	1.81	2.27
Nilgiri langur	3 (3.2)	8	2.26	1.91	11.07
Porcupine	1 (1.1)	8	2.26	0.65	3.8

[a] Estimated mean live weight (kg) of individuals consumed
[b] Estimated weight of prey consumed per collectible scat produced
[c] $D = (A \times C) / \sum (A \times C)$
[d] $E = (D \div B) / \sum (D \div B)$

Table 33. Average weight, sex, age composition, and estimated total biomass of Nilgiri tahr in the Mukurthi National Park, South India, 1995

Sex / age class	Average weight (kg)[a]	Percent composition[b]	Observed number[b]	Estimated total biomass (kg)
Males				
Young males	19	8.75	13	247
Yearling males	50	7.1	11	550
Light brown males	82	20.7	32	2624
Dark brown males	100	2.5	4	400
Saddle back males	102	7.7	12	1224
Females				
Young females	18	8.75	14	252
Yearling females	29	7.1	11	319
Adult females	38	37	57	2166

[a] Derived from the polynomial equations, to predict weights for a given age class
For males: $y = -3.52x^2 + 37.67x + 1.40$
For females: $y = -5.35x^2 + 34.54x + 5.46$, where y = average weight

[b] From foot surveys conducted in 1995

Table 34. Estimated number of tahr killed per year by leopards (*Panthera pardus*), and tigers (*Panthera tigris*) within the Mukurthi National Park, South India, January 1993-December 1995

Age / sex class	Mortality rate	Estimated mortality (tahr lost)[a]	Estimated tahr killed		
			Leopard	Tiger	Total
Young	0.569	29	4-8	1-2	5-10
Yearling	0.042	1	3-7	1-2	4-9
Adult females	0.403	23	9-18	2-4	11-22
Light brown males	0.403	13	5-10	1-2	6-12
Dark brown males	0.403	2	1	0-1	1-2
Saddle backs	0.403	5	2-4	0-1	2-5
Total		73	24-48	5-12	29-60

[a] Includes mortality from all causes

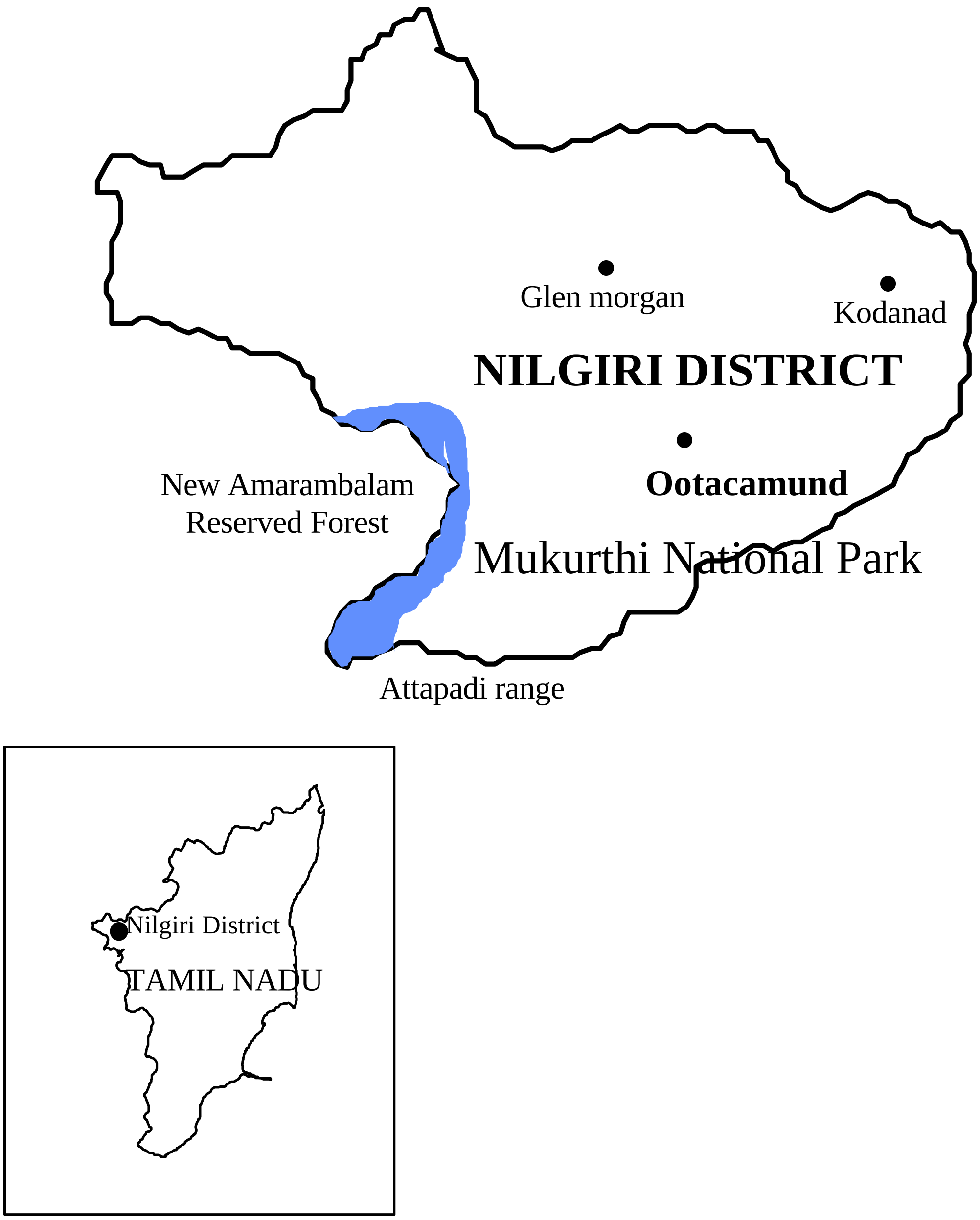


Figure 1. Map of Nilgiri district in Tamil Nadu, showing location of Mukurthi National Park, and areas outside the park that were tahr habitats

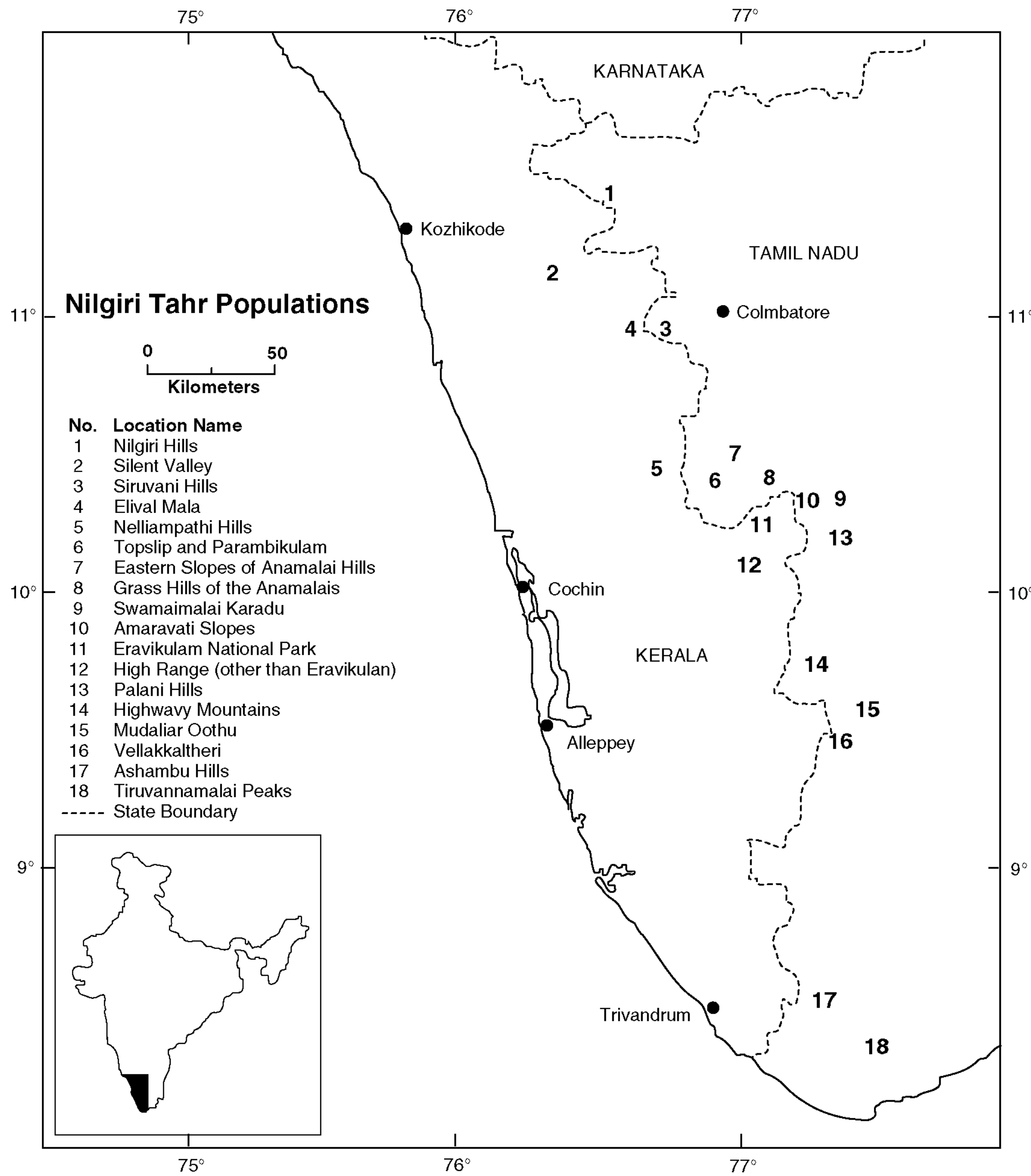


Figure 2. Map of South India showing the 19 Nilgiri tahr populations (after Rice 1984).

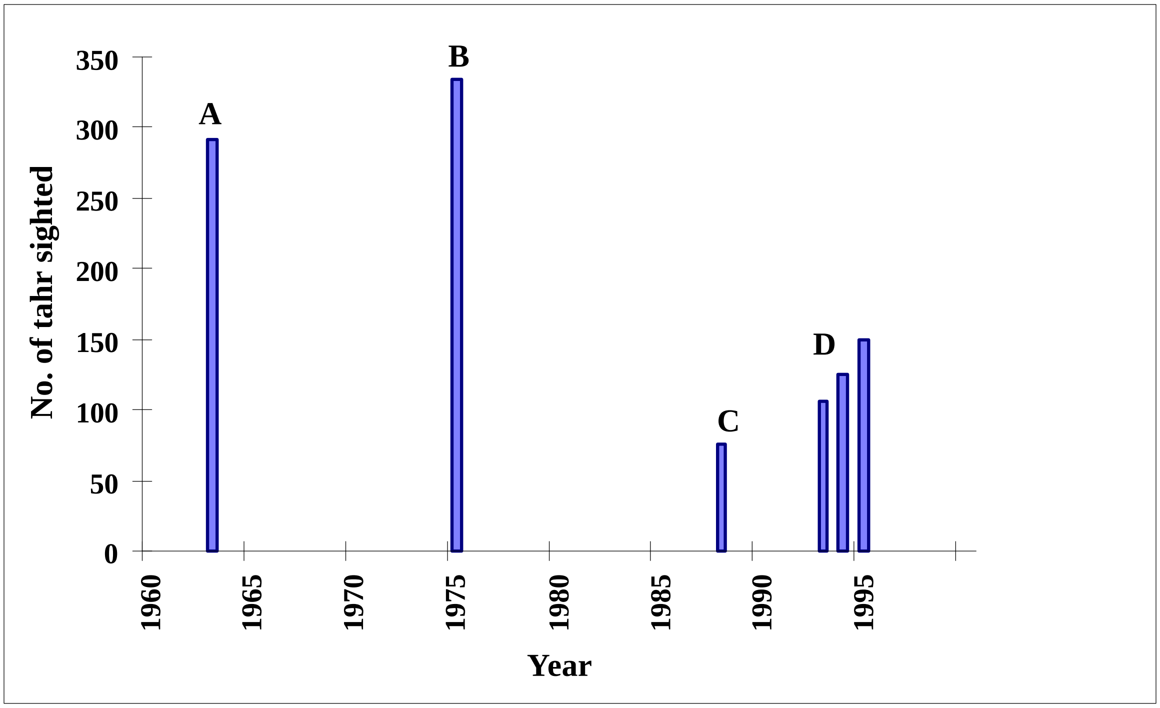


Figure 3. Number of Nilgiri tahr sighted in the Mukurthi National Park, South India, 1962 - 1995. A = Davidar (1963), B = Davidar (1975), C = NWEA (1987) and D = this study.

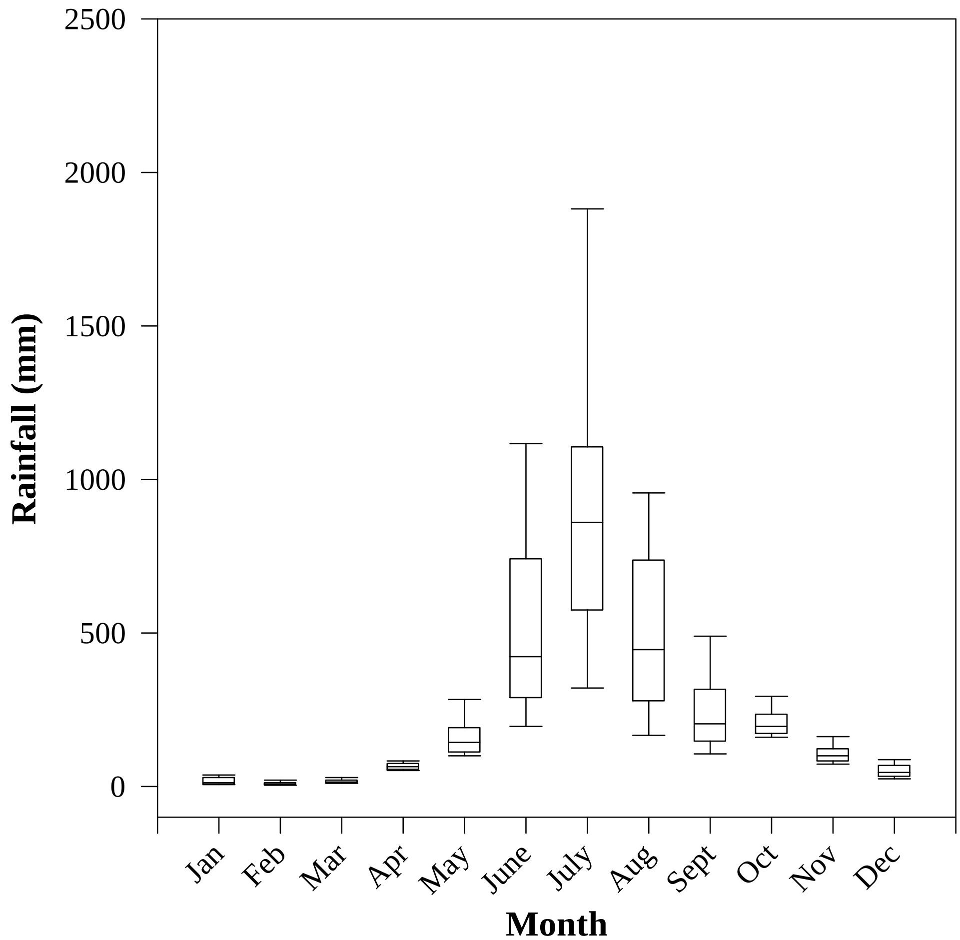


Figure 4. Average monthly rainfall recorded at 10 stations in the Mukurthi National Park, South India, from 1941 to 1970 (after Lengerke 1977).

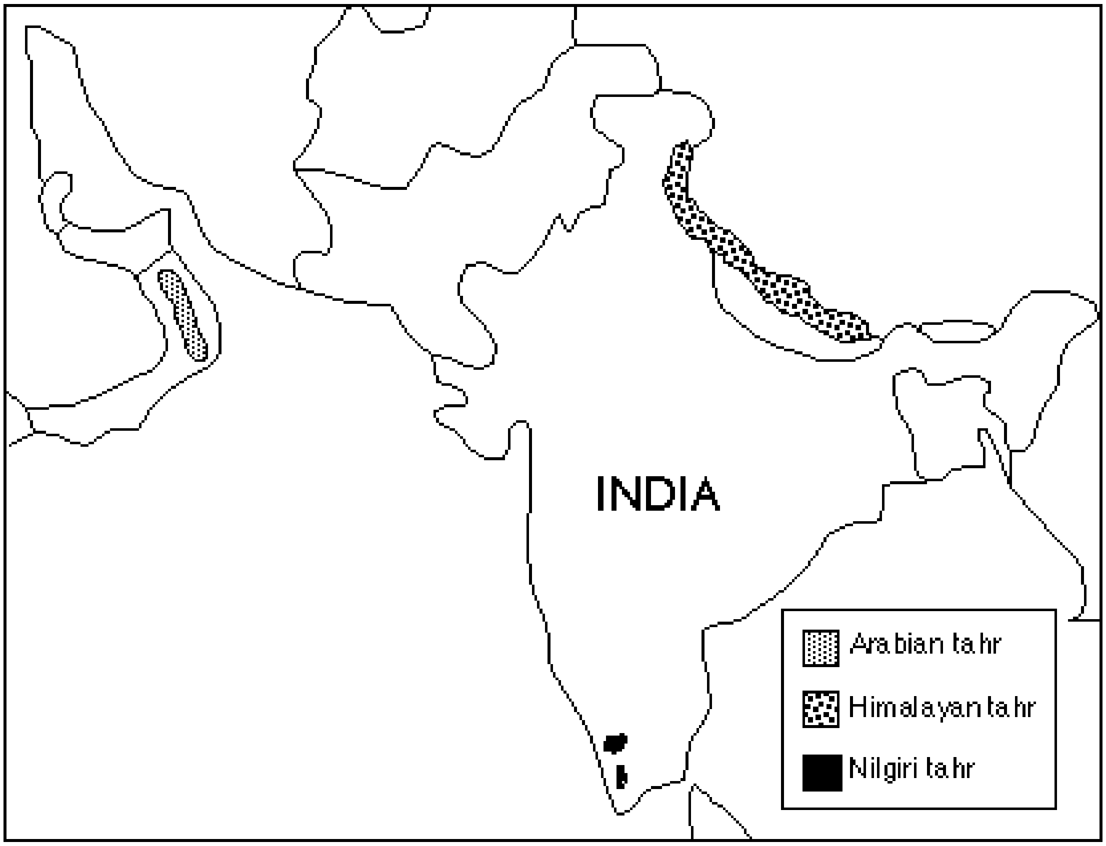


Figure 5. Map of Asia showing the distribution of the three species of tahr.

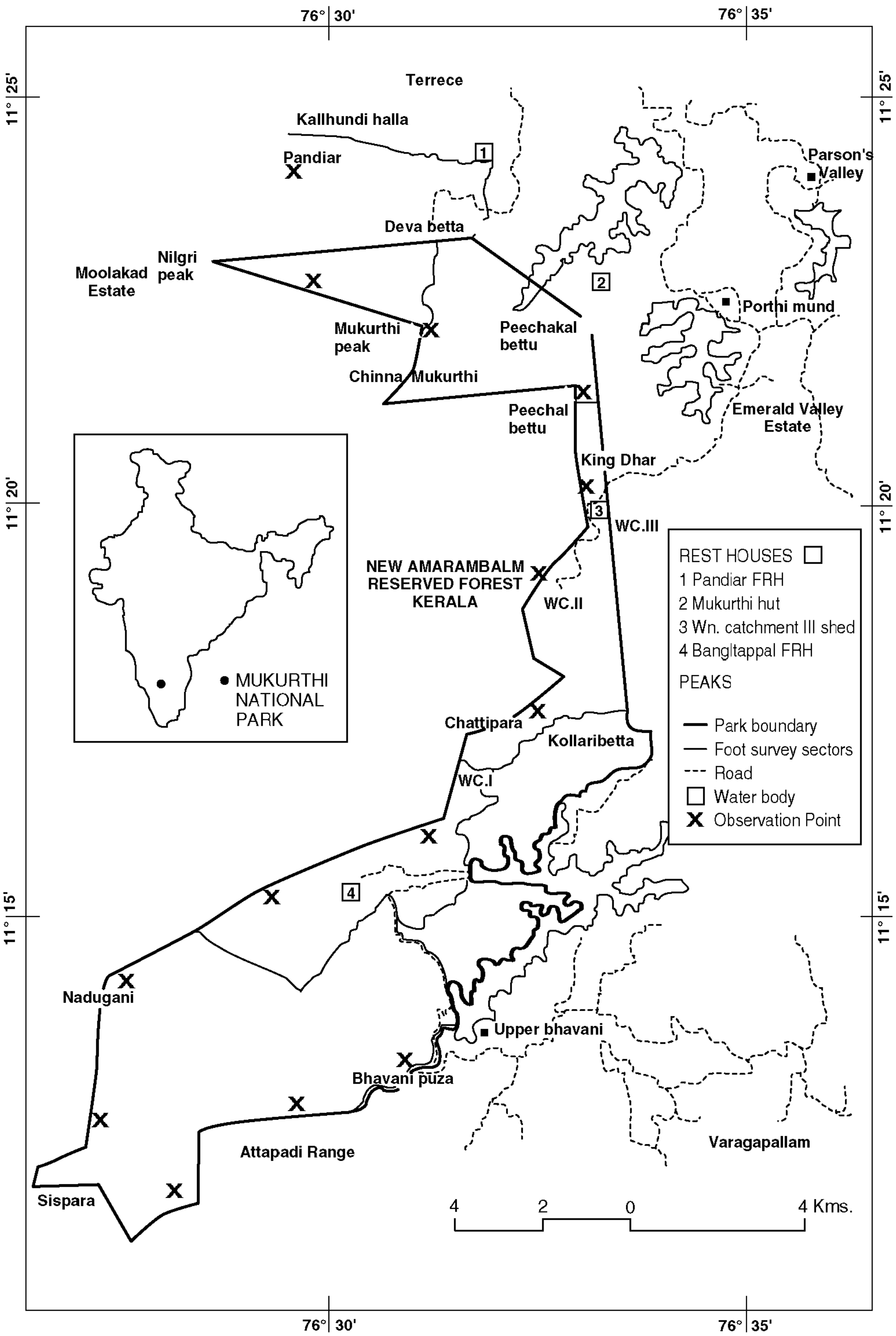


Figure 6. Map of Mukurthi National Park, South India, showing the five sectors used for foot surveys and total counts.

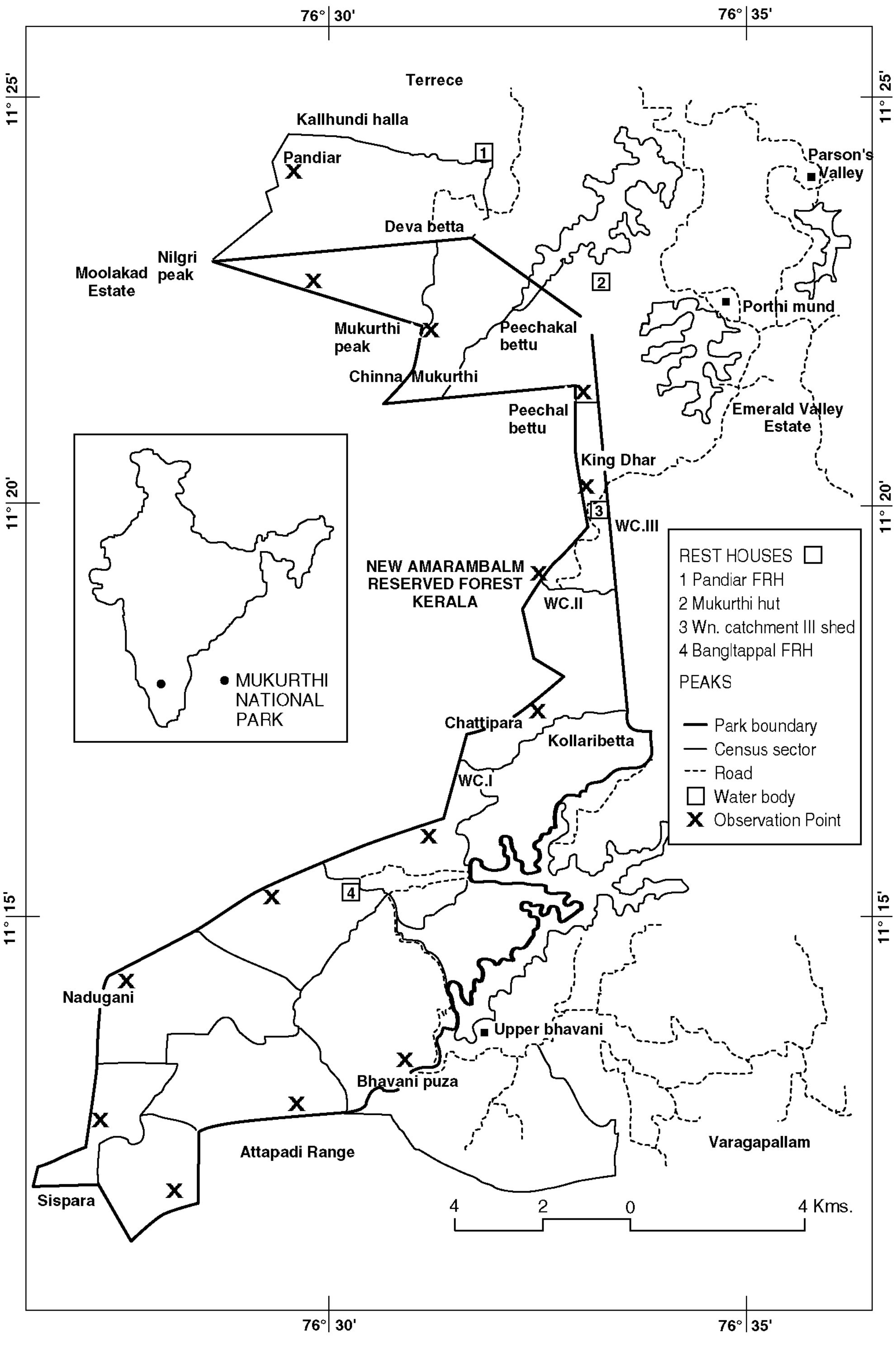


Figure 7. Map of Mukurthi National Park, South India, showing the 16 sectors used for the three-day census, and the location of the 16 observation points.

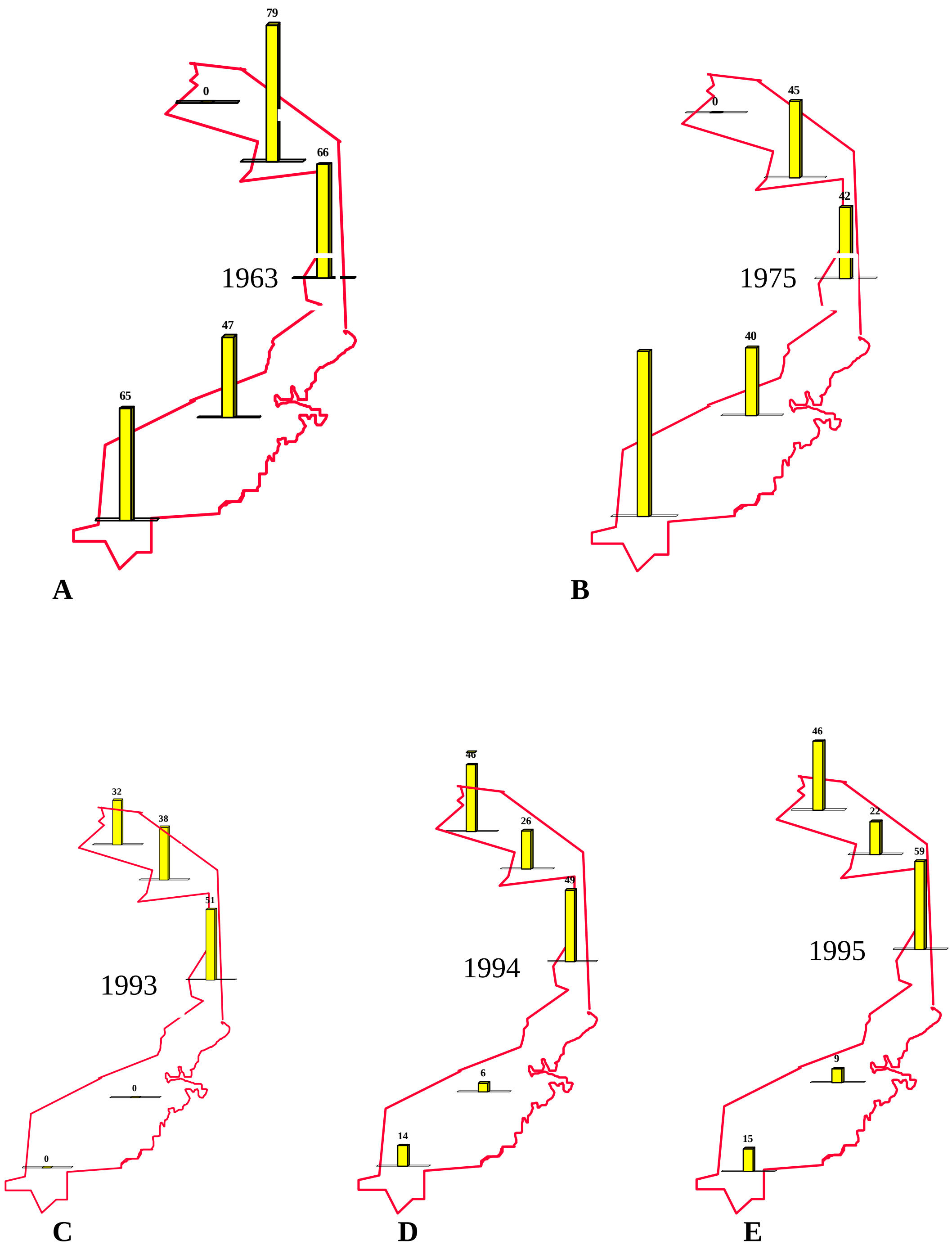


Figure 8. Nilgiri tahr distribution in the various sectors of the Mukurthi National Park, South India from 1963 to 1995. Figure A and B are based on Nilgiri tahr sightings by Davidar (1963) and Davidar (1976) respectively. Figures C, D, and E are based on Nilgiri tahr sightings during 1993, 1994, and 1995 respectively.

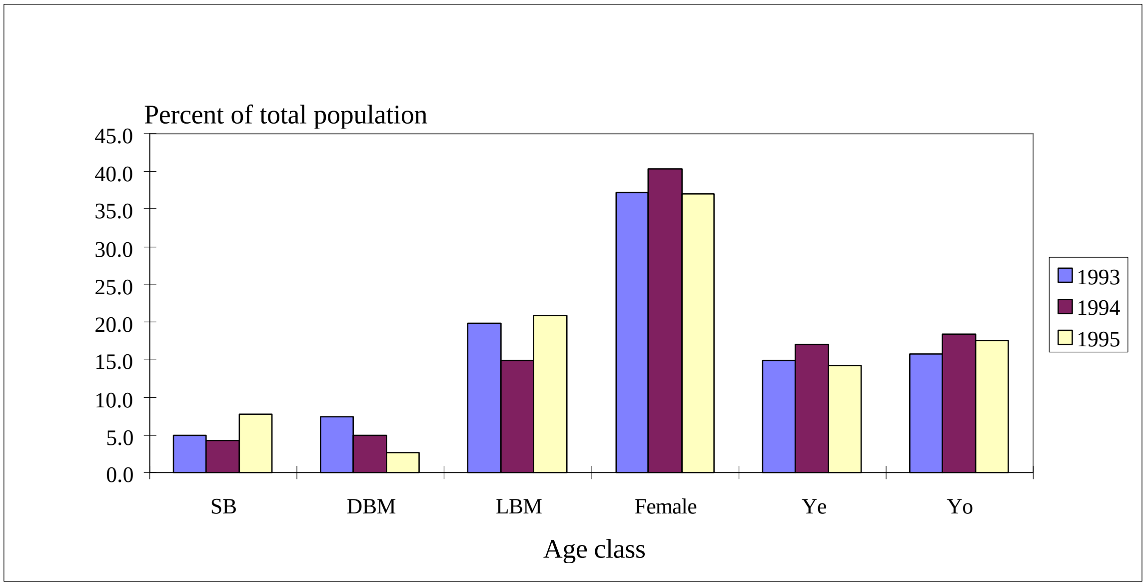


Figure 9. Sex and age-class composition of Nilgiri tahr in the Mukurthi National Park, South India, January 1993 to December 1994. Codes for age and sex classes are presented in Table 3.

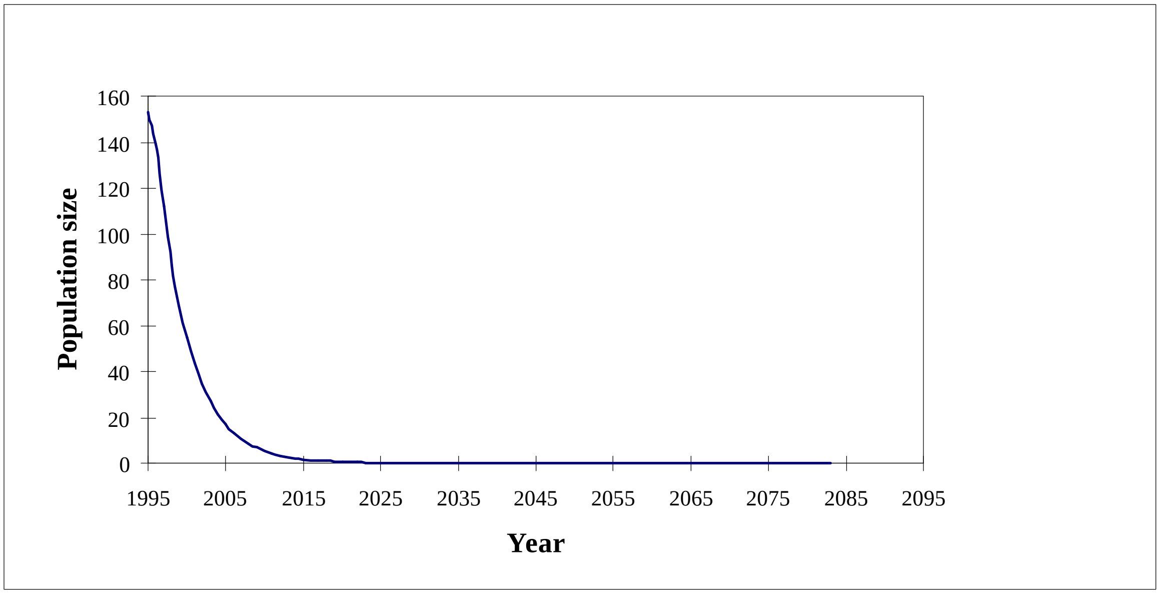


Figure 10. Projection of population size of the Nilgiri tahr in the Mukurthi National Park, South India, under current mortality rates of 0.56 for the young age class and 0.40 for the adult age class.

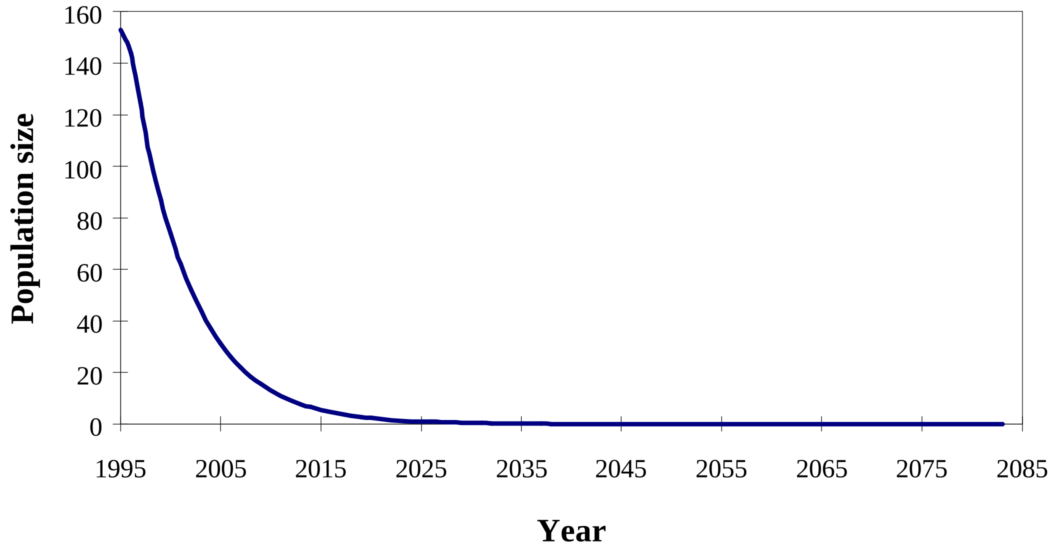


Figure 11. Projection of population size of the Nilgiri tahr in the Mukurthi National Park, South India, when the mortality rate for the young age class is reduced from 0.56 to 0.37 and adult mortality rate is 0.40.

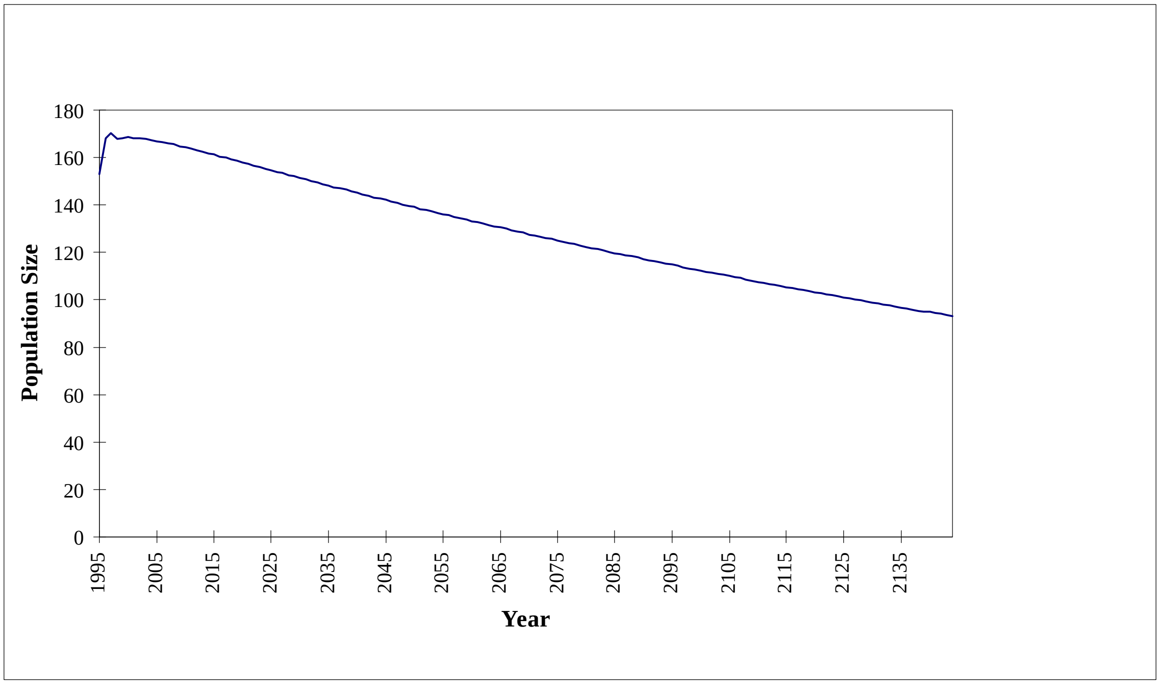


Figure 12. Projection of population size of the Nilgiri tahr in the Mukurthi National Park, South India, when the mortality rate for the young age class is 0.56 and adult mortality rate is reduced from 0.40 to 0.17.

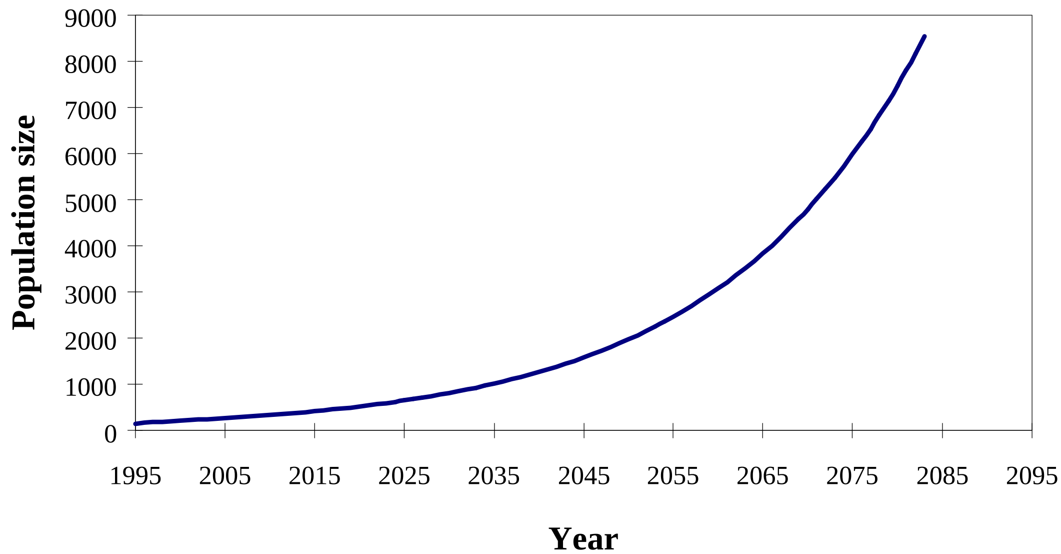


Figure 13. Projection of population size of the Nilgiri tahr in the Mukurthi National Park, South India, when the mortality rates for the young age class and adult age class are reduced from 0.56 to 0.37 and from 0.40 to 0.17 respectively.

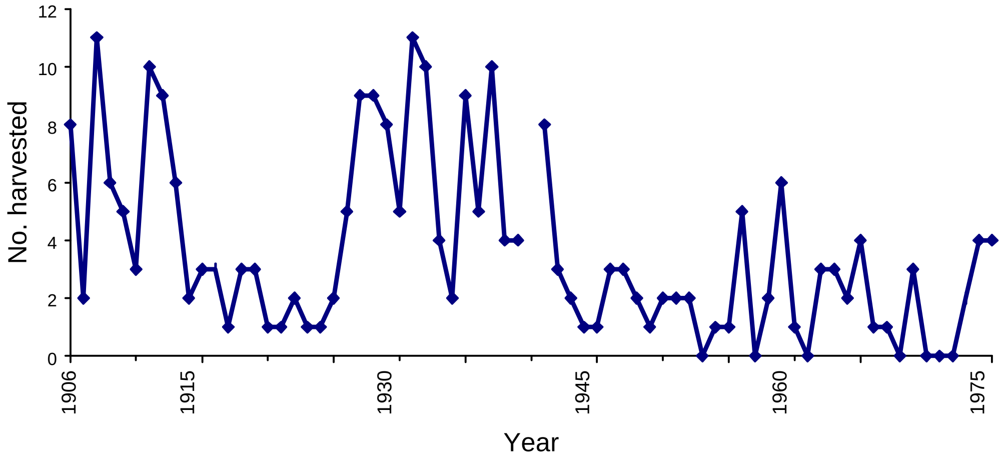


Figure 14. Nilgiri tahr harvest records from the Nilgiri Game Association hunter return records 1906 - 1972.

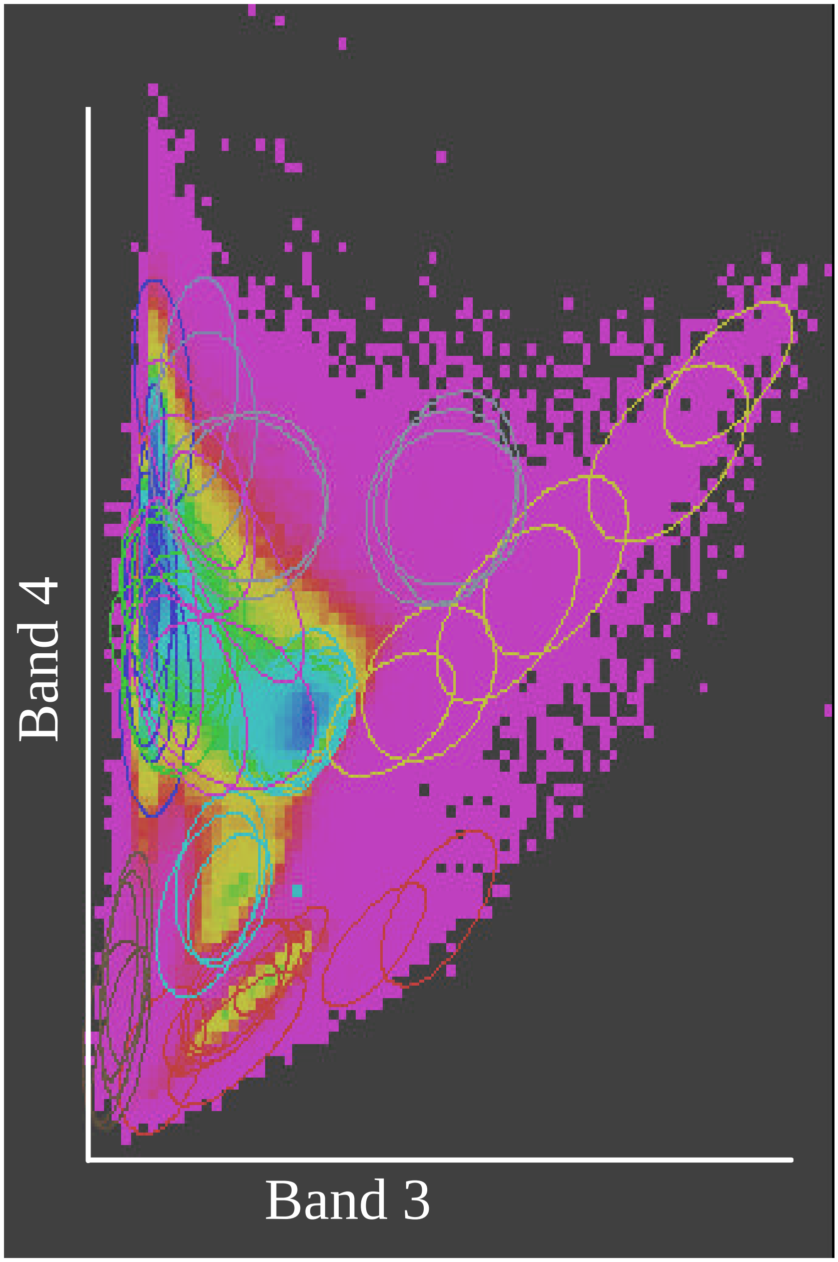


Figure 15. Bands 3 and 4 of the IRS 1B satellite image used to show the partitioning of the spectral signatures in feature space.

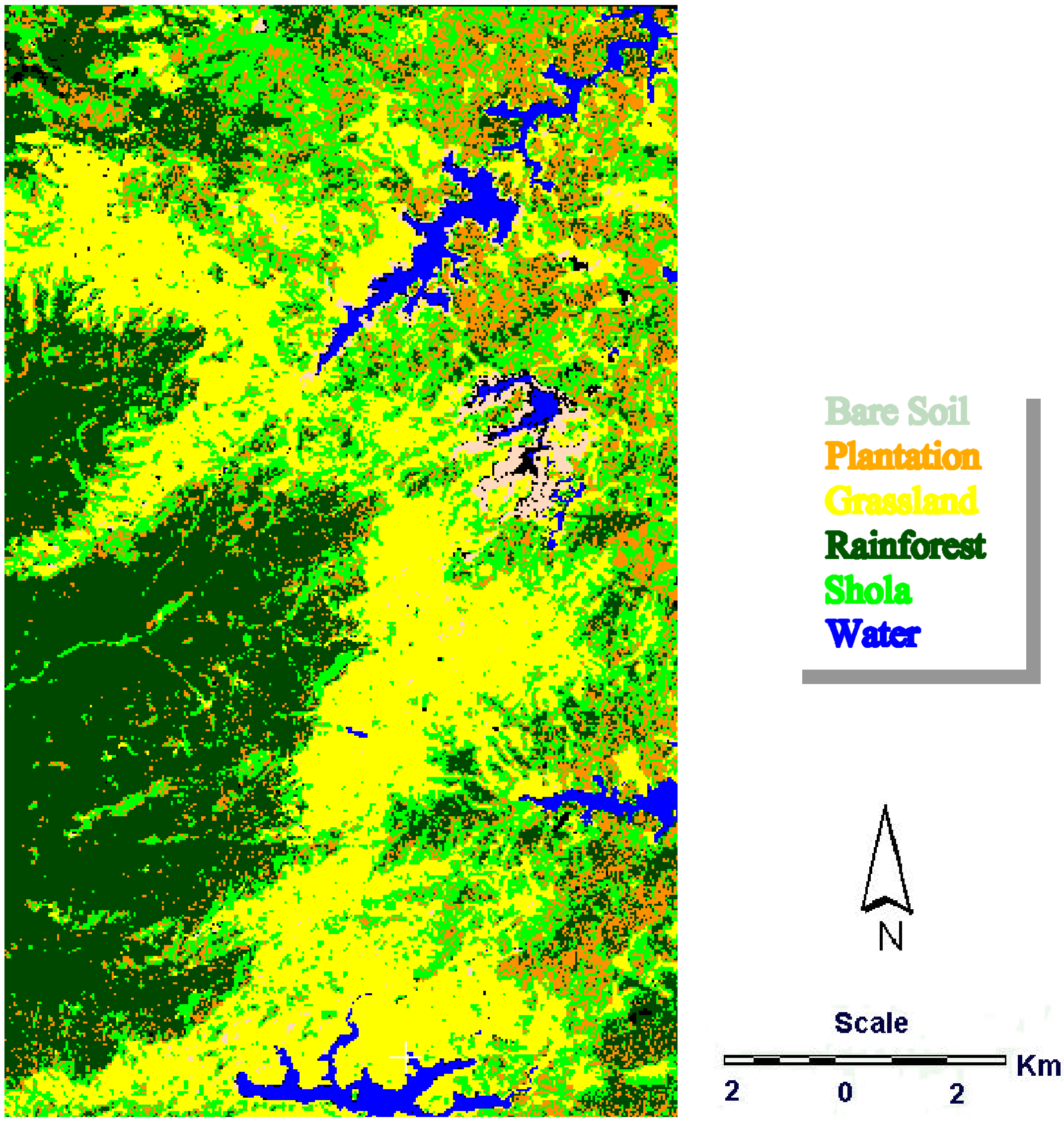
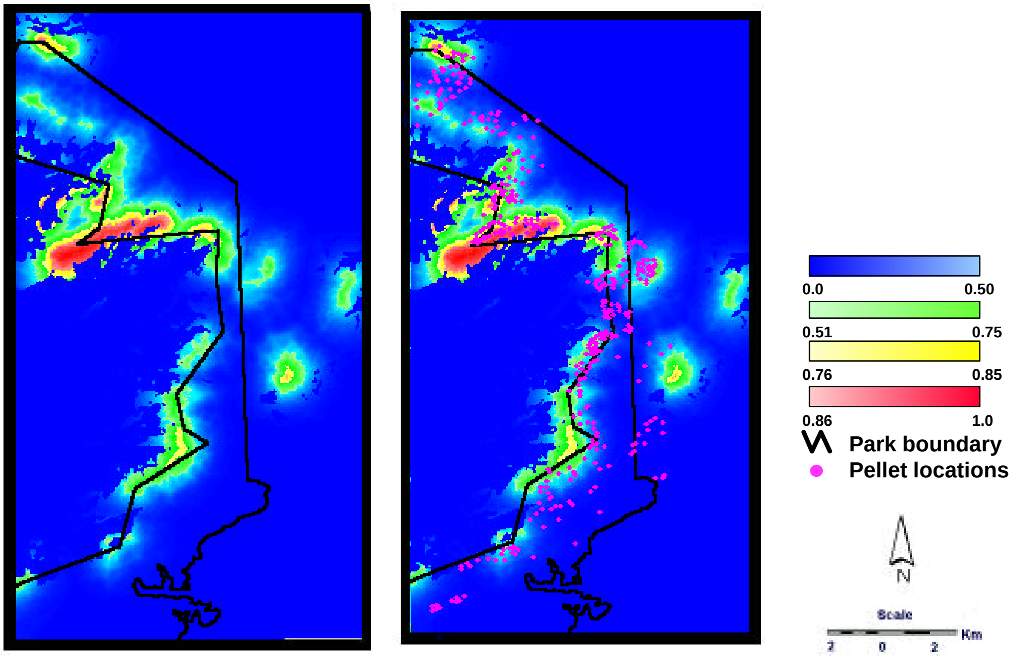
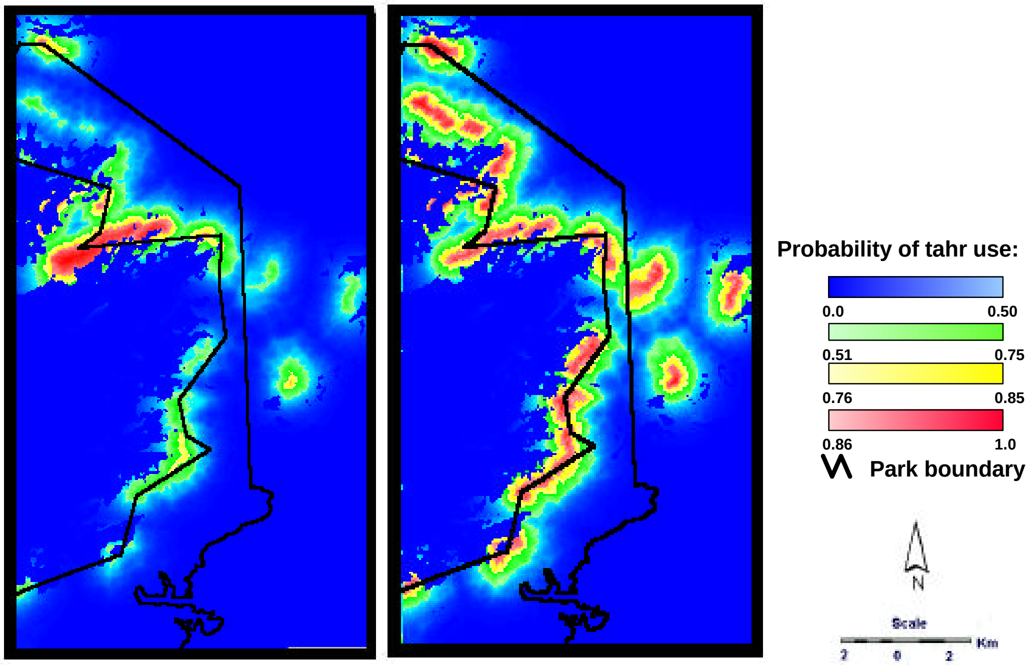


Figure 16. Supervised classification image of the Mukurthi National Park, South India and its surroundings. Image captured by IRS 1B satellite on 20 March 1995.



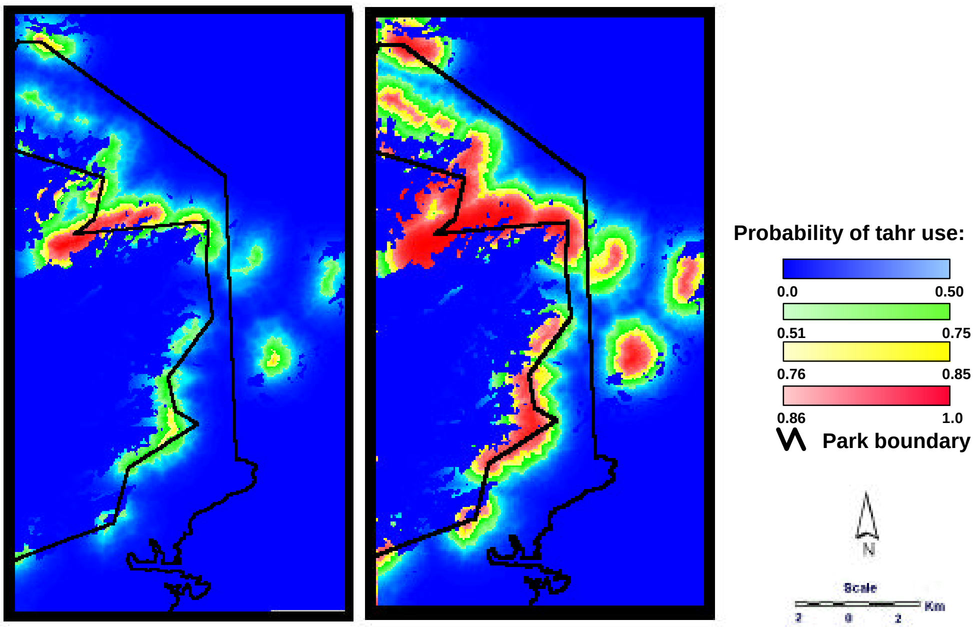
Model A Model B

Figure 17. Models showing the probability of tahr use within the Mukurthi National Park, South India. Model A shows the current probabilities of tahr use in 25x25-m pixels, Model B shows the current probabilities with pellet locations overlaid on the model.



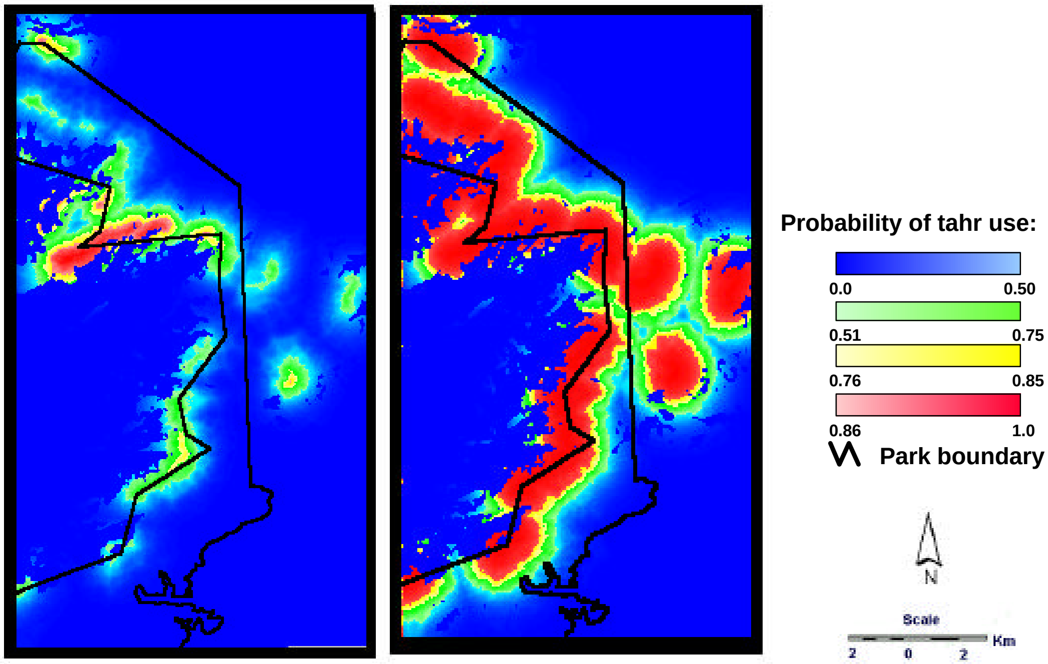
Model A Model B

Figure 18. Models simulating the effect of closure of roads on the probability of tahr use in the Mukurthi National Park, South India. Model A shows the current probabilities of tahr use in 25x25-m pixels and Model B shows the expected probability of tahr use when roads are closed.



Model A Model B

Figure 19. Models simulating the effect of removal of commercial forestry plantations within the Mukurthi National Park, South India. Model A shows the current probabilities of tahr use in 25x25-m pixels, Model B shows the expected probabilities when commercial forestry plantations are removed and the area allowed to return to grasslands.



Model A Model B

Figure 20. Models simulating the effect of closure of roads and removal of commercial forestry plantations on the probability of tahr use in the Mukurthi National Park, South India. Model A shows the current probabilities of tahr use in 25x25-m pixels and Model B shows the expected probability of tahr use when roads are closed and commercial plantations are removed.

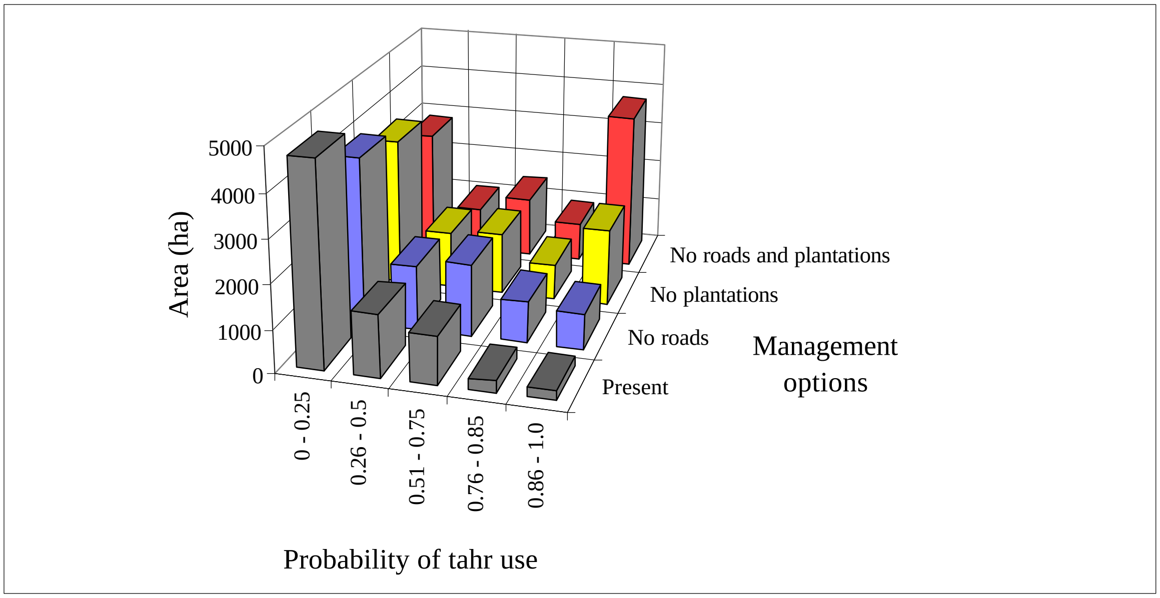


Figure 21. Changes in probabilities of use of areas by tahr given three simulated management options.

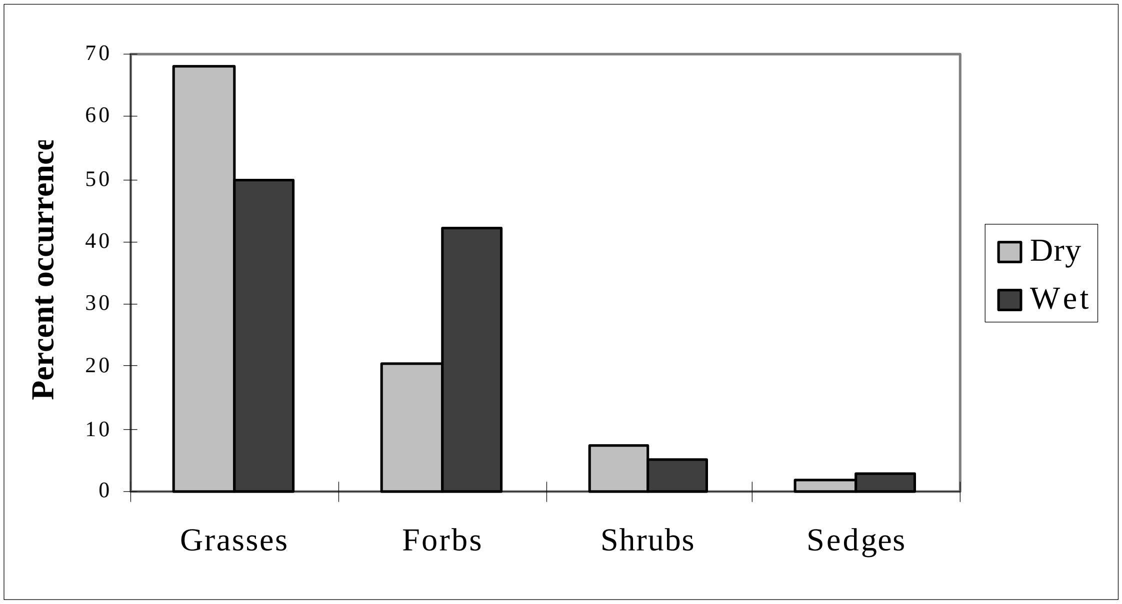


Figure 22. Seasonal differences in the vegetation composition of the grasslands in the Mukurthi National Park, South India, January 1993 - December 1995.

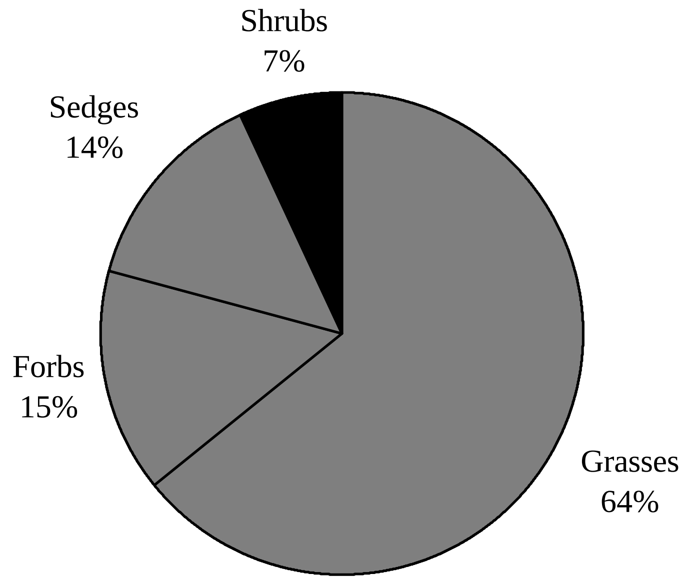


Figure 23. Dietary composition of the Nilgiri tahr when pellet samples from the Mukurthi National Park, South India, were combined to represent the diet over an entire year, January 1993 - December 1995.

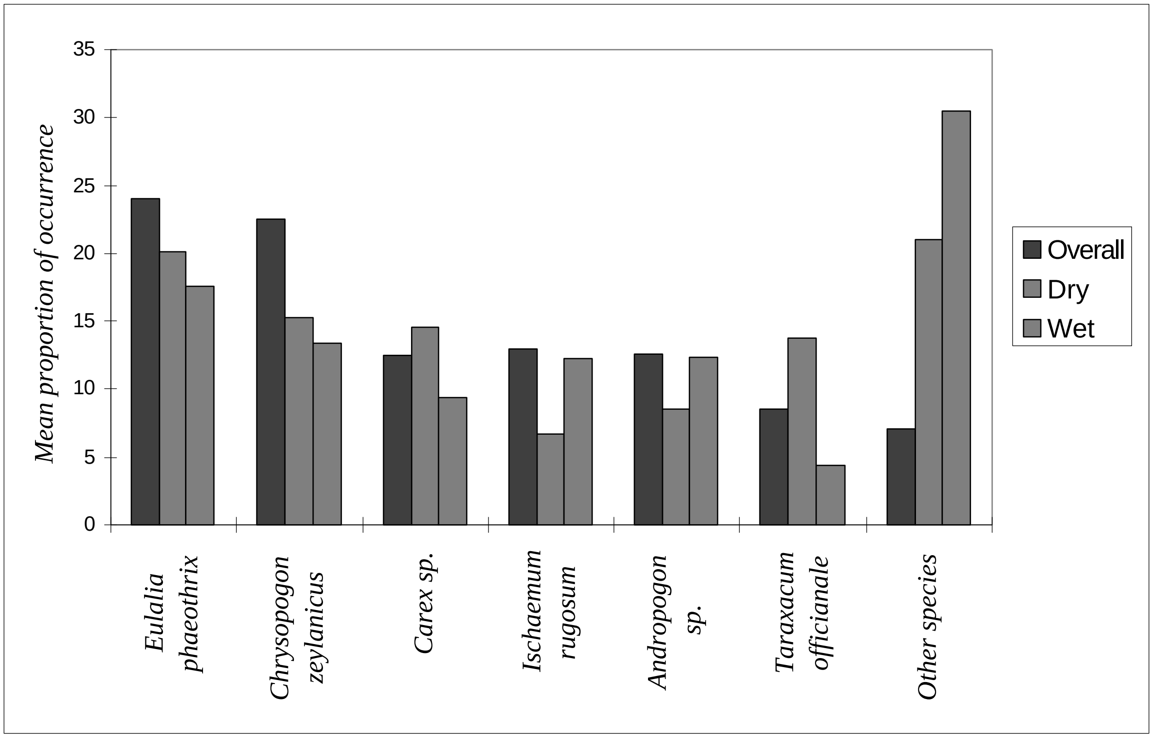


Figure 24. Mean proportion of occurrence of major forage species determined by microhistological analysis of fecal pellets of the Nilgiri tahr in the Mukurthi National Park, South India, January 1993 - December 1995.

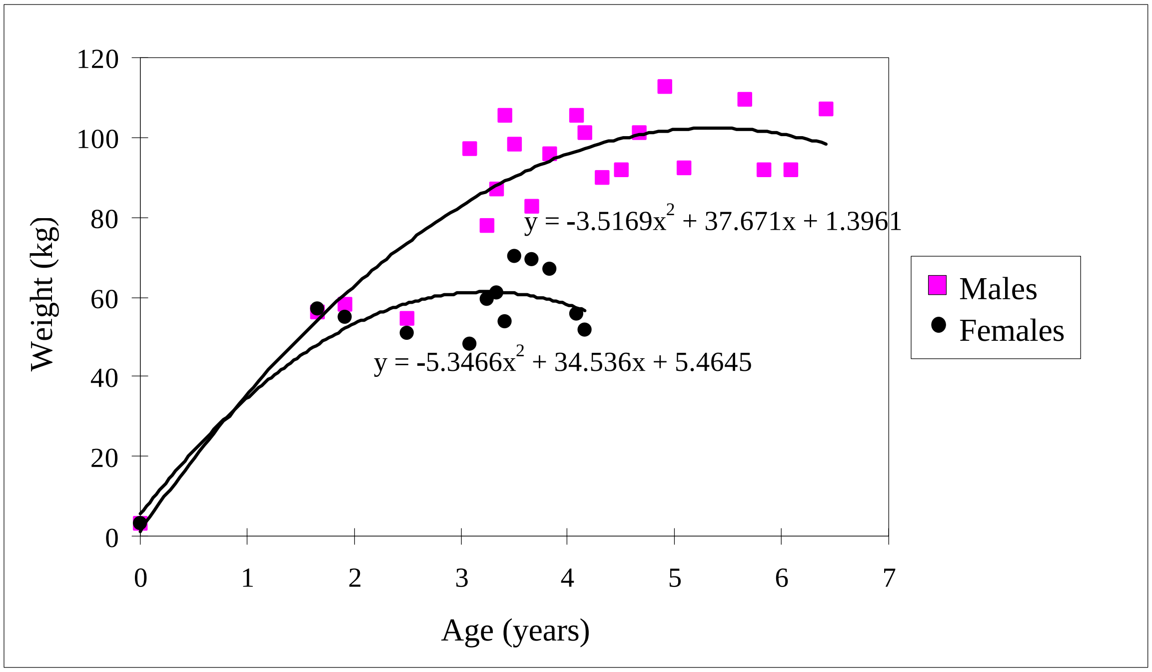


Figure 25. Polynomial regression analysis used to estimate average weight of male and female Nilgiri tahr. Data for the development of this model were collected from the captive population at Minnesota Zoo, Minneapolis, Minnesota, USA.

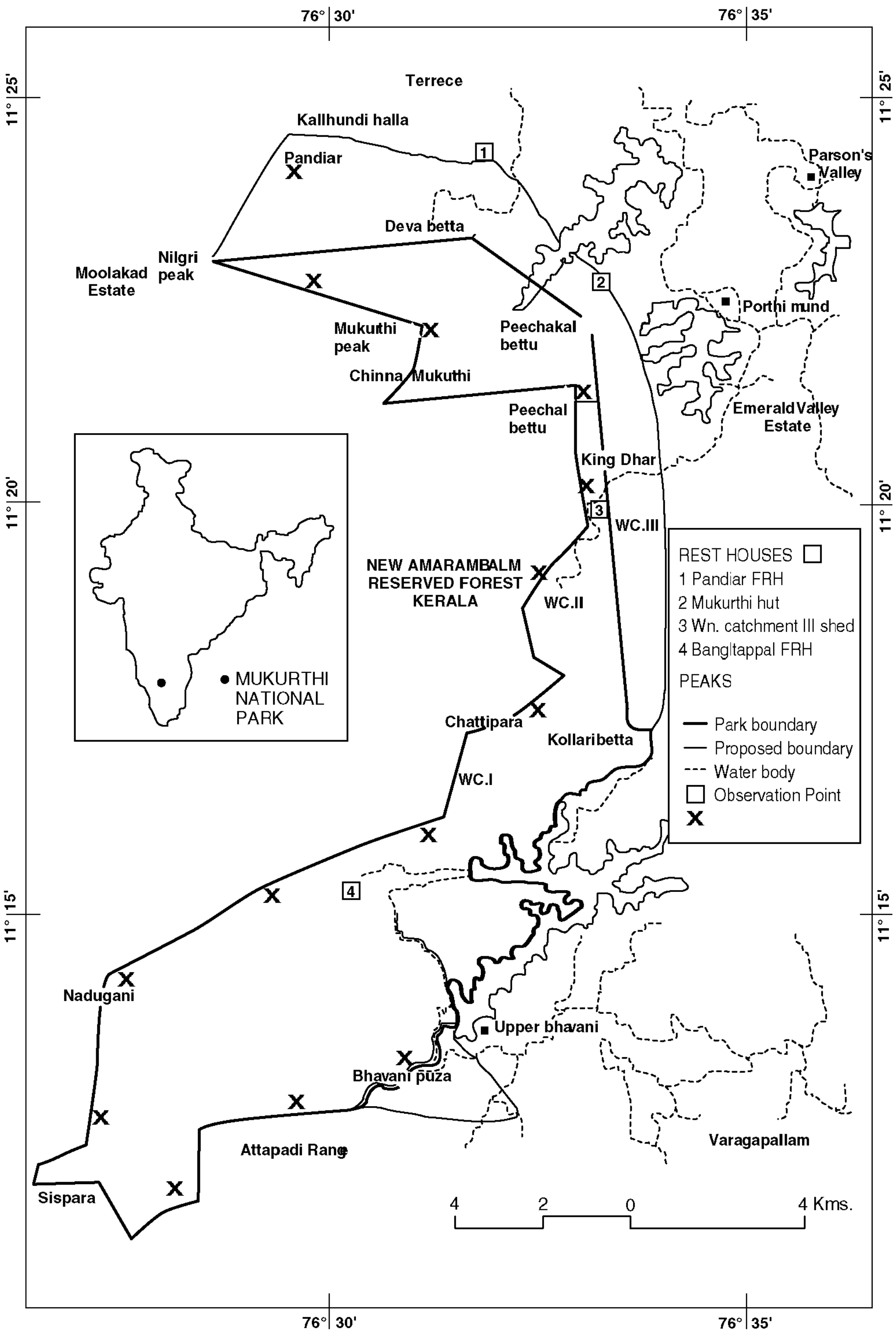
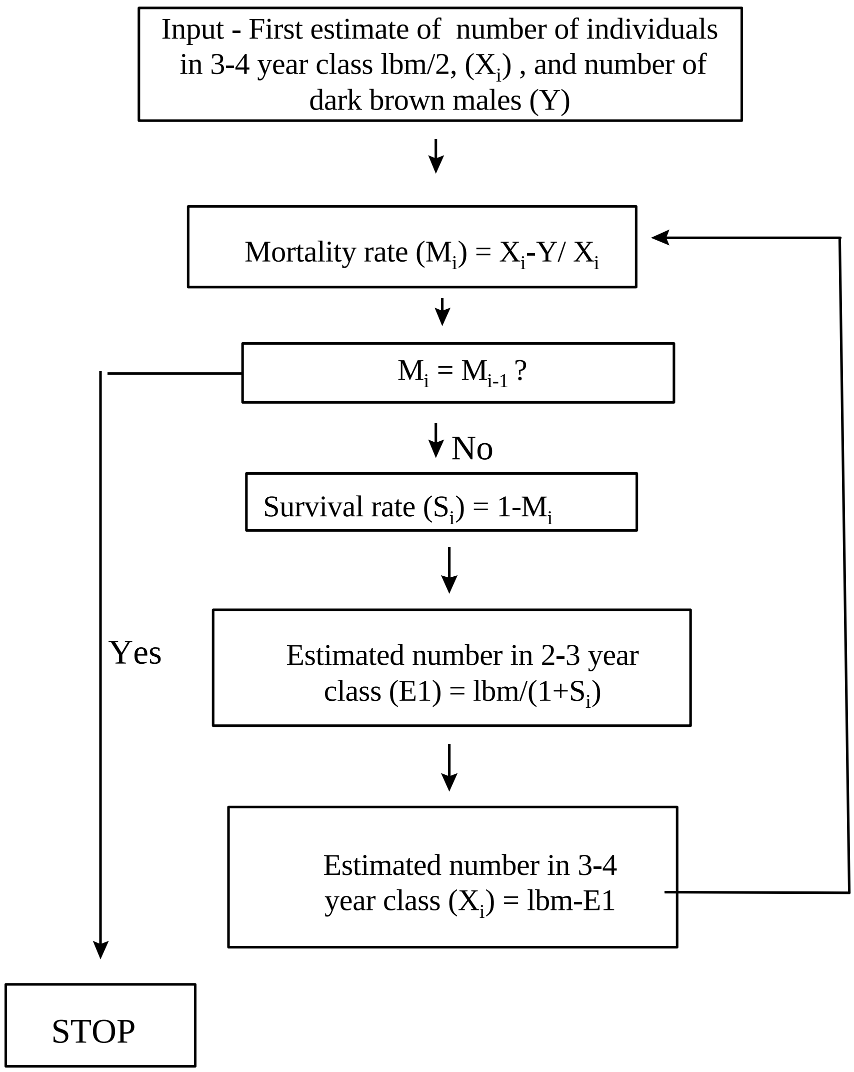


Figure 26. Map of the Mukurthi National Park, South India, showing the proposed new boundary of the park which will enclose areas that are currently used by Nilgiri tahr.

APPENDIX A

Flow chart depicting method used to calculate mortality rates for adult Nilgiri tahr in the Mukurthi National Park, South India.

Number of light brown males (lbm) in 1994 = 27
Number of dark brown males in 1995 = 6
lbm includes individuals in 2 year-classes
For first estimate of mortality I assumed a stable age distribution and equal numbers in the 2-3 and 3-4 age class
Where i = number of iterations



APPENDIX B

Table showing the transformed divergence index of the spectral classes used in the supervised classification of the IRS 1B satellite image of the Mukurthi National Park, South India.

Key:

Signature Name	Signature Number	Signature Name	Signature Number
Water 1	1	Bare Soil 5	29
Water 2	2	Bare Soil 6	30
Water 3	3	Commercial Plantation 1	31
Water 4	4	Commercial Plantation 2	32
Water 5	5	Commercial Plantation 3	33
Water 6	6	Commercial Plantation 4	34
Water 7	7	Commercial Plantation 5	35
Rain Forest 1	8	Commercial Plantation 6	36
Rain Forest 2	9	Tea Estate 1	37
Rain Forest 3	10	Tea Estate 2	38
Rain Forest 4	11	Shola Forest 1	39
Rain Forest 5	12	Shola Forest 2	40
Rain Forest 6	13	Shola Forest 3	41
Rain Forest 7	14	Shola Forest 4	42
Grassland 1	15	Shola Forest 5	43
Grassland 2	16	Shola Forest 6	44
Grassland 3	17	Agriculture 1	45
Grassland 4	18	Agriculture 2	46
Grassland 5	19	Shadow 1	47
Grassland 6	20	Shadow 2	48
Grassland 7	21	Shadow 3	49
Burnt Grassland 1	22	Shadow 4	50
Burnt Grassland 2	23	Shadow 5	51
Burnt Grassland 3	24	Water 8	52
Bare Soil 1	25	Water 9	53
Bare Soil 2	26	Agriculture 3	54
Bare Soil 3	27	Agriculture 4	55
Bare Soil 4	28	Agriculture 5	56

	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1202	1384	1664	1325	1123	2000	2000	2000	2000	2000	2000	2000	2000
2		1329	1523	1693	1643	1765	2000	2000	2000	2000	2000	2000	2000
3			422	1108	708	695	2000	2000	2000	2000	2000	2000	2000
4				1397	389	261	2000	2000	2000	2000	2000	2000	2000
5					1740	1757	2000	2000	2000	2000	2000	2000	2000
6						248	2000	2000	2000	2000	2000	2000	2000
7							2000	2000	2000	2000	2000	2000	2000
8								1535	1752	1910	1778	1396	1440
9									675	1227	701	1918	452
10										1141	1021	1742	1030
11											357	1964	558
12												1955	195
13													1894
14													

15	16	17	18	19	20	21	22	23	24	25	26	27
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	1999	1996	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	1999	1999	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
1998	1999	2000	2000	1999	2000	1991	1998	1970	1961	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	1998	1998	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	1999	1999	2000	2000	2000
	112	257	141	162	109	188	1988	1981	1956	2000	2000	2000
		257	129	160	138	252	1970	1941	1885	2000	2000	2000
			99	66	291	372	1952	1918	1868	2000	2000	2000
				103	116	325	1973	1954	1917	2000	2000	2000
					260	157	1956	1924	1860	2000	2000	2000
						385	1971	1956	1919	2000	2000	2000
							1960	1934	1872	2000	2000	2000
								326	327	2000	2000	2000
									234	2000	2000	2000
										2000	2000	2000
											1308	1981
												1673

28	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
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2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	1997	1989	1997	1997	1998	1993	1996	1993	1976	2000
2000	2000	2000	1874	1894	1983	1931	1955	1915	1999	1999	1739	2000
2000	2000	2000	1318	1040	1350	1316	1450	1148	1805	1899	889	1967
2000	2000	2000	967	1310	1417	975	832	1241	1924	1984	1226	1657
2000	2000	2000	1259	1527	1622	1521	1451	1517	1948	1989	1313	1960
2000	2000	2000	1998	1904	1892	1958	1980	1941	1193	1373	1910	1998
2000	2000	2000	1457	1620	1728	1642	1621	1626	1944	1985	1494	1988
2000	1940	1747	1957	1975	1941	1943	1908	1963	2000	2000	2000	1192
2000	1935	1783	1982	1993	1983	1967	1946	1989	2000	2000	2000	1285
2000	1949	1785	1998	2000	1998	1996	1992	1999	2000	2000	2000	1692
2000	1965	1844	1995	1998	1994	1992	1984	1997	2000	2000	2000	1586
2000	1932	1758	1990	1997	1991	1983	1966	1994	2000	2000	2000	1427
2000	1984	1899	1989	1993	1977	1983	1972	1990	2000	2000	2000	1492
2000	1938	1763	1910	1955	1914	1889	1817	1933	2000	2000	1999	894
2000	2000	2000	2000	2000	2000	1998	1998	2000	2000	2000	2000	1976
2000	2000	1998	1998	1997	1998	1977	1973	1996	2000	2000	1994	1915
2000	2000	1999	1995	1994	1995	1959	1953	1992	2000	2000	1986	1834
1998	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
1911	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
487	1824	1972	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
	1400	1810	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
		580	2000	2000	2000	2000	2000	2000	2000	2000	2000	1989
			2000	2000	2000	2000	2000	2000	2000	2000	2000	1956
				547	731	520	389	404	1983	1999	1014	986
					197	353	495	23	1750	1924	816	1197
						621	647	226	1671	1925	977	1107
							83	263	1848	1958	1061	920
								357	1902	1983	1106	739
									1814	1953	880	1087
										646	1941	1975
											1981	1999
												1786

41	42	43	44	45	46	47	48	49	50	51	52	53
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
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1999	1996	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
1997	1999	2000	1991	2000	2000	2000	2000	1997	1999	1998	2000	2000
1625	1915	1977	1678	1987	1989	2000	2000	1998	2000	1999	2000	2000
1855	1993	1984	1097	1981	1967	1999	1996	1912	1975	1951	2000	2000
1889	1988	1996	1647	1997	1996	2000	2000	1986	1997	1993	2000	2000
1756	1418	1883	1998	1916	1942	2000	2000	2000	2000	2000	2000	2000
1922	1988	1998	1816	1998	1998	2000	2000	1986	1995	1990	2000	2000
1994	2000	1886	1868	1994	1988	2000	2000	2000	2000	2000	2000	2000
1999	2000	1962	1890	1998	1996	2000	2000	2000	2000	2000	2000	2000
2000	2000	1990	1974	2000	1999	2000	2000	2000	2000	2000	2000	2000
2000	2000	1972	1964	1999	1997	2000	2000	2000	2000	2000	2000	2000
2000	2000	1979	1921	1999	1998	2000	2000	2000	2000	2000	2000	2000
1995	1999	1879	1946	1987	1974	2000	2000	2000	2000	2000	2000	2000
1994	2000	1912	1711	1996	1991	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	1993	2000	2000	1999	1999	2000	2000	2000	2000	2000
2000	2000	2000	1955	2000	2000	1978	1988	1990	2000	1998	2000	2000
2000	2000	2000	1895	2000	2000	1993	1996	1999	2000	2000	2000	2000
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2000	2000	1999	1999	2000	2000	2000	2000	2000	2000	2000	2000	2000
1809	1989	1886	800	1966	1945	2000	2000	2000	2000	2000	2000	2000
1191	1859	1567	1145	1798	1747	2000	2000	2000	2000	2000	2000	2000
997	1725	1211	1293	1622	1541	2000	2000	2000	2000	2000	2000	2000
1592	1967	1790	693	1870	1784	2000	1999	1991	1999	1997	2000	2000
1682	1976	1805	618	1885	1802	2000	1999	1993	1999	1998	2000	2000
1330	1904	1616	1053	1824	1768	2000	2000	1999	2000	2000	2000	2000
1031	937	1349	1990	859	968	2000	2000	2000	2000	2000	2000	2000
1475	1216	1883	1998	1750	1802	2000	2000	2000	2000	2000	2000	2000
1649	1931	1968	1226	1996	1996	2000	2000	2000	2000	2000	2000	2000
1797	1968	1660	577	1929	1870	2000	2000	2000	2000	2000	2000	2000
	636	617	1886	946	952	2000	2000	2000	2000	2000	2000	2000
		1049	1991	1328	1431	2000	2000	2000	2000	2000	2000	2000
			1918	993	933	2000	2000	2000	2000	2000	2000	2000
				1985	1970	2000	2000	1999	2000	2000	2000	2000
					46	2000	2000	2000	2000	2000	2000	2000
						2000	2000	2000	2000	2000	2000	2000
							405	1286	939	992	2000	2000
								1410	943	1039	2000	2000
									534	187	2000	2000
										251	2000	2000
											2000	2000
												1586

54	**55**	**56**
2000	2000	2000
2000	2000	2000
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2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	1999	1999
1999	1995	1994
1999	1995	1994
1999	1996	1994
1999	1997	1997
2000	1998	1996
2000	1999	1999
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
1988	1991	1997
1765	1837	1950
1798	1814	1916
1975	1930	1960
1996	1987	1988
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	1999
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
1957	1991	1989
1951	1989	1987
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
2000	2000	2000
	489	669
		484

APPENDIX C

List of some plants found in the grasslands of the Mukurthi National Park, South India.

Gramineae
Arundinella fuscata
Arundinella sp.
Andropogon polyptylum
Andropogon lividus
Andropogon oligantha
Agrostis penninsularis
Dicanthium polyptylum
Chrysopogon zeylanicus
Bracharia semiundulata
Eulalia phaeothrix
Eragrostis nigra
Festuca elatior
Isachne kunthiana
Ischaemum rugosum
Tripogon bromoides
Vulpia myuros

Eriocaulaceae
Eriocaulon brownianum
Eriocaulon collinum

Commelinaceae
Cyanotis sp.

Cyperaceae
Carex lindleyana
Carex filicina
Fimbristylis kingi

Orchidaceae
Habenaria cepalotes
Habenaria heyneana
Habenaria digitata
Satyrium nilgherrensis
Satyrium sp.

Amaryllidaceae
Curculigio orchioides

Labiatae
Leucas suffruticosa

Polygonaceae
Polygonum nepalense

Ericaceae
Gaultheria fragrantissima
Rhododendron nilgiricum

Melastomaceae
Osbeckia wightiana
Osbeckia aspera

Acanthaceae
Strobilanthes kunthianus
Strobilanthes nilgherrensis
Justicia nilgherrnsis

Gentianaceae
Gentiana pedicellata
Swertia corymbosa

Umbellifera
Heracleum rigens
Pimpinella leschenaultii
Bupleurum distkhophyllum

Santalaceae
Thesium wightianum

Geraniaceae
Geranium nepalense

Droseraceae
Drosera peltata

Saxifragaceae
Parnassia wightiana

Rosaceae
Fragaria nilgerrensis
Fragaria sp.

Balsaminaceae
Impatiens oppositifolia
Impatiens leschenaultii
Impatiens modesta
Impatiens nilgirica
Impatiens pussila

Elaeagnaceae
Elaegnus kologo

Scropulariaceae
Pedicularis zeylanica

Rubiaceae
Knoxia corymbosa
Knoxia mollis
Knoxia zeylanica

Caryophyllaceae
Drymaria cordata

Compositae
Anaphalis neelgherryana
Anaphalis notoniana
Helichrysum buddleioides
Emilia sonchifolia
Bipen humilis
Erigeron mucronatus
Euphatorium glandulosum
Senecio lavendulaefolius
Senacio sp.
Taraxacum officinale

Dipsacaceae
Dipsacus leschenaultii

Valerianaceae
Valerina leschenaultti

Papilionaceae
Smithia blanda

Ranunculaceae
Ranunculus wallichianus

VITA

Stephen Sumithran was born in Madras, India on December 26th 1964. He developed a keen interest in nature during his childhood, nurtured by his parents, Sanjeeva Raj and Margaret Raj. He received his Bachelors and Masters degree in Zoology from the Madras Christian College, India. He worked on the Eco-biology of the Vedanthangal and Nellapattu waterbird sanctuaries for his masters thesis. Upon his graduation in 1986, he worked on bats the Madurai Kamaraj University in the Animal Behavior Unit for nine months. In 1988 he enrolled at the West Virginia University in Morgantown and studied the effect of small mammal predation on gypsy moth larvae and pupae. He received a second Masters degree in Wildlife Management from West Virginia University in 1990. During the summers of 1990 and 1991 he worked at the Smithsonian Institutions' Conservation and Research Center at Front Royal, VA conducting a status survey of bats. At this time he also served as an Instructor in the International Wildlife Conservation and Management Training Program. He enrolled at Virginia Polytechnic Institute and State University in 1990 to pursue his doctorate in Wildlife Sciences. After the completing the requirements for his doctoral program, he will teach Conservation Biology and Habitat Ecology at the Humboldt State University in California.