Tropical Forest Diversity and Dynamism

Findings from a Large-Scale Plot Network

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Mudumalai Forest Dynamics Plot, India

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Site Location, Administration, and Scientific Infrastructure

Mudumalai Wildlife Sanctuary (11°36′N, 76°32′E) abuts the northern flank of the Nilgiri mountain range in the Western Ghats and is contiguous with the protected areas of Bandipur and Wynaad (Sukumar et al. 1992). Mudumalai was designated as a wildlife sanctuary in 1940, expanded in 1958, and expanded again to the current area of 32,100 ha in 1977. The 50-ha Mudumalai Forest Dynamics Plot is located in Compartment 17 of the Kargudi Range in the Mudumalai Wildlife Sanctuary, Nilgiris District, Tamilnadu State in southern India (fig. 33.1). This plot was set up and is managed by the Centre for Ecological Sciences of the Indian Institute of Science, Bangalore, India.

In addition to the Forest Dynamics Plot, a series of nineteen 1-ha permanent plots has also been set up along a rainfall gradient in the Mudumalai Wildlife Sanctuary. Another 1-ha permanent plot has been located outside Mudumalai, in a montane area at Thaishola, in the upper plateau of the Nilgiri District. A field station with moderately equipped laboratory, computer, telephone, and accommodation facilities is located in Masinagudi village near Mudumalai.

Climate

The western and central parts of Mudumalai receive most of their rainfall from the southwest monsoon during June-September, while the drier eastern region also receives significant rainfall from the northeast monsoon during October–November. Pre-monsoon showers also occur during April and May. The dry season usually starts in mid-November and lasts until mid-April with 6 consecutive months averaging less than 100 mm precipitation a month. Rainfall ranges from 700 mm/year at the eastern end of Mudumalai Wildlife Sanctuary to over 1800 mm/year at the western end. The dry season spans 5–6 months in most areas, but in the low rainfall regions, it extends to about 8 months. Rainfall in the 50-ha Forest Dynamics Plot averages about 1200 mm/yr, as discerned from 1941–70 and 1990–96 data at Kargudi (5 km south of the plot, von Lengerke 1977) and from

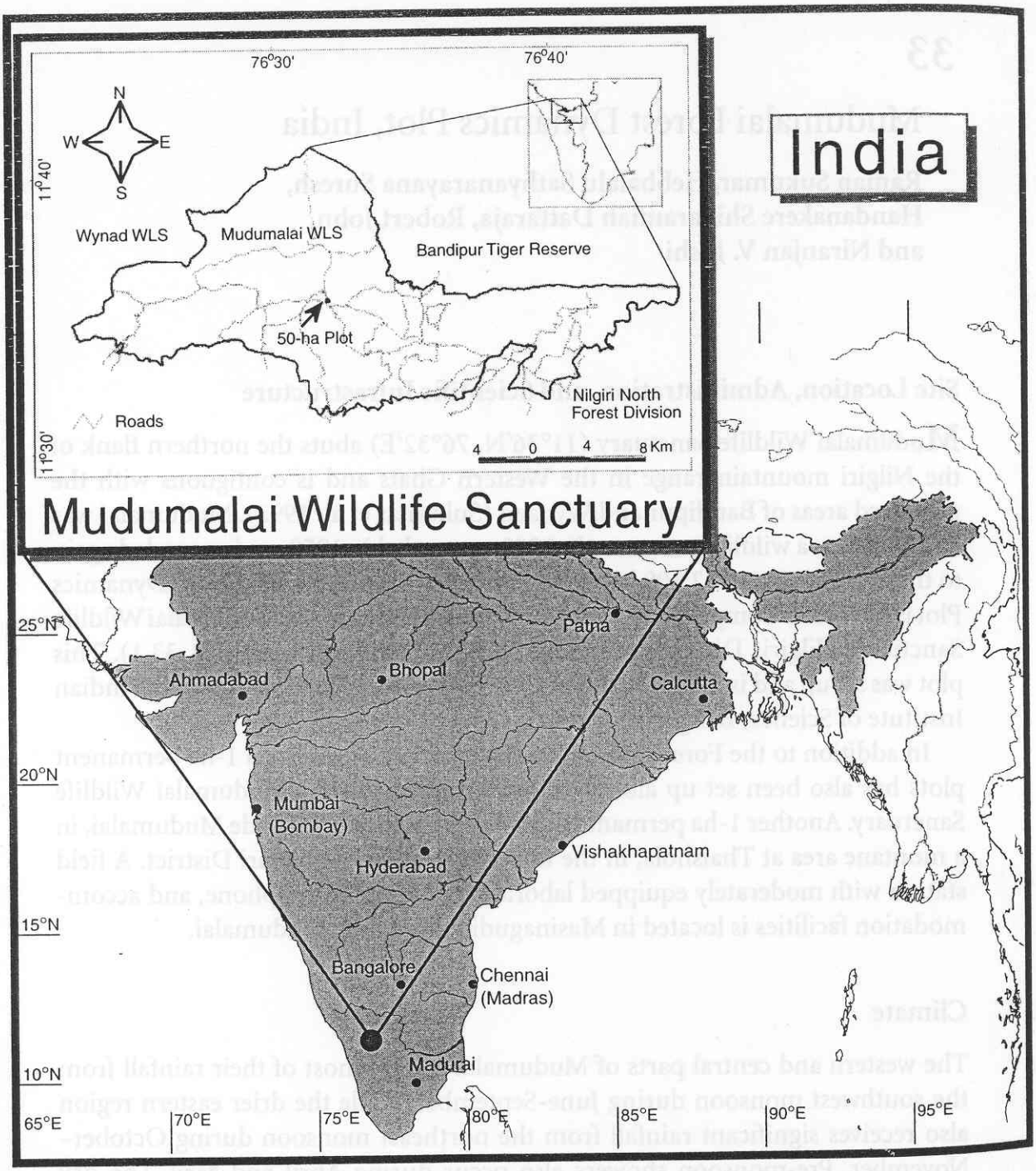

Fig. 33.1. Location of the 50-ha Mudumalai Forest Dynamics Plot.

records of the Indian Institute of Science and the Tamilnadu Electricity Board. See also table 33.1.

Topography and Soil

The 50-ha Mudumalai Forest Dynamics Plot has an undulating terrain with elevation varying between 980 and 1120 m above sea level (figs. 33.2 and 33.3). A

Table 33.1. Mudumalai Climate Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total/ Averages
Rain (mm)	7	9	88	119	129	160	146	130	126	170	115	50	1250
ADTMx (°C)	26.7	28.8	34.0	30.4	29.5	27.0	28.3	29.4	23.1	26.5	27.2	27.8	28.2
ADTMn (°C)	16.1	16.3	19.8	18.0	16.2	18.2	20.1	20.1	14.7	18.4	15.2	14.2	17.3
Solar Radiation	308	367	352	349	345	251	177	179	266	252	312	255	284

Notes: Mean monthly rainfall data from 1990 to 2000, and average daily temperature (ADT) maximums and minimums during 1990–2000. Solar radiation pertains to UPASI Tea Research Station at Gudalur, 15 km (linear distance) to the southwest of the 50-ha plot. Radiation during June–August can be expected to be slightly higher in the plot because of lower cloudiness.

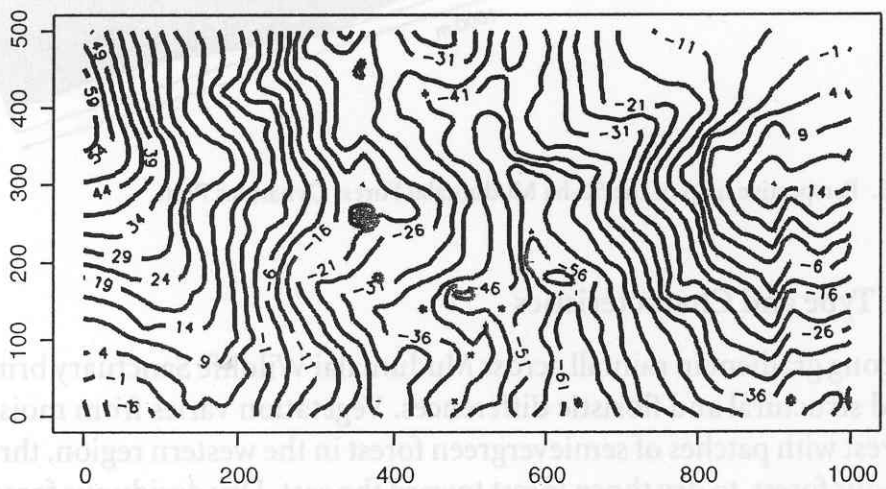

Fig. 33.2. Topographic map of the 50-ha Mudumalai Forest Dynamics Plot with 5-m contour intervals.

small stream, which is joined by a number of smaller streams, drains the 50-ha plot. The main stream crosses the plot in a southeast-northwest direction. All streams are typically dry after the monsoon season. The nineteen 1-ha plots in Mudumalai are located within the same elevation range as the 50-ha plot, while the montane forest plot in Thaishola is located at 1875 m.

The parent rock material of the 50-ha plot is either hornblende biotite gneiss or granite gneiss. The soils of Mudumalai Wildlife Sanctuary have been classified into four orders, Inceptisols, Alfisols, Mollisols, and Entisols (George et al. 1988). The soils of the Mudumalai Forest Dynamics Plot have been classified under order Alfisols, subgroup udic haplustalf and family clayey skeletal. Soils are dark brown to deep black in color, and are slightly acidic with pH values of 6.2–6.6. The total soil organic carbon content is 1.6–2.4%, while the nitrogen, phosphorus, and sulfur contents are 0.16, 0.07, and 0.02%, respectively. The soils are rich in such nutrients as iron, manganese, zinc, and copper.

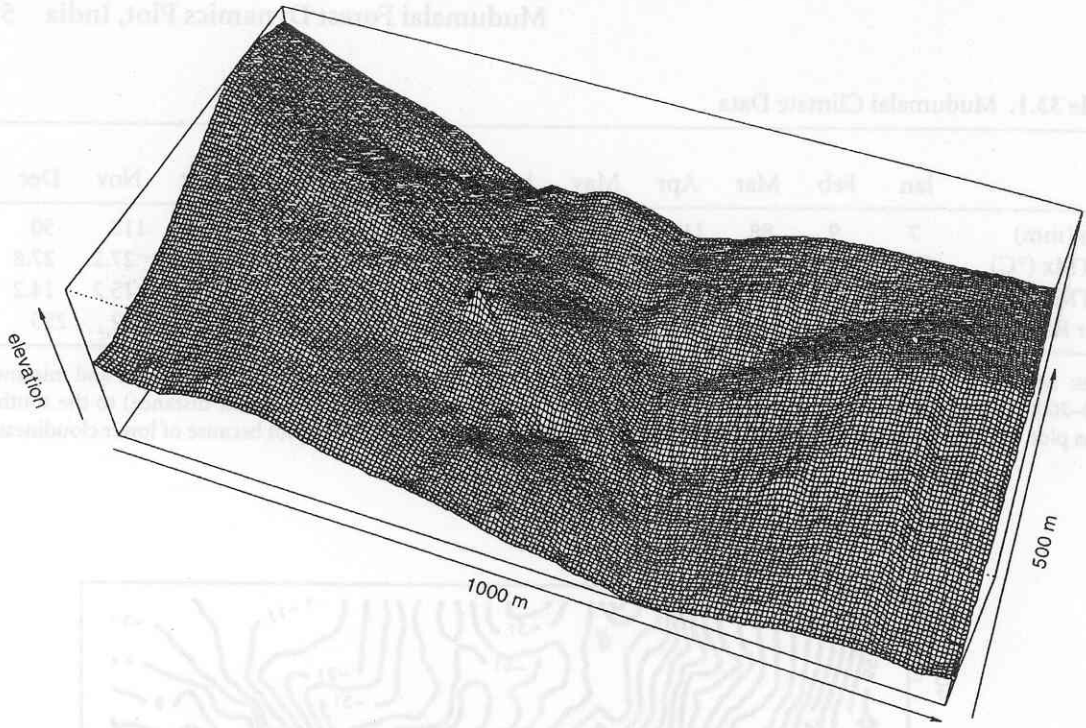

Fig. 33.3. Perspective map of the 50-ha Mudumalai Forest Dynamics Plot.

Forest Type and Characteristics

The strong gradient in rainfall across Mudumalai Wildlife Sanctuary brings about marked structural and floristic differences. Vegetation varies from moist deciduous forest with patches of semievergreen forest in the western region, through dry deciduous forest, to dry thorn forest toward the east. Dry deciduous forest, spread over the central and northern parts, constitutes the largest expanse of the sanctuary. The Mudumalai Forest Dynamics Plot is located in the transition zone between dry and moist deciduous forests. The vertical stratification in the dry deciduous forest is simple, with only a tree canopy layer (~10–18 m) and a ground layer of prominent dense grasses. A layer of midstory trees is also present, but it is sparse and discontinuous. The common canopy trees in the dry deciduous forest are *Tectona grandis* (Labiatae), *Terminalia crenulata* (Combretaceae), and *Anogeissus latifolia* (Combretaceae), though *Lagerstroemia microcarpa* (Lythraceae), characteristic of moist deciduous forest, is the dominant tree in the 50-ha plot. The understory has fewer species with *Kydia calycina* (Malvaceae), *Phyllanthus emblica*, (Euphorbiaceae), and *Catunaregam spinosa* (Rubiaceae) among the common species. A characteristic feature of the dry deciduous forest at Mudumalai is the presence of a dense understory of perennial, tall grasses (Gramineae) such as *Themeda cymbaria* and *Cymbopogon flexuosus*. Grass cover is generally inversely proportional to canopy cover; the grass cover is highest in the dry deciduous

forests that have been repeatedly burned. Canopy cover is about 50–75% in the deciduous forests, with higher values in the moister forests.

The canopy in the moist deciduous forest is about 20–25 m high and denser than that of the dry deciduous forest. The midstory is more continuous and grasses may be sparse or absent in the wetter parts. Tree species that are common in moist deciduous forest include *Lagerstroemia microcarpa* (Lythraceae), *Grewia tiliifolia* (Tiliaceae), *Syzygium cumini* (Myrtaceae), *Persea macarantha* (Lauraceae), *Meliosma simplicifolia* (Sabiaceae), and *Olea dioica* (Oleaceae). The low rainfall areas in the eastern parts of Mudumalai promote dry thorn forest or mixed deciduous forest. Here, the forest is defined by a ground layer of thorny evergreen shrubs about 3–5 m tall, with a sparse cover of deciduous trees. The average number of woody plant species per hectare in the dry thorn/deciduous forest is about 35, while it is 25 and 46 in the dry and moist deciduous forests, respectively. The common woody plant species in the dry thorn forest include *Gardenia turgida* (Rubiaceae), *Flueggea lycopyros* (Euphorbiaceae), *Anogeissus latifolia* (Combretaceae), and *Ziziphus xylopyrus* (Rhamnaceae).

The strong 5- to 6-month dry season typically begins in November and lasts until April. Leaves are completely shed in January and February and new leaves are flushed by the end of April (Murali and Sukumar 1993). Presently recovering from selective logging (which ended in 1968), the 50-ha plot comprises secondary forest that is maintained through regular burning of the ground layer. Species diversity varies within the plot and is only weakly associated with topographical features. However, a number of rare species characteristic of moist riparian forest such as *Mangifera indica* (Anacardiaceae), *Mallotus philippensis* (Euphorbiaceae), *Olea dioica* (Oleaceae), and *Bischofia javanica* (Euphorbiaceae) can be found along the stream banks of the plot. In the drier sites, the peak in species flowering extends well into the wet season, while in the medium-to-wetter sites, the peak occurs in the dry season. Bird-pollinated species tend to flower in the dry season, while wind-pollinated species flower in the rainy season when winds are stronger. For the majority of the tree species at Mudumalai, flowering and leaf flush are simultaneous (Murali and Sukumar 1994). Litter production varies along the rainfall gradient from about 750 kg/ha in the dry thorn forest to about 3750 kg/ha in the semievergreen forest patches toward the western part; the peak litter fall of 5030 kg/ha is reached in the deciduous forests of the central part (unpublished data). For census data and rankings, see tables 33.2–33.7.

Fauna

Over 200 species of birds, at least 17 species of amphibians, 42 species of reptiles, and 35 species of nonvolant mammals have been documented in the sanctuary. Mudumalai harbors one of the highest densities of large mammals in Asia

Table 33.2. Mudumalai Plot Census History

Census	Dates	Number Trees (≥1 cm dbh)	Number Species (≥1 cm dbh)	Number Trees (≥10 cm dbh)	Number Species (≥10 cm dbh)
First	May 1988–May 1989	25,553	70	15,037	62
	August 1989–January 1990	23,207	69	14,637	62
	June 1990–October 1990	22,146	69	14,295	62
	June 1991–October 1991	19,571	69	13,836	62
Second	June 1992–November 1992	17,628	67	14,047	63
	July 1993–September 1993	17,799	67	13,774	63
	June 1994–August 1994	17,176	69	13,480	63
	June 1995–November 1995	17,266	68	13,256	63
Third	June 1996–September 1996	15,304	65	13,070	63
	June 1997–January 1997	15,791	69	12,876	63
	July 1999–September 1998	16,397	69	12,739	62
	June 1998–October 1999	16,828	70	12,633	62
Fourth	June 2000–December 2000	18,024	71	12,576	63

Notes: Four full censuses have been completed. Unlike most other Forest Dynamics Plots, annual censuses for mortality and recruitment are also undertaken in this 50-ha plot. Tree girths were measured only once every 4 years, in 1988, 1992, 1996, and 2000. One species of bamboo, *Bambusa arundinacea*, was tagged and enumerated but is not included in the calculations reported in this chapter.

Table 33.3. Mudumalai Summary Tally

Size Class (cm dbh)	Average per Hectare							50-ha Plot				
	BA	*N*	*S*	*G*	*F*	*H′*	*α*	*S*	*G*	*F*	*H′*	*α*
≥1	25.5	366.8	24.7	22.0	16.6	0.944	6.2	71	55	29	1.089	9.4
≥10	25.1	244.8	19.8	18.4	14.2	0.870	5.3	63	51	29	1.014	8.7
≥30	20.8	105.7	14.0	13.4	11.0	0.830	4.4	50	42	24	0.970	7.6
≥60	7.11	15.8	5.4	5.0	4.7	0.561	3.5	28	22	15	0.875	5.7

Notes: *BA* represents basal area in m^2, *N* is the total number of individual trees, *S* is the total number of species, *G* is the total number of genera, *F* is the total number of families, *H′* is the Shannon–Wiener diversity index using $\log_{10}$, and *α* is Fisher's *α*. Two individuals were unidentified to species or morphospecies. Data are from the 2000 census.

Table 33.4. Mudumalai Rankings by Family

Rank	Family	Basal Area (m^2)	% BA	% Trees	Family	Trees	% Trees	Family	Species
1	Labiatae	364.8	28.2	10.6	Combretaceae	4761	26.2	Leguminosae	13
2	Combretaceae	355.0	27.5	26.2	Lythraceae	4054	22.3	Moraceae	7
3	Lythraceae	243.9	18.9	22.3	Leguminosae	3504	19.3	Euphorbiaceae	5
4	Tiliaceae	74.3	5.8	2.1	Labiatae	1924	10.6	Malpighiaceae	5
5	Myrtaceae	44.7	3.5	2.2	Sterculiaceae	573	3.2	Combretaceae	4
6	Sapindaceae	32.5	2.5	0.5	Malpighiaceae	566	3.1	Labiatae	4
7	Malpighiaceae	32.5	2.5	3.1	Euphorbiaceae	462	2.5	Oleaceae	3
8	Leguminosae	30.5	2.4	19.3	Bignoniaceae	432	2.4	Sapindaceae	3
9	Bignoniaceae	30.2	2.3	2.4	Myrtaceae	408	2.2	Tiliaceae	3
10	Euphorbiaceae	18.0	1.4	2.5	Tiliaceae	383	2.1	Olacaceae	2

Notes: The top 10 families for trees ≥1 cm dbh in 50-ha plot. Data are from 2000 census.

Table 33.5. Mudumalai Ranking by Genus

Rank	Genus	Basal Area	% BA	% Trees	Genus	Trees	% Trees	Genus	Species
1	*Tectona* (Labiatae)	353.3	27.3	10.4	*Lagerstroemia* (Lythraceae)	4054	22.3	*Ficus* (Moraceae)	6
2	*Terminalia* (Combretaceae)	254.1	19.7	14.4	*Cassia* (Leguminosae)	3206	17.7	*Grewia* (Tiliaceae)	3
3	*Lagerstroemia* (Lythraceae)	243.9	18.9	22.3	*Terminalia* (Combretaceae)	2612	14.4	*Terminalia* (Combretaceae)	3
4	*Anogeissus* (Combretaceae)	100.9	7.8	11.8	*Anogeissus* (Combretaceae)	2149	11.8	*Bauhinia* (Leguminosae)	2
5	*Grewia* (Tiliaceae)	74.3	5.8	2.1	*Tectona* (Labiatae)	1883	10.4	*Cassia* (Leguminosae)	2
6	*Syzygium* (Myrtaceae)	44.7	3.5	2.2	*Helicteres* (Sterculiaceae)	547	3.0	*Cordia* (Boraginaceae)	2
7	*Schleichera* (Sapindaceae)	32.2	2.5	0.4	*Catunaregam* (Malphigiaceae)	519	2.9	*Dalbergia* (Leguminosae)	2
8	*Catunaregam* (Malphigiaceae)	27.1	2.1	2.9	*Phyllanthus* (Euphorbiaceae)	422	2.3	*Lagerstroemia* (Lythraceae)	2
9	*Ficus* (Moraceae)	17.7	1.4	0.4	*Syzygium* (Myrtaceae)	408	2.2	*Olea* (Oleaceae)	2
10	*Phyllanthus* (Euphorbiaceae)	16.0	1.2	2.3	*Grewia* (Tiliaceae)	383	2.1	*Ziziphus* (Rhamnaceae)	2

Notes: Top 10 tree genera for trees ≥1cm dbh. Data are from 2000 census.

Table 33.6. Mudumalai Rankings by Species

Rank	Species	Number Trees	% Trees	Species	Basal Area (m^2)	% BA	% Trees
1	*Lagerstroemia microcarpa* (Lythraceae)	3708	21.9	*Tectona grandis* (Labiatae)	353.3	27.3	10.4
2	*Terminalia crenulata* (Combretaceae)	2572	14.0	*Lagerstroemia microcarpa* (Lythraceae)	240.4	18.6	21.9
3	*Cassia fistula* (Leguminosae)	2250	13.7	*Terminalia crenulata* (Combretaceae)	235.8	18.3	14.0
4	*Anogeissus latifolia* (Combretaceae)	2166	11.8	*Anogeissus latifolia* (Combretaceae)	100.9	7.8	11.8
5	*Tectona grandis* (Labiatae)	1885	10.4	*Grewia tilifolia* (Tiliaceae)	74.2	5.7	2.1
6	*Catunaregam spinosa* (Malphigiaceae)	538	2.9	*Syzygium cumini* (Myrtaceae)	44.7	3.5	2.2
7	*Phyllanthus emblica* (Euphorbiaceae)	430	2.3	*Schleichera oleosa* (Sapindaceae)	32.2	2.5	0.4
8	*Syzygium cumini* (Myrtaceae)	390	2.2	*Catunaregam spinosa* (Malpighiaceae)	27.1	2.1	2.9
9	*Grewia tiliifolia* (Tiliaceae)	386	2.4	*Terminalia bellirica* (Combretaceae)	16.4	1.3	0.2
10	*Radermachera xylocarpa* (Bignoniaceae)	317	1.9	*Phyllanthus emblica* (Euphorbiaceae)	16.0	1.2	2.3

Notes: 10 most abundant species in plot for trees ≥1 cm dbh. Data are from 2000 census.

Table 33.7. Mudumalai Tree Demographic Dynamics from 1988 to 2000

Tree size	Growth (mm/yr)			Mortality (%/yr)			Recruitment (%/yr)			Basal Area Losses (m^2/ha/yr)			Basal Area Gains (m^2/ha/yr)		
(cm dbh)	1988–92	1992–96	1996–2000	1988–92	1992–96	1996–2000	1988–92	1992–96	1996–2000	1988–92	1992–96	1996–2000	1988–92	1992–96	1996–2000
1–9.9	3.691	2.898	3.285	27.966	19.277	6.696	15.756	16.591	15.442	0.09	0.02	0.01	0.01	0.00	0.01
10–29.9	2.766	1.671	2.195	4.044	3.032	1.658	17.876	17.288	16.038	0.14	0.12	0.04	0.07	0.01	0.01
>30	3.744	1.819	3.218	0.732	0.585	0.465	18.631	17.707	16.614	0.14	0.13	0.13	0.12	0.13	0.19

including six species of the larger herbivores: the Asian elephant (*Elephas maximus*), gaur (*Bos gaurus*), sambar deer (*Cervus unicolor*), axis or spotted deer (*Axis axis*), muntjac or barking deer (*Muntiacus muntjak*), and chowsingha or four-horned antelope (*Tetracerus quadricornis*) (Varman and Sukumar 1995). There are three primate species: the common langur (*Semnopithecus entellus*), the bonnet macaque (*Macaca radiata*), and the slender loris (*Loris tardigradus*). Other arboreal animals include the malabar giant squirrel (*Ratufa indica*) and flying squirrel (*Petaurista philippensis*). There are three large predators: the tiger (*Panthera tigris*), leopard (*Panthera pardus*), and dhole or Asiatic wild dog (*Cuon alpinus*) (Venkataraman et al. 1995). One species of bear, the sloth bear (*Melursus uscinus*), also occurs in the sanctuary. Density estimates (mean ± S.E.) are available for the larger herbivores; elephant densities average 2.2 ± 0.6 individuals/km^2, gaur 2.2 ± 0.5/km^2, sambar 4.1 ± 1.1/km^2, and spotted deer 29.1 ± 4.7/km^2 (unpublished data for the year 2001).

Natural Disturbances

Mudumalai has a very high density of browsing large mammals that can cause damage to woody plants through their feeding activity. Yet only one understory tree, *Kydia calycina* (Malvaceae), and one shrub, *Helicteres isora* (Sterculiaceae), have drastically declined in the Mudumalai Forest Dynamics Plot as a result of feeding by elephants (chap. 21). Similarly, deer have damaged, by rubbing their antlers, only a small proportion of juvenile stems of a few species. It is likely that browsing by large mammals such as gaur exerts a greater influence on tree saplings <1 cm dbh, though this has not been monitored. Treefalls during storms are not common but known to occur occasionally during the winter monsoon when cyclones form.

Human Disturbances

The Nilgiri region, including Mudumalai, as with other regions in southern India, has an ancient history of human settlement (Hockings 1989; Prabhakar 1994). Remains of a megalithic culture that prevailed from about 100 A.D. onward can be seen in the midelevation forests. Hunter–gatherer societies such as the Kurubas, Irulas, Paniyas, and Kotas have inhabited this region for several centuries. Until the end of the 18th century, the human populations fluctuated in size in response to disease outbreaks and local strife. From the 19th until the mid-20th century, the presence of malaria certainly discouraged settlers from the plains from moving into this region, and population densities everywhere were lower than current levels. Anthropogenic disturbance to the forests would thus have been inevitable.

While the Mudumalai forests have a history of logging going back to the early part of the 19th century, the systematic extraction of timber began with the organization of the forest department by the British rulers during the mid-19th century (Ranganathan 1941). Elaborate forest working plans were developed and many species including *Tectona grandis* (Labiatae), *Pterocarpus marsupium* (Leguminosae), *Terminalia crenulata* (Combretaceae), *Lagerstroemia microcarpa* (Lythraceae), and *Dalbergia latifolia* (Leguminosae) were extracted for timber. Much of the timber was used for the construction of buildings, bridges, and railway sleepers and in mines. It appears that logging operations opened the forest to invasion by grasses, which in turn introduced anthropogenic fire to the forest. The history of fire before logging began has not been clearly documented (Wilson 1939; Ranganathan 1941). The factors that limited logging were the availability of nearby markets, the availability of elephants to transport the logs, and the prevalence of malaria and dysentery that discouraged people from working in the forests. Elephants were captured and trained for logging operations. Other mammals have been hunted to a limited extent for meat, but no known large mammal or bird has been extirpated from Mudumalai or its adjoining areas in recent times.

Mudumalai Wildlife Sanctuary, including the 50-ha plot, comprises secondary forest that is regenerating after several cycles of selective timber harvest by the Tamilnadu Forest Department for the species listed above. The last round of timber extraction was completed in the sanctuary by the mid-1980s. Records in the forest working plans indicate that fires increased in occurrence and spread due to the invasion and proliferation of grasses under the open canopy of logged forest. Grass densities were observed to decline when the forest canopy became denser under protection from fire (Wilson 1939; Ranganathan 1941).

At present, major disturbances in the sanctuary include frequent grass fires and grazing by livestock. During the extended 6-month dry season, the grasses are desiccated and highly flammable. Human-induced grass fires occur annually to varying extent in the central dry deciduous forest tracts and less frequently in the western (moist deciduous forest) and eastern (dry thorn forest) regions. Cattle grazing and small-scale cultivation are present only around human settlements in western and eastern parts; they are absent in the dry deciduous tracts in the central parts of the sanctuary where the 50-ha plot is located.

Intense and widespread fires usually result in high mortality among juvenile stems and decreased rates of recruitment in that year. Typical of dry, fire-affected forests, vegetative coppicing from burned stems and underground rootsuckers are common among many species. As reflected in the forest structure, the influence of large mammals and fires has kept juvenile tree densities and recruitment at low levels. Since the inception of the Mudumalai Forest Dynamics Plot in 1988, fires have swept through the plot 5 out of 13 years (1989, 1991, 1992, 1994, and 1996).

Better protection by the forest department prevented fires during 1997–2001, but a major fire occurred again during 2002, causing considerable mortality.

Collection of nontimber forest products (NTFPs) is currently banned in the sanctuary, although livestock grazing and collection of fodder is permitted in the eastern part. Until about a decade ago, several products were collected from the sanctuary; these included honey and fruits of *Phyllanthus emblica* (Indian gooseberry, Euphorbiaceae), *Sapindus emarginata* (Soap nut, Sapindaceae), *Acacia sinuata*, and *Tamarindus indica* (tamarind, Leguminosae). More details of the economy of NTFPs are given in Ganesan (1993) and Narendran et al. (2001).

Plot Size and Location

The 50-ha plot is 1000 × 500 m; its long axis lies east-west. The southwest corner of the plot is located at 11°35′48″ N and 76°31′45″ E.

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