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Savannas of north-east India

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Abstract. A survey of the savanna grasslands of north-east India is presented, including savanna types, life-forms, phenology, biomass and productivity, nutrients, fauna, and successional changes. The role of burning and grazing is stressed, and the management implications of ecological studies are considered.

Key words. Savanna grasslands, vegetation types, fire, grazing, north-east India.

INTRODUCTION

The Indian savannas have originated from woodland ecosystems through deforestation, abandoned cultivation and burning (Singh Hanxi Yang & Sajise, 1985; Misra, 1983; Gadgil & Meher Homji, 1985). These savannas are maintained at a sub-climax stage by repeated grazing and burning. This has led to the formation of mosaic types of savanna communities, depending upon the age and mode of origin, and the intensity of biotic disturbance. Since these communities represent different seral stages, they tend to differ in their species composition, productive potential, and nutrient cycling.

North-eastern India presents a wide variety of savanna ecosystems, depending upon various origins from a number of forest types, ranging from tropical rain forest, through sub-tropical and humid mountain forests to temperate forests (Puri, 1960; Champion & Seth, 1968).

North-east Indian savannas are spread over the plains, valleys and hilly regions of the north-eastern states of India, located between 22° 0′ N to 29° 5′ N latitude and 87° 7′ E to 97° 3′ E longitude. For this paper, north-east India comprises Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland and Tripura States.

GENERAL GEOGRAPHY

North-eastern India comprises the eastern part of the Himalayan range, intercepted by plains, valleys and hilly terrains representing recent land (Pleistocene) of alluvial sediments created especially by the Brahmaputra river system running across the rising mountain ranges of the Himalayas, Pre-Cambrian (metamorphosed and crystalline rocks) and other sedimentary rocks more than 500 million years old. The Manipur hills, along with the Naga and Mizo hills, consist of mainly tertiary strata, and came into existence as a result of the Tertiary folding of sedimentary strata in the shallow Tethys Sea (some 40–90 million years ago).

The climate of the region is significantly influenced by the topography, and in particular of the great complex of mountains flanking the Himalayas. The climate is typically monsoonal. The monsoon rains start in the first week of June and continue late into October or even into November. The region also experiences rain showers in the winter season. The rainfall is not only heavy, but is also spread over a longer period of the year. A marked contrast exists between the dry season, which generally lasts from November to February, and the wet season from April to October. March is a transitional month between the cool dry and the wet periods. The rainfall is high in this region, and Cherapunji, which receives the highest rainfall in the world, is located here. Climatological data for selected stations are set out in Table 1.

The difference in mean maximum temperature varies from 7°C to 12°C in the various stations, showing that temperature fluctuations are very low, and the mean maximum temperature does not exceed 32°C. Annual rainfall ranges from 1000 to 4000 mm.

Soils are chiefly derived from metamorphic rocks, schists, quartzites and gneisses. The soils are acidic in nature, containing high percentages of organic matter and nitrogen, and are generally poor in phosphorus and calcium. Alluvial, red, lateritic mountain and hill soil types are the main soils found in north-eastern India (Raychaudhary, 1966).

Of the total land area of north-east India, forest comprises 54%, land not available for cultivation 21%, the net crop area being 16% and that under pasture and grazing 0.93%. However, 13.44% of the total land is occupied under shifting cultivation. The total population of livestock is 12.83 million. Out of this, cattle comprise 64.5%, goats 11.47%, buffaloes 6.68% and other, 17.35%. Cattle are used primarily for milk production and for farm work.

TABLE 1. Climatological data for selected stations in northeast India.

	Altitude (m)	Temperature (0°C) Mean min.	Mean max	Rainfall (mm)	Wet month	Dry month
Burnihat	100	12–24	25–32	1550	6	6
Imphal	785	4–24	22–29	1184	7	5
Shillong	1600	6–16	16–24	1800	7	5
Ukhrul	1800	3–15	16–28	1484	7	5

SAVANNA TYPES AND THEIR DISTRIBUTION

Bor (1940) classified the savannas of Assam into three habitat types:

(i) Tropical: In this habitat, grasses, generally found in forest or along forest margins, include *Pseudostachyium polymorphum,** *Babusa pallida, Melocanna bambusoides, Lophatherum gracile* and *Centotheca leppecea. Panicum humidrom, Saccolepis interrupta, Hymenachne assamica, Elusine indica, Vassia aispiolata* and *Leersia hexandra* are the more common species found outside the forest on moist habitats. Typical savannas of the uplands consist almost entirely of *Imperata cylindrica*, but associated with this species are *Saccharum spontaneum, S. narenga, Apluda aristata, Cymbopogon pendulus, Arundinella* sp. and *Ophiurus megaphyllus*.

(ii) Subtropical habitats: In forest and along forest margins, species of *Dendrocalamus* and *Bambusa* abound, but the majority of bamboos belong to the genus *Arundinaria*. Herbaceous forest species includes *Oplismenus compositus, Cyrtococcum radicaus, Polygon monspelliensis Isachne albens, Ichnanthus vicinus* and *Panicum khasianum*. In moist habitats outside the forest, the most common species are *Alopecurus myosuroides*, several species of *Panicum, Eragrostis, Paspalidium, Echinochloa* and *Isachne, Deyeuxia elalio, Arundinella khasiana, Saccolespsis indica* and *S. myosuroides*, species of *Anthraxon, Dimeria fuscescens* and *Coelachne pulchella*.

In xerophytic habitats, *Imperata cylindrica* is the main species over large areas. Common associates are several species of *Themeda, Erianthus* and *Eulalia, Andropogon ascinoides, Sorghym nitidum, Saccharum neranga, Cymbopogon khasianus, Thyrsia* and *Zea*.

(iii) Temperate habitats: The common grasses are *Denthonia cachemyriana, Bromus asper, Calamagrostis emodis, Deyeuxia scabrescens, D. magarum, Capillipedium pteropechys, Tripogan filiformis* and several species of *Arundinaria*.

Certain tree species, such as *Careya arborea, Callicarpa arborea* and *Schima wallichii*, are scattered among the seven dominant grasses, namely *Saccharum narenga, Sorghum nitidum, Themeda triandra, Andropogon ascinodis, Erianthus longisetosus, Imperata, cylindrica* and *Ophiurum megaphyllus* in the Shillong plateau (Bor, 1942). Chief associates of the grasses in the community are *Atylosia elongata, Crotalaria humifusa, Desmodium sambuense, Eriosema chinensis, Flemingia latifolia, Indigofera astropurpurea, Lespedeza stenocarpa, Priotrapis cytrisoides, Alteris khasiana, Crinum amoenum* and *Hedychum spicatum*, while *Pheonix acaulis* is very common.

Rowntree (1954) reported two grassland and savanna types in Assam, namely:

(a) *Imperata–Saccharum–Themeda*, which is found on higher well-drained land throughout Assam, and which is dominated by *Apluda mutica, Arundinella bengalensis, Crotalaria striata, Eupatorium odoratum, Imperata cylindrica, Leea* sp., *Narenga porphyrocoma* and *Themeda arundinacea*.

(b) *Alphinia–Phragmites–Saccharum*, a community occurring on recent alluvium in the flood plains of rivers all over Assam. The dominant species are *Alpinia, Erianthus ravennae, Phragmites karka, Saccharum procerum, S. spontaneum, Albizzia procera* and *Bombax malabaricum*.

Champion & Seth (1968) have reported the following savannas and grasslands in Assam:

(i) Moist *sal* savannas: These are open *sal* forest with tall grasses in the east of the Brahmaputra valley with *sal* itself (*Shorea robusta*) and other tree species like *Lagestroemia parviflora, Wrightia tomentosa* and *Salmalia malabarica*. Among prominent grasses are *Themeda arundinacea, Imperata cylindrica, Cymbopogon nardus* and *Desmostachya bipinnata*.

(ii) Low alluvial savanna woodlands: These are most extensively found in the Brahmaputra valley and other parts of north-east India. The common tree species are *Salmalia malabarica* and *Albizzia procera* with *Themeda, Erianthus* and *Saccharum* as the characteristic genera of grasses.

(iii) Eastern wet alluvial grasslands: These treeless grasslands occur on the small alluvial sites which are being cut off by main rivers. They are flooded during the monsoon season but the stiff soil dries out completely during hot weather. This alternation appears to be too severe for tree growth and presumably grassland formation. In most cases, fire runs through the grass annually. *Pharagmites karka* and *Saccharum procerum* are generally the main grass species found in this grassland type where they form a very dense and high grass stratum.

(iv) *Syzygium* parkland or high savannas: These high savannas are distributed on heavy alluvium adjoining the *Sal* forests of the Brahmaputra valley. They tend to comprise very open stands of low branching trees about 3 m high, usually waterlogged during the rains; the ground cover dominants are *Imperata cylindrica, Saccharum spontaneum, Ophiuros* sp. and *Vetiveria* sp. These stands are burnt annually. The main shrubs and trees are *Glochidion assamicum, Leea edgievorthii, Syzygium ceresoideum* and *Emblica officinalis*.

* Nomenclatural authorities for plant species follow Hooker (1875–97).

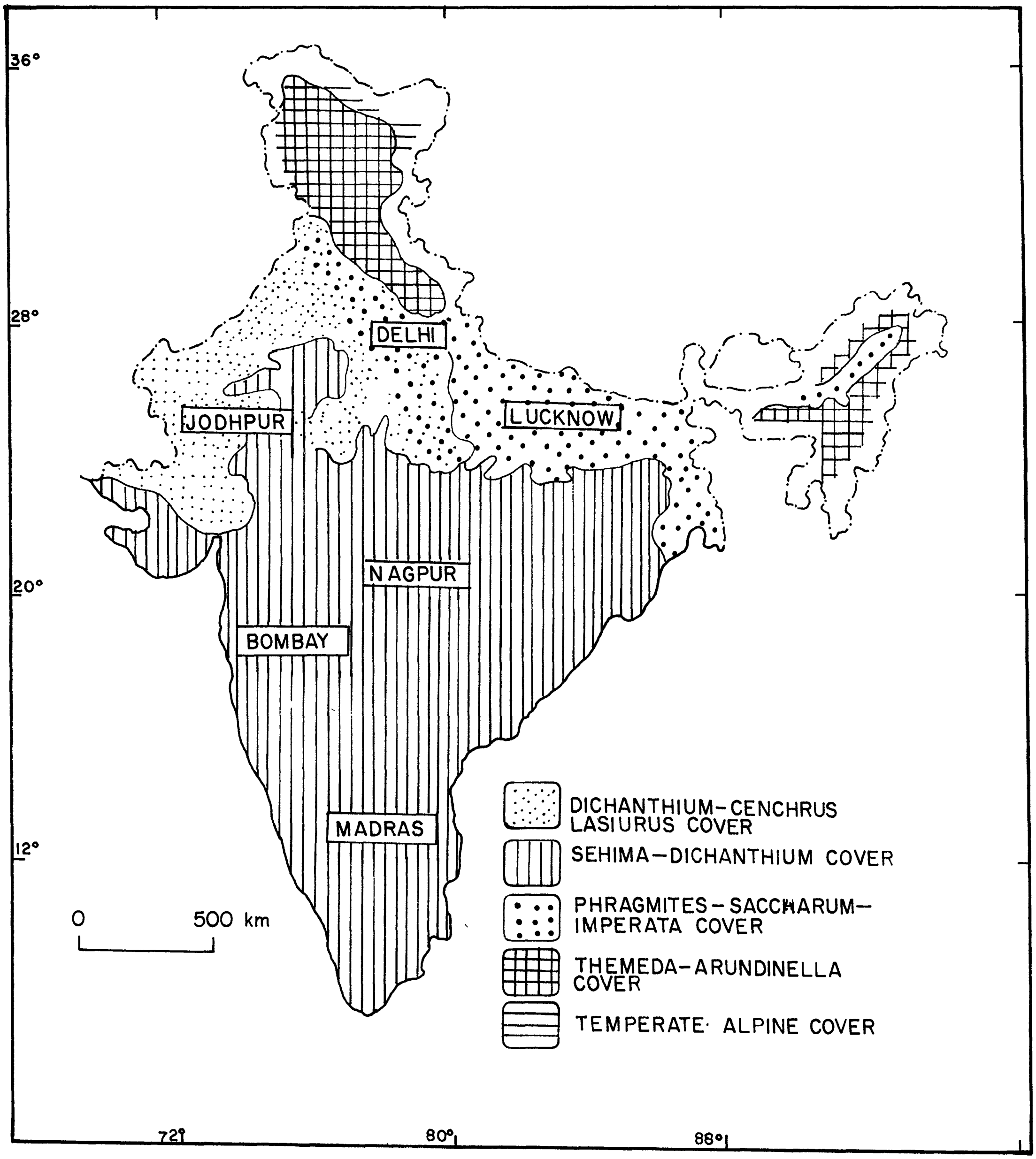

FIG. 1. The grass cover of India (after Dabadghao & Shankarnarayan, 1973).

This last type appears to be an intermediate stage between wetter and well-drained savannas in which tall trees such as *Salmalia* and *Albizzia* replace the low *Syzygium*.

(v) Assam sub-tropical hill savanna woodlands: Repeated shifting cultivation has altered the original forest and has led to the formation of open grasslands with scattered pines or broad-leaved forests.

(vi) Assam sub-tropical pine savanna: Pine occurs as scattered trees over grass, obviously as a result of biotic disturbances. *Agrostis* spp. and *Brachypodium sylvaticum* are the main grasses.

Out of the five broad savanna types recognized by Dabadghao & Shankarnaryan (1973) three savanna types, namely *Phragmites–Saccharum–Imperata*, *Themeda–Arundinella* and Temperate-Alpine, are found in the north-eastern region (Fig. 1).

The *Phragmites–Saccharum–Imperata* type covers the plains of the Ganga and Brahmaputra valley and extends into the plains of the Punjab covering all the states of the north-eastern region. The topography is level, low lying, ill-drained, with a high water table. Rainfall is up to 4000 mm per annum. The soil reaction varies from very acidic to mildly alkaline, with a pH range of 4.5–7.5. The cover consists of nineteen principal grass species, and fifty-six other herbaceous species, including sixteen legumes.

The common grasses are: *Bothriochloa intermedia*, *Chrysopogon aciculatus*, *Desmotachya bipinnata*, *Imperata cylindrica*, *Paspalum conjugatum*, *Phragmites karka*, *Saccharum arundinaceum*, *S. bengalensis*, *S. spontaneum*, *Sporobolus indicus* and *Vetiveria zizanoides*. Main shrubs are: *Clerodendron* sp., *Dendrocalamus hamiltonii*, *Lantana camara*, *Leea indica*, *Vitex negundo*, *Garcinia cowa* and

Miliusa sp. The main trees are: *Palaguium polyanthum, Diospyrus topoisa, Terminalia chebula, Tectona grandis, Eugenia* sp. and *Kayea assamica.*

The *Themeda–Arundinella* type covers the entire northern and north-eastern mountain area of the north-eastern states, including West Bengal, Uttar Pradesh, Punjab, Himachal Pradesh and Jammu, and Kashmir. It occurs in the altitudinal range between 350 and 2100 m above sea-level. The rainfall ranges from 1000 to 12,500 mm at Cherapunji in north-east India. There are sixteen principal grasses, including: *Arundinella bengalensis, A. nepalensis, Bothriochloa intermedia, Chrysopogon fulvus, Cymbopogon jwarancusa, Eragrostiella nardoides, Eragrostis nutans, Apuda mutica, Eulaliopsis binata, Heteropogon contortus, Ischaemum barbatum, Sporobolus indicus* and *Themeda anatheria.* The main shrubs are *Daphne cannabina, Cyclea* sp., *Crataeva nurvala, Rubus racemosus, Viburnum corieceum.* Key trees are: *Ficus nemoralis, Pinus khasya, Phoebe* sp., *Quercus* sp., *Schima wallichii, Castanopsis tribuloides* and *Alnus nepalensis.*

The Temperate Alpine type extends from the high hills of the northern mountain belt, comprising Jammu and Kashmir, Himachal Pradesh, Punjab, Uttar Pradesh, West Bengal, Assam, Meghalaya, Arunachal and Manipur. It occurs above 1500 m in north-east India and above 2100 m in north-west India. The occurrence of snow during winter is quite a common feature. There are fourteen principal grasses and sixty other herbaceous species, including six legumes. The common grasses are: *Agropyron canaliculan, Agrostis canina, A. filipes, A. munroana, A. myrianthus, Andropogon tristis, Calamagrostis epigejos, Chrysopogon gryllus, Danthonia jacquemontii, Phleum alpinum, Poa pratensis* and *Helictotrichon asperum.* The main shrubs include: *Rubus revens, Strobilanthes* sp. and *Berberis aristata.* The dominant trees are: *Rhododendron arboreum, Quercus* sp., *Betula utilis, Pyrus aucuparia Larix griffittiana, Picea spinulosa* and *Lyonia ovalifolia.*

The *Phragmites–Saccharum–Imperata* and the *Themeda–Arundinella* types are distinctly sub-tropical and the temperate alpine cover is distinct from these types (White, 1968). Recently Yadava & Kakati (1985) and Yadava & Singh (1988) reported *Imperata–Bothriochloa* and *Phragmites–Saccharum–Zizania* grassland communities in the plain and wetlands of Manipur respectively.

In the middle altitudes below 2000 m, the grasses are: *Anthoxa clarkei, Arundinella mutica, Catillipedium assimile, Eulalia palma, Holcus Ianatus, Microstetgium cilliatum, Saccharum rufipilum, Sporobolus indicus* and *Themeda villosa.* Shrubs and trees are: *Viburnum corieceum, Luculis pineiana, Rubus racemosa, Quercus* spp., *Rhododendron arboreum* and *Alnus nepalensis.*

In the higher altitudes above 2000 m there is the *Mischanthus–Arundinella* community, with scattered trees of *Rhododendron griffithii* and *R. arboreum.* Besides *Mischanthus nepalensis* and *Arundinella mutica*, other associates are *A. triachata, A. nepalensis, Anemon revularis, Bambusa vulgaris, Cnicus involucratus* and *Lilium macklinae.*

TABLE 2. Percentage of perennial and annual species in certain dry and humid savanna sites.

Savannas	Perennial	Annual	Source
Dry savanna			
Pilani	31.0	69.0	Gill (1975)
Kurukshetra	37.5	62.5	Singh & Yadava (1974)
Humid savanna			
Imphal	55.0	45.0	Kakati (1985)

LIFE FORMS AND THE PHENOLOGY OF SAVANNA SPECIES

Life forms

The flora is generally dominated by annual species as compared to the perennial species in savannas experiencing strong seasonality in climate and a high intensity of grazing and burning. The number of perennial species was less in dry savannas as compared with humid savannas, and the situation is the reverse in the case of annual species (Table 2). Thus the number of perennial species increases with the increase in the rainfall at savanna sites.

Phenology

(a) *Grasses.* The sprouting and germination of seeds in the majority of the grass species starts during the pre-monsoon period, and continues with vigorous growth to complete their flowering and fruiting within the rainy season or in the post-monsoon period (Singh & Yadava, 1974; Yadava & Kakati, 1985).

Kakati (1985) has divided the species into five groups on the basis of their flowering stage in grassland and savanna at Imphal: (i) those which flower only in the moist summer season, e.g. *Imperata cylindrica*; (ii) flowering starts in summer and continues in the rainy season, e.g. *Paspalum orbiculare, Eragrostis atrovirens* and *Echinochloa colonum*; (iii) flowers only in the rainy season, e.g. *Desmodium bipinnata, Axonopus compressus, Sporobolus diander, S. indicus* and *Ischaemum rugosum*; (iv) flowering starts in the rainy season and continues up to the winter season, e.g. *Bothriochloa intermedia, Fimbristylis dichotoma* and *Mimosa pudica, Digitaria longiflora* and *Setaria glauca*; (v) those which flower only in the winter season, e.g. *Hemarthria compressa.*

(b) *Woody components.* The phenology of the woody species varies with the coexistence of evergreen and deciduous woody plants in the savannas. In the north-eastern region, trees drop their leaves in great quantity during the long dry period of December–March (cold and warm dry period) as compared with other parts of India, where leaf drop occurs in the warm and dry month of April (Boojh & Ramakrishnan, 1981; Shukla & Ramakrishnan, 1982; Singh & Singh, 1987; Yadava & Singh, 1988). Leaf-life for broad-leaf species is on average longer in north-eastern India (20 months) than in the central Himalayan trees (13 months). In north-eastern India, most of the forest tree

TABLE 3. Above ground biomass (g/m²) of various species in different months.

Species	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Bothriochloa intermedia	123.0	213.2	328.9	343.2	183.0	190.4	192.4	124.8	145.4	218.2	234.0	246.5	283.8
Digitaria longiflora	4.5	0.3	1.7	1.2	1.7	0.2	—	—	0.9	1.5	1.0	—	—
Desmodium bipinnata	2.4	7.3	0.3	1.3	2.8	—	1.7	—	1.3	1.2	2.4	2.8	1.4
Eragrostis atrovirens	9.3	27.9	19.8	8.1	—	0.6	8.3	11.6	1.2	9.4	18.3	1.2	—
Fimbristylis dichromata	29.3	28.8	16.7	10.8	8.0	2.6	2.3	0.2	0.1	1.5	0.4	0.1	0.2
Hemarthria compressa	6.5	4.7	2.7	4.5	20.9	9.6	3.1	3.6	3.8	1.6	0.4	2.1	1.3
Imperata cylindrica	229.3	221.7	195.9	286.6	242.1	197.3	178.4	125.2	168.9	244.5	321.5	231.0	340.6
Kylligya triceps	2.0	1.0	1.3	0.3	1.3	0.5	0.1	0.8	0.03	2.5	1.3	1.1	2.7
Leersia hexandra	4.0	21.2	11.0	19.5	20.9	2.5	3.4	6.7	0.1	1.6	2.0	2.2	6.2
Paspalum arbiculare	0.5	9.1	2.4	30.3	19.0	11.4	5.3	19.4	3.5	3.6	3.9	7.1	14.7
Sporobolus indicus	—	—	3.0	—	1.8	—	—	—	3.6	14.8	12.5	6.4	1.7
Other grasses	—	—	2.2	—	9.6	—	—	—	—	0.7	1.3	2.8	2.3
Other forbs	—	0.5	0.6	0.1	0.9	0.6	3.3	—	—	28.1	52.0	39.9	26.9

species exhibit flowering during the warm and dry period with another small peak being observed in the autumn.

PLANT BIOMASS AND NET PRIMARY PRODUCTION

Work on plant biomass and net primary production have been reviewed by Yadava & Singh (1977), Singh & Joshi (1979) and Singh *et al.* (1985) for the tropical grasslands of India, but, sadly, little work has been done on plant biomass and net primary production in the savannas of north-eastern India (Yadava & Kakati, 1984, 1985). Therefore the data generated by Yadava & Kakati (1984, 1985), Yadava (1987) and Yadava & Singh (1988) have been used for discussion in this paper.

(a) Biomass

The majority of above-ground biomass is contributed by grasses, followed by sedges and forbs (Table 3). Out of twelve plant species studied, there were eight grasses, two sedges, and only one forb and shrub. The majority of the total live plant biomass was contributed by two dominant species, i.e. *Imperata cylindrica* and *Bothriochloa intermedia*. The percentage contribution of *Imperata cylindrica* varied from 36% (April) to 55.8% (June) whereas *B. intermedia* ranged from 35.7% (October) to 56% (August). The maximum percentage contribution in both the species was recorded during the flowering stage.

Above-ground biomass ranged from 292.3 g m^{-2} (January) to a maximum of 706.6 g m^{-2} in September. Standing shoots varied from 532.5 g m^{-2} (June) to 1158 g m^{-2} (January). Litter ranged from 167.0 g m^{-2} (November) to 231.8 g m^{-2} (June). Low amounts of litter during the rainy season indicate the disappearance of the old litter. The values of standing shoots are comparatively higher than of live shoots and litter in this savanna (Fig. 2).

Below-ground biomass exhibited two peaks in November and April, coinciding with the dry cool winter and early moist and warm summer. The maximum value of the below-ground biomass was recorded in April (1614 g m^{-2}), and the minimum in July (1000.6 g m^{-2}). Below-ground biomass values are comparatively higher than those of other Indian grass savannas (Yadava & Kakati, 1984). The amount of biomass in different components is of the order below-ground > standing shoots > live shoots > litter.

TABLE 4. Net above ground and below ground, and total net primary production in different seasons (g m^{-2}).

Season	Rainfall (mm)	ANP	BNP	TNP	Rate of production (g m^{-2} day^{-1})
Rainy	766	913.4	447.8	1361.1	11.2
Winter	153	36.4	412.2	448.6	3.0
Summer	404	619.2	36.2	655.5	7.1
Annual	1313	1569.0	896.2	2465.2	6.7

(b) Net primary production

There is clearly a seasonal influence on the growth pattern of major species, which is reflected by wide variation in the seasonal values of net primary production. The rate of above-ground net production was highest in the rainy season, and lowest in the winter season, while below-ground net production was also highest in the rainy season and lowest in the summer season (Table 4).

The maximum total net production was in August (656.7 g m^{-2}) and lowest in November (55.8 g m^{-2}). The rainy season contributed a maximum of 1361.1 g m^{-2} to the total net primary production of 2465.2 g m^{-2} with a minimum in winter (448.6 g m^{-2}).

System transfer functions. System transfer functions were calculated on the basis of annual production and its transfer in different components for one savanna from each of the dry and moist types and the data are presented in Table 5.

The accumulation of standing dead litter and its transfer to the litter compartment is faster in dry savanna than in moist savanna. There is complete disappearance of roots in dry savanna.

The major portion of the total net production is channelled underground in dry savanna whereas the reverse occurs in moist savanna. The net accumulation is, however, high in the case of moist savanna (41% of TNP) and very low in dry savanna (12% of TNP). The surplus

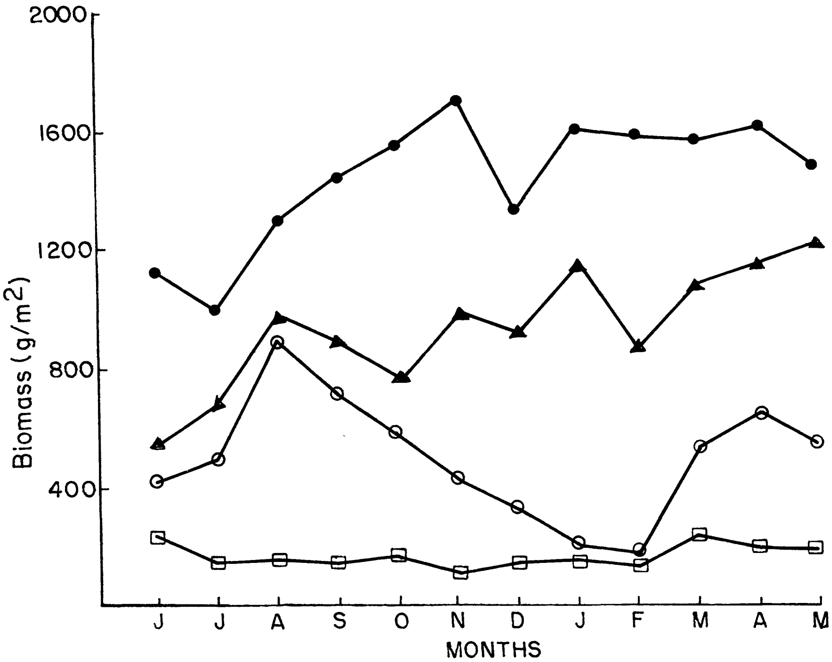

FIG. 2. Changes in the above-ground live biomass (○), standing dead (▲), litter (□) and below-ground biomass (●) in different months through the year.

TABLE 5. System transfer functions of dry matter for selected savannas.

Compartment	Pilani, dry savanna	Imphal, moist savanna
TNP–ANP	0.35	0.64
TNP–BNP	0.65	0.36
ANP–SD	1.00	0.81
SD–L	0.89	0.45
ANP–L	0.80	0.36
L–LD	0.81	1.19
BNP-RD	1.00	0.87
TNP-TD	0.88	0.59

TNP=Total net primary production; ANP=Above ground net primary production; BNP=Below ground net primary production; SD=Standing dead shoot production; L=Litter production; LD=Litter disappearance; RD=Root disappearance TD=Total disappearance.

amount of production could be utilized for grazing or burning in the savannas to maintain these savannas at a given level of succession, or it may lead to succession to woodlands.

Turnover rate of roots. The maximum amount of root biomass was replaced during the rainy season (31%), the lowest in the summer season (12%). The lower value in summer results from vigorous sprouting and upward translocation of reserve food material from underground parts. Annually 44% of roots were replaced.

NUTRIENT CYCLING

Nutrient cycling in climax woodland and savanna is being taken into consideration for comparison in our studies (Kakati, 1985; Yadava, 1987). The aerial perennial biomass of a 30-year-old stand of *Quercus* forest amounts to 1869.5 kg m^{-2} and includes 37.45 g of N, P, K, Na.

In *Quercus–Rhododendron* forest the amount of nutrients was 29.0 g m^{-2} for an aerial biomass of 2150.8 kg m^{-2}.

A comparison of the nutrient economy of three communities was carried out of the basis of the calculation of the amount included in a thousand kg of perennial biomass and the amount required (= amount taken up from soil) to build up this same weight of biomass (Table 6).

Quercus and *Quercus–Rhododendron* woodlands immobilize nearly the same amount of four cations; there are, however, some differences between these elements. The *Bothriochloa–Imperata* community immobilizes more nutrients in comparison to the woodland communities. There were significant differences between woodland communities and the grass savanna community in the uptake of nutrients, the highest value being recorded for *Quercus* woodland, the minimum in the grass savanna community.

The two woodland communities differed in the amount of nutrient uptake, yet required almost the same amount of nutrients for the production of biomass. But in the grass community, the amount of uptake is low, but requires 30% more nutrients to build up biomass in comparison with the woodland communities.

On calculation of immobilization in the perennial biomass as a percent of the uptake from soil, it showed that *Quercus* stands use more nitrogen and potassium, but low amounts of sodium. The phosphorus requirement, however, is almost the same. Grassland communities use high proportions of nitrogen and phosphorus.

The data for the standing quantities and cycling of nutrients in both forest and grassland savanna are given in Table 7. This shows that 40% of total nitrogen present in the

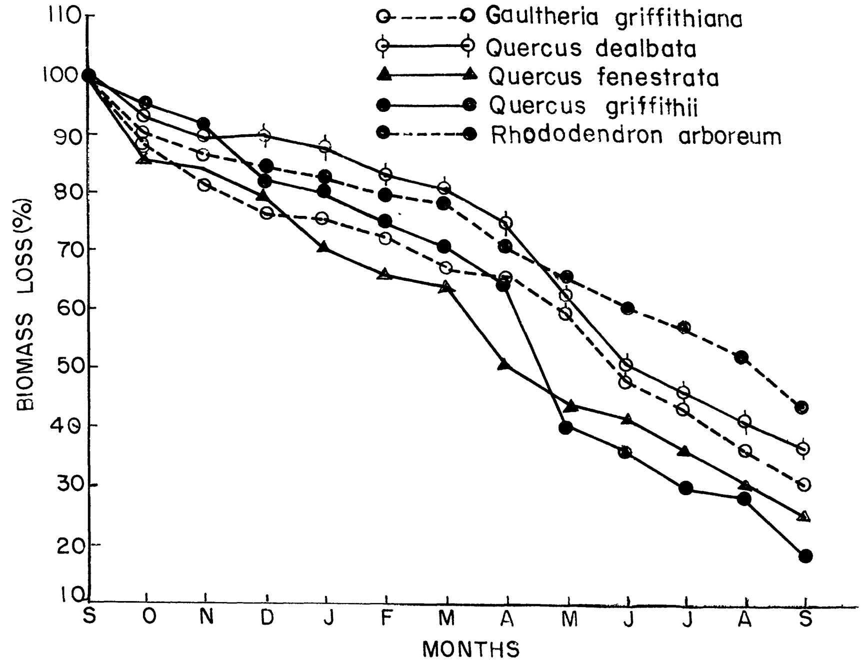

FIG. 3. Percentage of biomass remaining after different period of decomposition.

TABLE 6. Nutrients required (kg) to build a thousand kilograms of above-ground biomass in woodland and grass savannas.

	Fixation/immobilization					Absorption uptake				
Vegetation type	N	P	K	Na	Total	N	P	K	Na	Total
Woodland										
Quercus	7.5	0.6	2.2	0.2	10.5	15.3	1.0	3.8	0.6	20.70
Quercus–Rhododendron	8.8	0.3	2.0	0.2	11.3	13.1	0.4	2.7	0.2	14.4
Savanna										
Bothriochloa–Imperata	12.8	2.1	—	—	14.9	2.7	0.3	—	—	3.0

TABLE 7. Standing state and cycling of nutrients in sample forests and savannas in north-east India.

	Standing state (kg ha^{-1})			Cycling (kg ha^{-1} yr^{-1})		
Savanna type	Plant material	Soil	Total	Uptake	Release	Retention
Nitrogen						
Forest	2084.9	3168.0	5252.9	277.6	31.9	245.7
Savanna	447.7	6313.8	6761.5	446.8	303.7	143.1
Phosphorus						
Forest	66.0	86.4	152.4	8.6	1.5	7.1
Savanna	56.3	145.7	202.0	44.4	20.2	16.2

forest savanna resided in plant material, whereas in grass savanna it is only 6.63%. For phosphorus, 43% of total phosphorus in the forest savanna is retained in the plant system, with 28% in the grassland savanna. Thus the uptake of N and P is comparatively more in grass savanna that in forest savanna, and correspondingly release of nutrients is also greater in grass savanna than in forest savanna. The uptake of N and P is comparatively higher than the values reported by Singh, Singh & Yadava (1979) and Misra (1983).

Thus the conversion of forest land into savanna lands has a marked impact on the pattern of nutrient cycling and the nutrient budget. Therefore special attention is needed to study the long-term effects on these in developing sensible management practices for the savannas of the region.

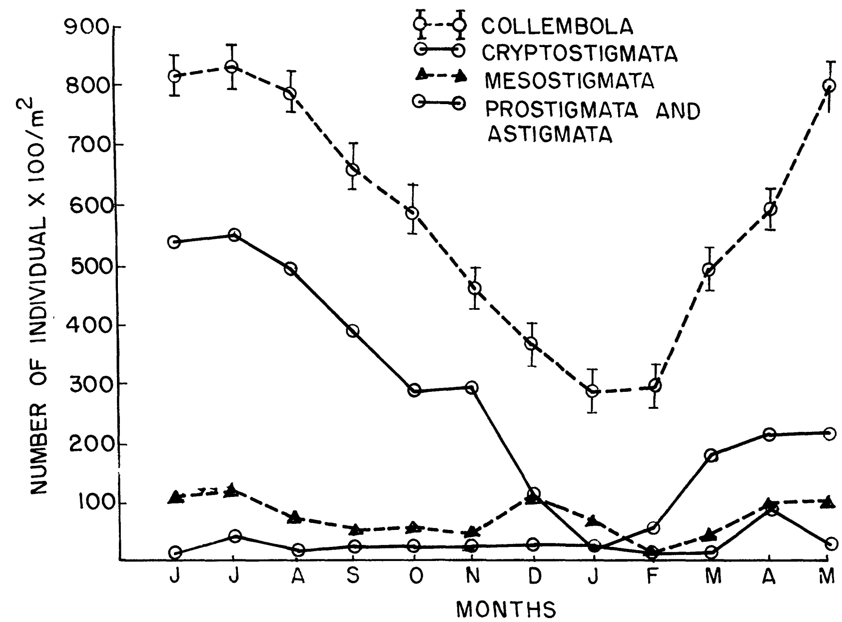

FIG. 4. Monthly variation in the population density of micro-arthropods in a forest stand.

TABLE 8. Protein value of grasses and fodder trees in the savannas of north-easst India (Kakati, 1985; Borthakur *et al.*, 1979).

Species	Crude protein (%)
Grasses	
Arundinella bengalensis	10.6
Axonopus compressus	14.5
Bothriochloa intermedia	7.8
Brachiaria sp.	7.0
Chrysopogon compressa	14.4
C. gryllus	7.0
Digitaria sp.	14.3
Hemarthria compressa	15.4
Leersia hexandra	11.9
Imperata cylindrica	10.0
Paspalum orbiculare	10.3
Sporobolus indicus	8.3
Thysanolaena maxima	10.21
Tree leaves	
Bauhinia malabarica	17.1
Bauhinia purpurea	24.0
Callicarpa arborea	20.6
Dalbergia sissoo	20.7
Macaranga thouars	15.1
Orbechia cumite	20.2
Veronia cinera	13.8
Vitex peduncularis	13.5

NUTRITIVE VALUE

Crude protein values of the important grass and tree fodder species growing in the north-eastern savannas are given in Table 8. These values are compartively higher than those reported for the semi-arid and dry sub-humid savannas (Yadava & Singh, 1977). The percentage of crude protein varies species to species, and also in different phenological stages, exhibiting a high value during the flowering and mature stages.

DECOMPOSITION

Recently Laishram & Yadava (1988) have studied the effects of initial lignin and nitrogen in the decomposition of the leaves of certain forest species, i.e. *Gaultheria griffithiana, Quercus griffithii, Quercus dealbata, Quercus fenestrata* and *Rhododendron arboreum*. The maximum weight loss was observed for *Q. griffithii* (82.49%), a broad-leaf deciduous species, the lowest for *R. arboreum* (41.15%), an evergreen species (Fig. 4). It was found that the rate of decomposition of the leaf litter was highly influenced by the initial lignin and nitrogen content of the litter.

SECONDARY PRODUCERS

The population density of soil arthropods was higher in the original forests than in the shifting cultivation (*Jhum*) sites in Meghalaya State. The population density of soil micro-arthropods was recorded to be at its maximum in May, coinciding with the high temperatures and pre-monsoon showers, whereas the minimum was in the January and February cool dry period. The soil fauna was reduced to half of that of the undistributed forest soil (Darlong & Alferd, 1982). In Manipur State, the maximum population of soil microarthropods was observed in July, the minimum in February (Fig. 3) (Thingbaijam, Yadava & Elangbam, 1986). Distributed sites slowly became colonized to the densities found in the adjacent forests. Collembolla and Acarina are the dominent orders in these forest and disturbed sites, and are influenced above all by soil moisture, temperature, and ground floor litter.

Laishram & Yadava (1988) have studied the seasonal changes in the soil respiration rates in the forests. The maximum value for soil respiration was obtained during the summer season (598 $mgCO_2m^{-2}h^{-1}$), the minimum in the winter season (424 $mgCO_2m^{-2}h^{-1}$). Thus, the moist summer period is more cogenial for the growth of micro-organisms in the soil. The value of soil respiration was lower in savanna (194 $mgCO_2m^{-2}h^{-1}$) than in the original forest (Kakati & Yadava, 1984).

VERTEBRATES

The north-eastern region is very rich in vertebrates, when compared with other parts of India. The large herbivores, such as rhinoceroses (1000), elephants (5000), wild buffaloes, brow antler deer, barking deer, sambhar and spotted deer are among the most prominent vertebrates in the region (Prater, 1968).

Bothriochloa–Imperata grass savanna may support 3.5 cattle ha^{-1} (Kakati, 1985). Biomass data on verebrates is unfortunately lacking, and it is not possible to speculate on their role in the short- and long-term functioning of the savannas in the region.

SUCCESSIONAL CHANGES UNDER BIOTIC DISTURBANCES

Successional patterns for various savanna cover types are suggested below (after Dabadghao & Shankarnarayan, 1973):

(i) Succession in the *Phragmites–Saccharum–Imperata* types is as follows:

Phragmites–Saccharum–Imperata (savanna)
↑
Burning and cutting ↓ Grazing
Saccharum–Imperata–Sclerostaychya
↑
Burning and grazing ↓ ↓
Desmostachya–Imperata (depauperate) *Vetiveria*
↑ ↓
Sporobolus–Paspalum–Chrysopogon

The *Phragmites–Saccharum–Imperata* type consists of tall, coarse, grasses, generally growing in swampy and wet places. On cutting and burning the grass is primarily used for thatching purposes. In disturbed conditions, the swampy areas invariably show the dominance of *Phragmites karka*, even when subjected to grazing to some extent. *Phragmites karka* is the first to go in drier habitats due to cutting and burning; it is replaced by *Saccharum*, *Imperata* and *Sclerostachya*. The introduction of grazing at this stage, along with burning, will favour the appearance of *Vetiveria zizanoides*. Continuous burning induces *Imperata cylindrica* to assume a depauperate form in humid situations. In north-eastern India, further grazing and burning induces yet further degredation to *Sporobolus*, with *S. indicus*, *Paspalum*, with *P. congugatum* and *P. orbiculare*, and *Chrysopogon*, with *C. aciculatus*. This indicates a change-over to mesophytes from hydrophytes.

Since this savanna cover favours tall, coarse and unpalatable species, and only on deterioration to a *Desmostachya* and *Imperata* (depauperate stage), these species can be utilized for grazing. Thus management practices should be designed to induce the change in habitat from hydrophytic to mesophytic. Burning, followed by heavy grazing, would induce the early palatable growth in these otherwise coarse species. Recently Deb-Roy (1986) has also recommended limited burning practice in the management of these grass species in the Manas Wild Life Sanctuary in Assam, which is the home of many endemic species, such as the pygmy hog, rhinocerus, and wild buffaloes, etc.

(ii) Succession in the *Themeda–Arundinella* type is as follows:

Themeda–Arundinella
↑
Protection Grazing ↓ Burning
Arundinella–Chrysopogon *Dimeria fuscescens*
↑
Protection Grazing ↓ ↓
Heteropogon–Bothriochloa *Eragrostis leioptera*
↑
Protection Grazing ↓ ↓
Cynodon *Cynodon* *Cynodon dactylon*

Themeda anathera, being the most desirable species, obviously deserves the highest consideration in the management of this type. Light grazing during the monsoon season and moderate grazing during the post-monsoon period does not appear to create any harmful effects.

Studies in the successional trends in the temperate alpine type of the north-eastern region is lacking, and further study is needed.

CONCLUSION

Most of the savannas of north-eastern India have been derived following the destruction of the forests through shifting cultivation and they then represent sub-climax communities induced by burning and grazing. Burning and grazing are the most important factors in both the moist and dry savannas. In general, the area experiences a high rainfall. The length of the growing season, along with species composition and the intensity of grazing and burning governs the net primary production. Mineralization is rapid in grass species, as compared to woody species. There are few studies on the functioning of the savanna ecosystems in north-eastern India. Therefore further reseach efforts are needed to fully understand the functioning of these savannas in relation to both stresses and disturbances.

REFERENCES

Boojh, R. & Ramakrishnan, P.S. (1981) Phenology of trees in a sub-tropical evergreen mountane in north-east India. *Geo. Eco. Top.* **5**, 189–209.

Bor, L.N. (1940) A list of the grasses of Assam. *Ind. For. Res. (Bot. N.S.)*, **1**, 47–102.

Bor, L.N. (1942) The relict vegetation of Shillong Plateau–Assam. *Ind. For. Res.* **3**, 152–195.

Borthakur, B.N., Prasad, R.N., Ghosh, S.P., Singh, A., Awasthi, R.P., Rai, R.N., Verma, A., Datta, H.H., Sachan, J.N. & Singh, M.D. (1979) *Proc. Agro-forestry Seminar, Indian Council of Agricultural Research, New Delhi*, pp. 109–131.

Champion, H.G. & Seth, S.K. (1968) *A revised survey of the forest types of India.* Govt. of India Publ., Delhi, 404pp.

Dabaghao, P.M. & Shankarnarayhan, K.A. (1973) *The grass cover of India.* ICAR, New Delhi, 713pp.

Darlong, V.T. & Alfered, J. (1982) Differences in arthropod population structure in soils of forests and Jhum sites of North-East India. *Pedobiologia*, **23**, 112–119.

Deb-Roy, S. (1986) Fire in wet grassland habitats of Assam. *Ind. For.* **112**, 191–197.

Gadgil, M. & Meher Homji, V.M. (1985) Land use and productive potential of Indian savanna. *Ecology and management of world savannas* (ed. by J. C. Tothill and J. J. Mott), pp. 107–113. Australian Academy of Science, Canberra.

Gill, G.S. (1975) Herbage dynamics and seasonality of primary productivity at Pilani, Rajasthan. Ph.D. thesis, Birla Institute of Technology and Science, Pilani, India.

Kakati, L.N. & Yadava, P.S. (1984) Soil respiration in the grassland eco-system at Imphal. *J. Curr. Bios.*

Hooker, J.D. (1875–97) *The flora of British India.* L. Breeve & Co., London.

Kakati, L.N. (1985) Structure and functioning of the grassland ecosystem at Imphal. Ph.D. thesis, Manipur University, Imphal, India.

Laishram, I.D. & Yadava, P.S. (1988) Lignin and nitrogen in the decomposition of leaf litter in a sub-tropical forest ecosystem at Shiroy hills in north-eastern India. *Plant and Soil*, **106**, 59–64.

Laishram, I.D. & Yadava, P.S. (1988) Soil and litter respiration in a mixed oak forest ecosystem at Shiroy hills, Manipur, in north-eastern India. *Plant and Soil.*

Misra, R. (1983) Indian savanna. *Tropical savanna* (ed. by F. Bourleere), pp. 151–166. Elsevier Scientific Publications, Amsterdam.

Prater, S.H. (1968) *The book of Indian animals.* Bombay Natural History Society.

Puri, G.S. (1960) *Indian Forest Ecology*, Vol. I. Oxford Book and Stationary Co., New Delhi.

Rowntree, J.B. (1954) An introduction to the vegetation of the Assam valley. *Ind. For. Res.* (N.S.), **9**, 1–87.

Raychaudhari, S.P. (1966) *Land and soil.* National Book Trust, New Delhi.

Shukla, R.P. & Ramakrishnan, P.S. (1982). Phenology of trees in a sub-tropical humid forest in north-eastern India. *Vegetatio*, **49**, 103–109.

Singh, E.J. (1988) Phytosociology, primary productivity and nutrient cycling in the sub-tropical forest ecosystem at Shiroy hills, Manipur. Ph.D. thesis, Manipur University, Imphal, India.

Singh, J.S., Hanxi Yang & Sajise, P.F. (1985) Structure and functional aspects of Indian and south east Asia savanna ecosystems. *Ecology and management of world's savanna* (ed. by J. C. Tothill and J. J. Mott), pp. 34–55. Australian Academy of Sciences, Canberra.

Singh, J.S. & Joshi, M.C. (1979) Primary production. *Grassland ecosystems of the world. Analysis of grassland and their uses* (ed. by R. T. Coupland). International Biological Programme, Vol. 18, pp. 197–218. Cambridge University Press.

Singh, J.S., Singh, K.P. & Yadava, P.S. (1979) Ecosystem synthesis. In *Grassland ecosystems of the world. Analysis of grasslands and their use.* (ed. by R. T. Coupland). International Biological Programme, Vol. 18, pp. 231–239. Cambridge University Press.

Singh, J.S. & Yadava, P.S. (1974) Seasonal variation in composition plant biomass and net primary production of a tropical grassland at Kurukshetra, India. *Ecol. Monogr.* **44**, 351–376.

Singh, J.S. & Singh, S.P. (1987) Forest vegetation of the Himalaya. *Bot. Rev*, **53**, 80–191.

Thingbaijam, B.S., Yadava, P.S. & Elangbam, J.S. (1986) Population density of soil arthropods in the sub-tropical forest ecosystem at Shiroy hill, Manipur. *Proc. Symp. Pest. & Env. Poll.* pp. 278–288.

White, R.O. (1968) *Grassland of the monsoon.* Faber and Faber, London.

Yadava, P.S. (1987) Ecological studies on forest ecosystem of Manipur. Manipur University, Imphal: Final Technical Report (DOE-L-14013/15182), p. 145.

Yadava, P.S. & Kakati, L.N. (1984) Biomass dynamics and net primary productivity in grassland community at Imphal. *Int. J. Biometeorol.* **28**, 123–145 (supplement).

Yadava, P.S. & Kakati, L.N. (1985) Seasonal variation in herbage accumulation, net primary productivity and system transfer function in an Indian grassland. *Ecology and management of world's savanna* (ed. by J. C. Tothill and J. J. Mott), pp. 273–276. Australian Academy of Science, Canberra.

Yadava, P.S. & Singh, J.S. (1977) *Grassland vegetation: Its structure, function, utilization, and management.* Today and Tomorrow's Printers and Publishers, New Delhi, India.

Yadava, P.S. & Singh, E.J. (1988) Some aspects of ecology of forest in Shiroy, Manipur in north-eastern India. *Int. J. Ecol. Environ. Sci.* **14**, 103–113.