LITTER PRODUCTION, NUTRIENT INPUT AND RELEASE DURING DECOMPOSITION IN DEGRADED MOIST DECIDUOUS AND SUBTROPICAL WET HILL FORESTS OF MEGHALAYA

BY

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THESIS SUBMITTED IN FULFILMENT OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN BOTANY

NORTH-EASTERN HILL UNIVERSITY
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FEBRUARY
1990

DEDICATED

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We certify that the thesis entitled **'Litter production, nutrient input and release during decomposition in degraded tropical moist deciduous and subtropical wet hill forests of Meghalaya'**, submitted by **Mr. Ashok Kumar Singh, M.Sc.**, for the **Degree of Doctor of Philosophy in Botany** of the North-Eastern Hill University, Shillong, embodies the results of original research work carried out by him under our supervision. Mr Singh has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. The work has not been submitted for any degree of any other University.

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PREFACE

Human interference in the form of shifting agriculture (Jhum) is the major destructive force of vegetation in the entire north-east India. Forested areas after few years of jhumming are left for vegetation regrowth. Some earlier workers have studied the secondary succession on abandoned jhum fallows in Meghalaya. This piece of research work lays emphasis on investigating functional attributes of the seral communities. The study was conducted in the young ($\leqslant$ 5 year old) and old (15 - 20 year old) stands of subtropical wet hill and tropical moist deciduous forests of Meghalaya.

The thesis is divided into six chapters. General introduction and review of relevant work is given in the first chapter. Second chapter describes the study sites and climate of the area. Community composition and tree phenology are dealt with in the third chapter. Data pertaining to litter production and accumulation have been discussed in the fourth chapter. Results of mineral elements (N, P, K) input through litter and their release during decomposition are discussed in the fifth chapter. A general discussion is given in the last chapter followed by a summary. Literature cited is given at the end.

I take this opportunity to express my profound gratitude and indebtedness to my Supervisors, Professor R.R. Mishra and Dr. H. N. Pandey, Department of Botany, North-Eastern Hill University, Shillong, for their constant inspiration and valuable guidance during the course of study. I am grateful to Professor R.S. Tripathi, Dr. J. P. Gaur and Dr. G. D. Sharma, for their helpful suggestions and to my uncle Professor R. P. Sinha, Emeritus Professor of Botany, Patna University for his keen interest and inspiration throughout the research tenure.

I am thankful to Professor Y. S. Chauhan, Head of the Department of Botany, NEHU, Shillong, for providing necessary laboratory facilities.

My heartful thanks goes to Dr. Y. Kumar and to my friends Dr. M. L. Khan, Messers Umashankar, A.C. Kalita, R.S. Lapcha, L. Boral, T. Pachuau and U.K. Shahoo for their cooperation and help.

I am also thankful to Mr. Joseph F. Khongbuh, CIEFL Regional Centre, Shillong, who took pain in typing flawlessly and giving a good presentation of this dissertation.

I express my heartfelt sentiments to my wife for her endurance and encouragement during the tenure of the study.

Financial support by the Ministry of Environment and Forests, Government of India, in the form of a research project sanctioned to my Supervisors is thankfully acknowledged.

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SHILLONG
THE 28 FEBRUARY 1990

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CHAPTER 1

GENERAL INTRODUCTION AND REVIEW OF LITERATURE

Forests all over the world are exposed to different kinds of natural and human disturbances. Natural disturbances and concommitant recovery mechanism are integrated aspects of normal ecosystem behaviour (White 1979). Human disturbances, on the other hand, differ sharply in kind, scale, intensity and frequency and may or may not be more extensive than natural disturbances. Many kinds of human disturbances have a higher frequency than natural disturbances. This is obvious in shifting cultivation practice followed in humid tropical forests (Reiners 1980). The interaction of man's activities with physiography and climate has led to the extensive degradation of original vegetation and soil in many parts of the world (Rosen 1984).

The structure of plant and animal communities and subsequent development of vegetation is strongly influenced by nature and intensity of disturbance (White 1979, Pandey and Singh 1984). Effects of human intervention on basic ecosystem processes such as energy flow and nutrient and hydrologic cycles are widely prevalent both in temperate and tropical countries of the world (Lamottee 1981). And some amount of quantitative data are now available that permit us to predict: (1) the changing structure of forest through time after massive disturbance, (2) the changing status of nutrient stores in ecosystem, and (3) the changes in water balance of whole ecosystem as they develop following disturbance (Mooney 1977). But, still our understanding of the impacts of man's intervention with the structure and function of natural ecosystem is far from complete.

The north-eastern region of India is characterized by luxuriant growth of deciduous, humid evergreen and mixed coniferous types of forest vegetation. Much of the original vegetation, however, have either been totally disappeared or transformed into degraded secondary forests by different kinds of human activities. Two major activities that have contributed to the large scale destruction of the forests in the north-east India are large scale extraction of timber and shifting cultivation, locally called 'Jhum'. Jhumming is the predominant form of agriculture which supports about 1.6 million tribal population, spread over in an area of 0.426 million hectares in the entire north-eastern region. Shortening of jhum cycle (the intervening fallow period before the farmer returns to the same site) during last few decades under increasing pressure of rising population is a major cause of rapid environmental degradation including deforestation in the region.

Removal of tree canopy either through selective felling or clear cutting of forest and abandonment of land after few years of cultivation provide suitable site for the commencement of secondary succession. Secondary successional pattern subsequent to 'Jhumming' depends upon the weeding practice at the time of agriculture, type of vegetation that is slashed and seed source available to soil (Ramakrishnan et al. 1981). The seral communities on jhum fallows differ from one another in species composition, diversity and dominance and show differences in population structure of the constituent species. Such a variability in the community structure influences the energy and nutrient budgets of the ecosystem by altering the amount and pattern of the litter production and decomposition. Recovery of vegetation is closely associated with the recovery of biogeochemical cycle. Initially, recovery in nutrient cycle during succession was attributed to the increasing capacity of ecosystem to entrap and hold nutrients (Odum 1969). More specifically rapid rate of net primary production, high elemental storage in successional vegetation, faster recovery of evapotranspiration and reduction in mineralisation have been offered as mechanisms for minimising nutrient losses from the ecosystem (Vitousek et al. 1979).

Based on the long history of research and observations of earlier workers on succession, Marglef (1968), Odum (1969) and Whittaker (1975) identified general trends in community development. Their synthetic treatments helped subsequent researchers (Connell and Slatyer 1977, Van Hulst 1978) to examine the empirical . .. and experimental basis of succession theory. Virtually all current discussion on succession considers only secondary succession which may be the result of severe disturbances associated with natural catastrophies, man-induced changes or due to subtle processes. In each instance the individual species in the ecosystem interacts in such a way that disturbance to any one of them or to one part of the system may affect the entire community. White (1979) has pointed out the problems of assessing the impact of disturbance on natural vegetation and has described disturbance as a tripartite continuum of frequency, predictability and magnitude. Depending on the degree of disturbance Connell (1979) has proposed six hypotheses which operate during plant succession.

Succession is characteristically variable both in its environment and species composition. The variability is partly attributed to the climate, geographical location, geomorphological features, site disturbance and the number and kind of species present in the community (Bazzaz 1979). The functional changes such as organic productivity, litter production, rate of decomposition and mineral cycling during progression of succession have been examined by Golley *et* al. (1974). Recent studies (Meentemeyer et al. 1982) show aboveground litter production to be the dominant pathway joining the living biological component to the non-living soil component of the ecosystem through organic matter decomposition cycle. It acts as an input-output system on the soil surface and determines several other functions of the ecosystem. Therefore, recently much emphasis has been placed on determining the nutrient flux accompanying litterfall and decomposition in forest ecosystem.

Forest litter is the layer of residues of leaves, branches, bark, fruits and other parts of plants that accumulate on the surface of soil. The classic work of Ebermayer (1876) on the production and chemical composition of forest litter demonstrated conclusively the importance of litter fall in the nutrient cycling in forest ecosystem. At the same time its significance in soil development was shown by Muller (1887). The studies on the litterfall in forest ecosystems have been reviewed by Lutz and Chandler (1946), Adaltonen (1948) and Bray and Gorham (1964). The role of physical environment in litter production has been discussed by Jordan (1971), Jensen (1974) and Jordan and Murphy (1978). Recently, the importance of forest litter in soil and slope conservation, forest management resistant to anthropogenic and pyrogenic activities and forest productivity have been emphasized by Sapozhnikov (1984).

The early work on litter dynamics in the tropics has been done in Africa by Laudelout and Meyer (1954) in equatorial forest. Greenland and Kowal (1960) and Nye (1961) have determined the litter fall and nutrient content in moist tropical forest of Ghana. In South Central America Jenny et al. (1949) studied the litter dynamics in temperate and tropical forests and Klinge and Rodrigues (1968) in Amazonia Terra. Firma. Forest. Ewel (1976) studied litter production in successional forest of eastern Guatemala. Litterfall in relation to climate has been studied by Tanner (1980, 1981) in the montane rain forests of Jamaica. In south east Asia some work has been done in Thailand (Kira et al. 1967), New Guinea (Edwards 1977), Edwards and Grubb 1977) and Malaysia (Gong 1972, Lim 1978, Ogawa 1978, Yoda 1978, Proctor et al. 1983).

In India, litter production studies have been confined mainly to the tropical deciduous forest (Champion 1936, Puri 1953). Litter production, its nutrient content and turnover in dry deciduous forest at Varanasi were determined by Singh (1968, 1969). Subsequently, information on this aspect was added by Gaur and Pandey (1978), Vyas and Garg (1984) and Kapur et al. (1986). The litter production in the forests of north-east India has been investigated by Singh and Ramakrishnan (1982) and Boojh and Ramakrishnan (1981).

The importance of litterfall, particularly leaffall during early stages of succession has been reviewed by Golley *et al*. (1974). The rate of litterfall and nutrient input has been investigated in very few successional communities of the tropics. Gomez Pompa (1974) has carried out a number of studies on litter dynamics in successional communities in the tropics. He emphasized the importance of mineral turnover in community development during succession. Van Cleve and Viereck (1981) have examined the role of standing dead biomass on the forest floor during succession in the boreal forest of Alaska.

A large number of factors affect litter production and composition in forest ecosystem. Effects of climate, soil, forest type and physiography have been discussed in great depth by Bray and Gorham (1964), Swift (1977), Turnbull (1983) and Meentemeyer (1984). Bray and Gorham (1964) have shown the influence of climate on litter production. The mean annual litter production averages 1 t/ha for Arctic-Alpine Zone, 11 t/ha for equatorial forests and 3.5 and 5.5 t/ha for cool and warm temperate forests, respectively. It ranges from 5.5 to 15.3 t/ha in tropical forests (Madge 1965, Muller and Neilsen 1965, Hopkins 1966, Kira and Shidei 1967, Hains and Foster 1977, Brassel *et al*. 1980, Tanner 1980). The rate of litterfall decreases with decrease in availability of light during the growing season along a world wide gradient (Jordan 1971). Bray and Gorham (1964) have shown the role of temperature in controlling total litterfall at different latitudes. The maximum amount was observed at the equator, declining steadily at 65° N latitude in Europe where forest grades into Tundra. The litterfall pattern may vary even at the same latitude in coastal and montane forests due to differences in total amount of light available for growth during growing season (Jordan and Murphy 1978).

Jorgensen _et al_. (1975) noted that water and nutrient availability also limits litter production.

Physical effects of rain have also been considered in litterfall. The increased weight of senesced material in the canopy due to wetting caused them to fall (Brassel _et al_. 1980). But, Tanner (1980) has observed that litterfall per day during the dry season was about two times and during the hurricane period it was about 4 times more than during the wet period. Ovington (1957) was first to quantify the dry matter production in _Pinus sylvestris_ plantation from early stage of development to fully mature stage and concluded that it is a function of stand development. However, Bray and Gorham (1964) have shown that there is no inherent tendency towards higher or lower litterfall with increasing age from 30 to more than 100 years of age; the variation may be encountered at lower age where canopy is underdeveloped.

The litter which falls seasonally or continuously is attacked by a variety of microorganisms and is decomposed to such a degree that it becomes an inseparable ingredient of the soil system (Swift 1983). The relationship between litterfall and litter standing crop on the forest floor has been used to measure turnover (k) of forest floor material (Jenny et al. 1949, Greenland and Nye 1959). Olson (1963) has reviewed the studies carried out in different types of forests both in tropical and temperate climates. The litter turnover coefficient has been estimated in few tropical lowland forests of Nigeria by Madge (1965), Hopkins (1966) and Swift et al. (1981). In dipterocarp forest of Malaya, the turnover of leaves and small litter was calculated by Ogawa (1978), Yoda (1978), Andersen et al. (1983) and Gong and Ong (1983). Similar studies in temperate deciduous forest were conducted by Reiners and Reiners (1970) at Minnesota, Harris et al. (1975) at Tennessee, Rochow (1975) at Missouri and Lang and Forman (1978) at New Jersey. The tropical rain forests have the values greater than 1 suggesting complete turnover within a year while values less than one indicate turnover time ranging from few years to several decades, generally reported from temperate and alpine forests.

The weight loss from litter bags has been widely used to measure the rate of decomposition of plant litter in different climatic zones (Edwards and Heath 1963, Wiegert and Evans 1964).

Litter forms an important nutrient pool and plays a significant role in regulating structure and function of forest ecosystem in a variety of ways. The large volume of information on this aspect has been reviewed by Ovington (1962), Olson (1963), Rodin and Bazilevish (1967), Swift et al. (1979) and Singh (1967). In the tropical forests nutrient content of litterfall was determined by Laudelout and Meyer (1954), Nye (1961), Hopkins (1966), Bernhard (1970), Egunjobi (1974), Haines (1977) and Lamb (1985). Litterfall is an important process through which major amount of mineral elements is transferred to the soil in forest ecosystem. Intensive studies on nutrient cycling incorporating litter production and decomposition aspects have been carried out by Likens and Bormann (1972), Fogel and Cromai (1977), Meentemeyer (1978), Birk and Simpson (1980), Cooper (1982), Lindsay (1988) and Staaf (1988). In India, similar studies are available from Central Himalaya and dry deciduous forests (Rai and Srivastava 1982, Mehra et al. 1985, Upadhyay 1988, and Singh 1968, 1969). Some studies on litter decomposition in the tropical moist deciduous forest of Meghalaya have been carried out by Singh (1984).

Decomposition of organic material is the vital aspect of overall nutrient cycling within the forest ecosystem (Reichle, 1981). One of the variable influencing the rate and extent of decomposition of biodegradable materials is the supply of mineral nutrients, especially of nitrogenous materials, since microorganisms have a relatively high requirement of nitrogen and nitrogenous compounds which are often limiting in the decomposers' habitats (Park 1976). The importance of mineral supply to microorganisms during decomposition was recognised early in the present century. Hutchinson and Richards (1921) introduced the term 'nitrogen factor' to quantify the relationship between available N and decomposition. The C/N ratio of the decomposable material was later used by Waksman and Tenney (1928), Tenney and Waksman (1929) and Jensen (1931) to quantify the nitrogen release to discuss the variation in decomposition rate. ~~and nitrogen release.~~ Since different elements have different patterns of release over time and the elements are retained with different strength in the litter structure, attempts have been made to explain the dynamics of a single element and its status as a limiting or non-limiting nutrient for microbial growth

(Gosz et al. 1973, Parnas 1975, Swift et al. 1979). The element in non-limiting concentrations are released during the whole decomposition period, while the limiting ones may be immobilized for a short period (Berg and Staaf 1981). In its general features, carbon : element ratio has gained support from litter decomposition studies concerning several elements in forest ecosystem (Lousier and Parkinson 1976, MacLean and Wein 1976, Berg and Staaf 1980).

The closed nutrient cycling within the forest ecosystem is often disrupted by human intervention and leads to nutrient losses from the system. Deforestation of an experimental watershed in New England increased nitrogen export in streams and decreased organic matter increment within the ecosystem (Likens et al. 1969, 1970; Marks and Bormann 1972). The cutting of tropical forests also leads to increased litter breakdown, mineralization and subsequent nutrient loss (Edmiston 1970, Witkamp 1970, Gonzalo de las salas 1973). Bernhard - Reversat (1975) also recorded increased nitrogen loss following the clearance of tropical rain forest in Brazil and Africa.

Forest ecosystem exhibits mechanisms for capture, distribution and conservation of elements essential to system persistence (Witkamp 1971, Dommerques and Mangenot 1970, Gose et al. 1972, Likens et al. 1972, Satchell 1974). Nutrient immobilization, mineralisation and release have been postulated as the conservation mechanisms which are controlled by decomposer- plant interactions (Parkinson 1967, Witkamp 1971, Henderson and Harris 1974, Harris et al. 1975). Indirect measurements of microbial immobilization and release of elements have shown microbial influence on element leaching and root uptake (Witkamp and Frank 1970, Witkamp 1971). The information on inputs (through litterfall), exports, substrates and decomposer organisms are essential for an understanding of elemental conservation mechanisms of forest ecosystem (Mitchell 1974, Jensen 1974, Levïlt 1972, Reichle et al. 1981) and its recovery process following disturbance.

The objective of the present study were to collect data on some of the above mentioned aspects in the moist deciduous and wet hill mixed coniferous forests of Meghalaya, to understand the structural and functional changes particularly nutrient dynamics through litter production and decomposition during their regrowth after jhumming. Community structure, phenology, litter production, decomposition, Nitrogen (N), Phosphorus (P) and Potassium (K) return through litter, their accumulation on forest floor and release from decaying litter were studied for a period of two years during 1987-88. The results have been discussed in five chapters of the dissertation.

CHAPTER 2

STUDY SITE

Location

The state of Meghalaya (latitude - 25°05' - 26°10' N, longitude - 90°0' - 92°45' E, altitude - 100 - 1900 m) forms the north-eastern tip of Indian peninsula. On the basis of landform association, lithology, micro- and macroclimatic conditions and the prevalent fluvial processes, Rai (1986) has divided the Meghalaya plateau into northern hill region, southern dissected plateau and Shillong plateau. The study sites are located in the northern hill region and the central plateau of the State. The site in the northern hill region is located at an altitude of 100 m near Burnihat while that on the central plateau in Shillong is at an altitude of 1500 m. The two sites are about 80 Km apart and lie between 25°34' to 26°0' N latitude and 90°56' to 91°50' E longitude (Figure 2.1). At each site two regenerating forest stands (young, $\leq$ 5 year old, old- 15-20 year old) after tree cutting were selected for detailed study. The area of each stand was about 0.75 ha. The physiographic characters of the stands are given in Table 2.1.

Climate

The climate is typically monsoonic. But due to high rainfall rainy season extends for about six months from May to October. The winter season (December - February) is marked

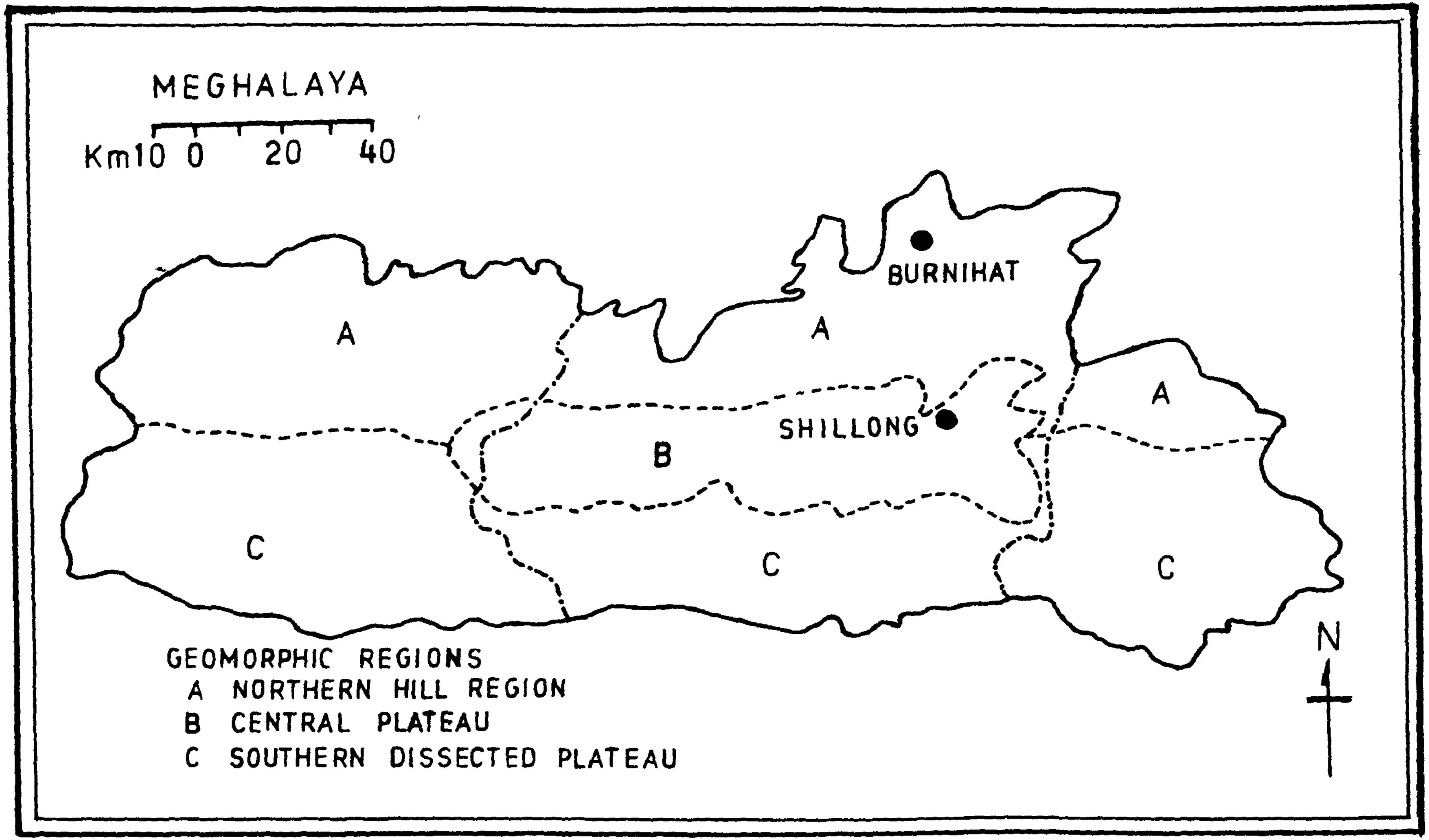

Figure 2.1. Map of Meghalaya showing location of the study sites.

Table 2.1. Stand age and physiographic characters of the study sites

Location	Altitude above sea level (m)	Approximate stand age (yr)	Slope	
			Aspect	Angle
Burnihat:				
Young stand	100	5	North-east	50°30'
Old stand	-do-	15 - 20	South-east	64°23'
Shillong:				
Young stand	1500	5	South-east	47°50'
Old stand	-do-	15 - 20	South-east	64°40'

by low temperature and scanty rainfall. The summer season (March - April) is short and mild. Annual rainfall, mean min. and max. temperatures and their monthly values during study period (1987-88) are given in the climatic diagrams (Figure 2.2). At Burnihat annual mean min. and max. temperatures were 2 and 38°C, respectively. The corresponding values for Shillong were 3 and 23°C. Annual rainfall at Burnihat and Shillong was 2220 and 3788 mm, respectively. Atmospheric temperature (Figure 2.3) exhibited similar seasonal pattern at both the sites but temperature fluctuation during rainy and winter seasons was more at Burnihat than Shillong.

Soil

The hill slopes are covered by thick weathered lateritic soils derived from the underlying metamorphosed quartzite, gneiss, schist and granite rocks. It is red to deep brown in colour, sandy to sandy loam in texture and acidic to neutral in reaction. The range of variation in pH, nutrient and organic matter content as reported by several workers are shown below:

pH	-	4.9 - 7.4
NH_4^+ - N(ppm)	-	2 - 23
NO_3^- - N(ppm)	-	0.5 - 2
P(ppm)	-	0.075 - 0.5
Organic matter (%)	-	2.5 - 5

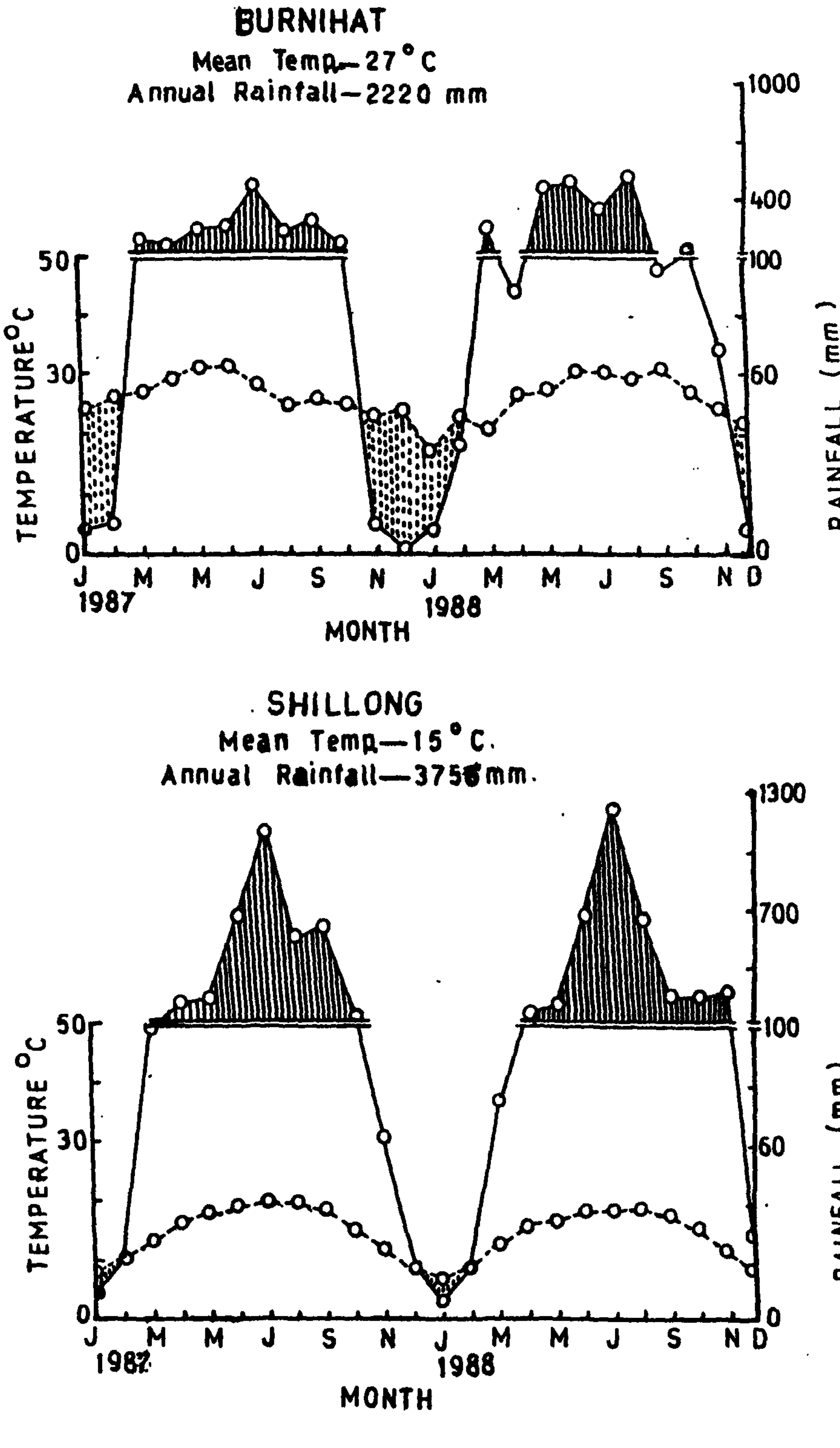

Figure 2.2. Climatic diagrams of study sites. Mean temperature (---O---), Rainfall (——O——). Area with vertical lines shows the humid period and that with dots indicates period of relative drought.

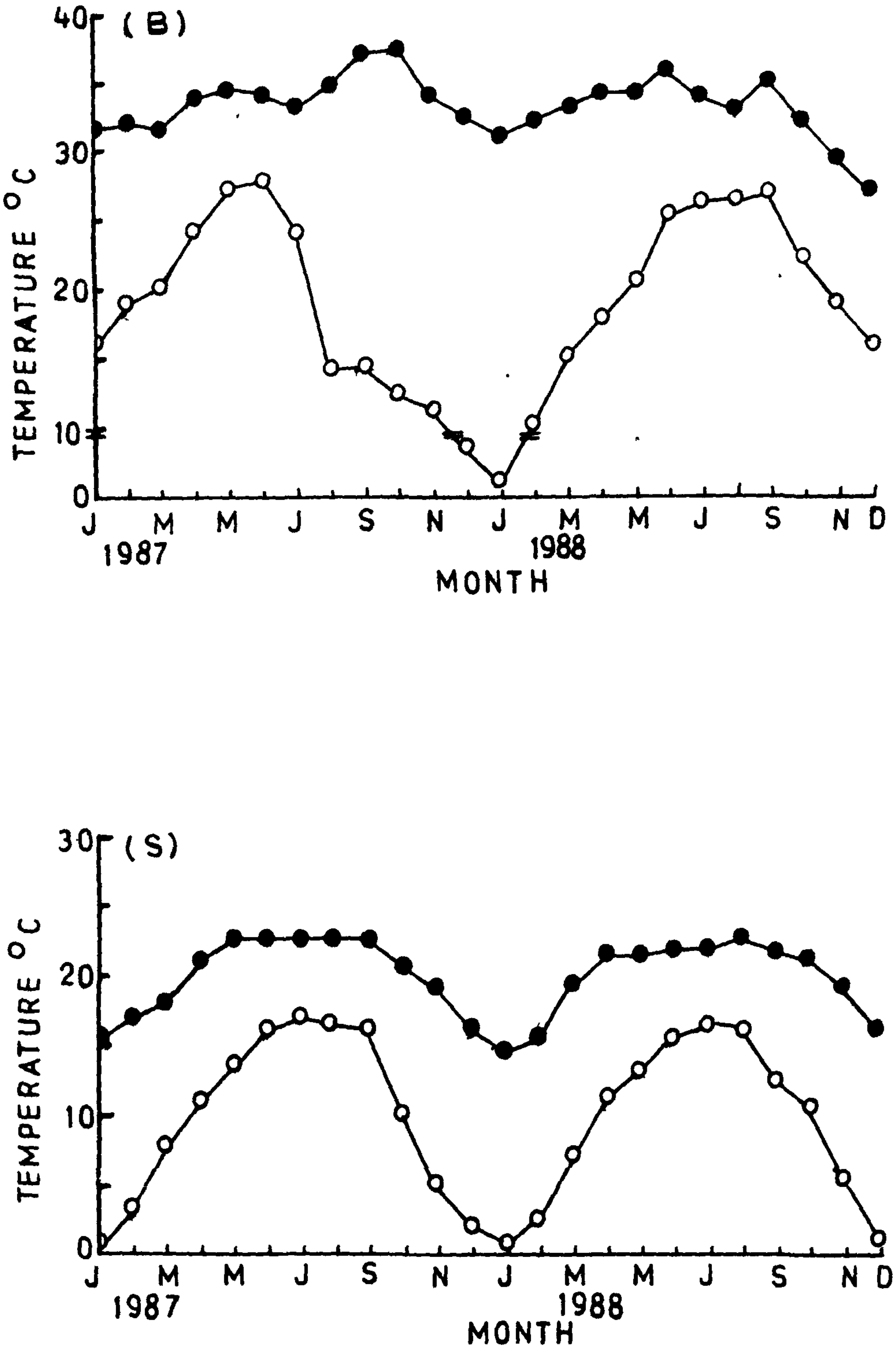

Figure 2.3. Monthly variation in the minimum (O) and maximum (O) temperatures (°C) at Burnihat (B) and Shillong (S) during 1987-88.

Monthly variation in temperature of the top soil (upto 15 cm depth) at all the four stands (Figure 2.4) during the study period showed distinct seasonal and altitudinal variations. The temperature was invariably high in the young stand. Soil moisture ranged between 12 and 19% and showed marked seasonal variation. The values were generally high in the old stand at both the elevations.

Vegetation

The forest at lower altitude falls under group - '3' (sub group $3C_2$) of moist deciduous forest type and that on the higher altitude has been grouped under '$8B_2$' of sub-tropical wet hill forest type by Champion and Seth (1968). According to these authors the floristic component of moist deciduous forest is closely allied to Himalayan forms such as Shorea spp, Schima spp, Dillenia spp, Vitex spp etc., which represents a true climax. At higher altitude Quercus spp, Beilschmiedia spp, Michilus spp, Bucklandia spp, Ficus nemoralies etc. are important components of the original forest. Human disturbances in the form of tree cutting and shifting cultivation have greatly altered the species composition and community structure of the original forests, whose cover had been reduced to above 9% of the total forested area of the state. According to Meghalaya Forest Statistics (1983-84), about 91% of the total forested area in the state is in the form of degraded forests.

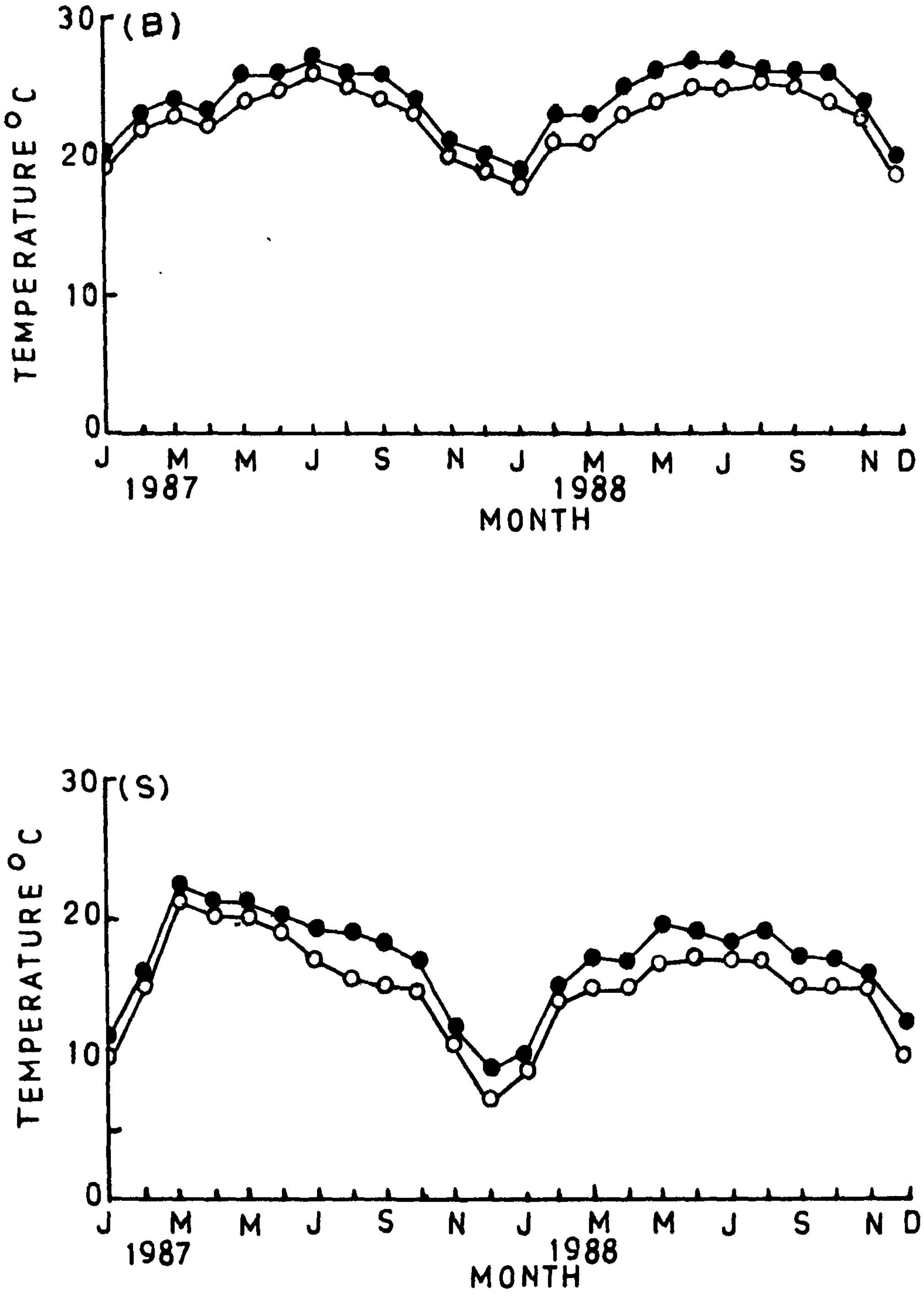

Figure 2.4. Monthly variation in surface (0-15 cm) soil temperature in the young (●) and old (O) forest stands at Burnihat (B) and Shillong (S) during 1987-88.

Site history and anthropogenic activities

Shifting agriculture or Jhumming is the major human activity in the state. Earlier Jhum cycle used to be of 10 - 30 years, but on account of increasing population pressure it has come down to about 4 - 5 years at many places. In this practice almost all the trees in a patch of forest are cut and the slash is burnt after drying. At higher elevation slash is burnt by arranging them in rows parallel to the hill slope but at the lower altitude slash is not burnt in this manner. In the young stand at lower altitude all but a few trees of Mallotus philippensis were cut near the ground. M philippensis was cut at about 2 m height. Enquiry with local people revealed that trees were cut about 5 years ago in the young stand and 15 - 20 years ago in the old stand at both the altitudes. After tree cutting and burning of the slash the land was put under cultivation for about 2 years and then left fallow without any disturbance for vegetation recovery.

CHAPTER 3

COMMUNITY COMPOSITION AND PHENOLOGY

INTRODUCTION

Species composition, tree population structure and successional pattern in forest ecosystem are strongly influenced by natural and man induced disturbances. These changes play an important role in regulating processes like energy flow, hydrology and nutrient cycling within the ecosystem (Harmon *et al*. 1983). In Meghalaya the age old practices of tree cutting and shifting cultivation are the major human activities which have led to the destruction of original vegetation and development of degraded seral forest stands of different ages.

General description of the forest vegetation of Meghalaya has been given by Champion and Seth (1968). But information about the seral communities is restricted only to some communities on the jhum fallows both at lower and higher altitudes of the state (Tokey and Ramakrishnan 1983, Mishra and Ramakrishnan 1983). Recently, phytosociological attributes of disturbed and undisturbed sub-tropical wet hill forest of Meghalaya have been given by Khan *et al*. (1987). This chapter describes the species composition and tree population structure of the four regenerating forest stands wherein detailed study was conducted during 1987-88. Description of the stand structure is based on the phytosociological parameters such as phenology, frequency, density, abundance and importance value of species.

METHODS

Phytosociological analysis of the forest stands was done during July-August 1987. Ten quadrats, each of 10m x 10m, 5m x 5m and 1m x 1m size were placed randomly in each stand for the sampling of trees ($\geq$3m height), saplings(<3m height) and ground flora, respectively. Frequency, density, basal cover and importance value index (IVI) were determined according to Misra (1968). Tree species were divided into six diameter classes viz., 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 cm for frequency and density determinations. Species diversity was determined by using Shannon-Wiener (1963) information function ($\bar{H}$).

$$\text{Shannon-Wiener Index } (\bar{H}) = -\sum_{i=1}^{s} (Ni/N) \log (Ni/N)$$

Where,

Ni = importance value of species,

N = importance value of all species.

Concentration of dominance (cd) among the species was calculated according to Simpson Index (Simpson 1949).

$$Cd = \sum (Ni/N)^2$$

Where,

Ni and N are the same as the species diversity index.

Similarity index was calculated according to Jaccard (1912).

$$\text{Jaccard's Similarity Index (ISJ)} = \frac{C}{A + B + C} \times 100$$

Where,

A = presence of total number of species in stand A,

B = presence of total number of species in stand B,

C = number of common species.

Phenological studies were restricted to tree species only. Records of leaffall, flushing (leafless condition), flowering and fruit maturity were made at monthly intervals for two years (1987-88) and data are given in this chapter.

RESULTS

Tree layer

Tree species composition and phytosociological attributes of the young and old stands at Burnihat and Shillong are given in Tables 3.1 and 3.2. Species richness, diversity and dominance are given in Table 3.3. Similarity index between the young and old stands was higher at Shillong than Burnihat (Table 3.4). At both the altitudes species richness and diversity were low in the young stand. The young stand at Burnihat was devoid of fully developed trees, however,

Table 3.1. Frequency (%), density (plant/ha) abundance, basal cover (% x 10^{-3}) and IVI of tree species in the young and old forest stands at Burnihat

Tree species	Young stand					Old stand				
	Frequency	Density	Cover	Abundance	IVI	Frequency	Density	Cover	Abundance	IVI
Mallotus philipeensis (Lan) Mull. Arg	50	90	19.3	1.8	246.8	-	-	-	-	-
Manihot esculenta crantz	10	10	0.6	1.0	26.2	10	10	0.3	1.0	6.9
Toona ciliata Roem	10	10	0.8	1.0	27.3	20	30	9.1	1.5	29.9
Holarrhena antidysentrica wall	-	-	-	-	-	60	170	20.2	2.8	95.1
Vitex glabrata R.Br.	-	-	-	-	-	70	100	23.7	1.4	88.2
Litsea monopctala (Roxb) Pers	-	-	-	-	-	10	30	4.9	3.0	18.3
Bauhinia purpureu L.	-	-	-	-	-	10	30	2.5	3.0	19.9
Cassia fistula L.	-	-	-	-	-	10	20	6.2	1.0	17.9
Morus lavigata wall	-	-	-	-	-	10	10	2.9	1.0	10.9
Beilschmidia roxburghiana Nees.	-	-	-	-	-	10	20	1.1	2.0	10.7
Syzgium cuminii (L) Skeds.	-	-	-	-	-	10	10	0.6	1.0	6.9

(-) = absent

Table 3.2. Frequency (%), density (plant/ha), abundance, basal cover (% x 10^{-3}) and IVI of tree species in the young and old forest stands at Shillong.

Tree species	Young stand					Old stand				
	Frequency	Density	Cover	Abundance	IVI	Frequency	Density	Cover	Abundance	IVI
Pinus kesiya Royl ex Gord	100	1060	19.9	19.0	199.2	100	350	27.5	3.5	132.8
Alnus nepalensis D Don										
Myrica esculenta Buch-Ham ex D Don	60	70	2.8	1.1	10.5	80	130	23.5	1.6	89.2
Elaenguns latifolia Linn	20	120	0.1	1.1	38.0	20	30	0.2	1.5	10.3
Lyonia ovalifolia (Wall) Drude	20	80	0.1	1.0	13.5	60	90	0.03	1.5	30.9
Rhus javanica L.	-	-	-	-	-	20	20	0.3	1.0	9.3
Castenopsis indica A. Dc.	-	-	-	-	-	20	20	0.1	1.0	9.6

(-) = absent

Table 3.3. Species richness, index of diversity ($\bar{H}$) and dominance (cd) in the young and old forest stands at Burnihat and Shillong

Community parameter	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Species number:				
Tree layer	3	10	5	7
Ground layer	4	3	7	6
Total	7	13	12	13
Diversity Index ($\bar{H}$):				
Tree layer	0.592	1.872	1.055	1.465
Ground layer	1.225	1.070	1.779	1.622
Total	1.730	2.220	2.168	2.287
Dominance Index (cd):				
Tree layer	0.900	0.206	0.445	0.298
Ground layer	0.323	0.350	0.188	0.228
Total	0.218	0.139	0.131	0.129

Table 3.4. Jaccard's similarity index between the young and old forest stands at Burnihat and Shillong

	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Young stand (Burnihat)	100	25	0	0
Old stand (Burnihat)		100	0	0
Young stand (Shillong)			100	71.42
Old stand (Shillong)				100

a few sprouting stumps of Mallotus philippensis, Manihot esculents and Toona ciliata of about 2 m height were present in the old.. The old stand with ten tree species was dominated by Holarrhena antidysentrica. At higher altitude there were five tree species in the young stand and seven in the old stand. Five species were common to both. Pinus kesiya was dominant in both the stands. Myrica esculenta was co-dominant in the young stand and Alnus nepalensis in the old stand (Table 3.2).

At lower altitude total tree density and basal cover were 110 plant/ha and 2.1 x 10^{-3}%, respectively in the young stand. The corresponding values in the old stand were 430 plant/ha and 7.1 x 10^{-3}%. At higher altitude the values of tree density and basal cover were 1350 plant/ha and 2.3 x 10^{-3}% in the young stand and 680 plant/ha and 5.1 x 10^{-3}% in the old stand.

Frequency was generally low at both the altitudes. Vitex glabrata and Holarrhena antidysentrica showed higher frequency at Burnihat while Pinus kesiya and Alnus nepalensis exhibited higher values at Shillong. Frequency distribution of trees of different girth classes is shown in Figure 3.1. At lower altitude the young stand showed highest frequency of very young trees (diameter 10-15 cm) and there was complete absence of trees in 25-30 cm diameter class. In the old

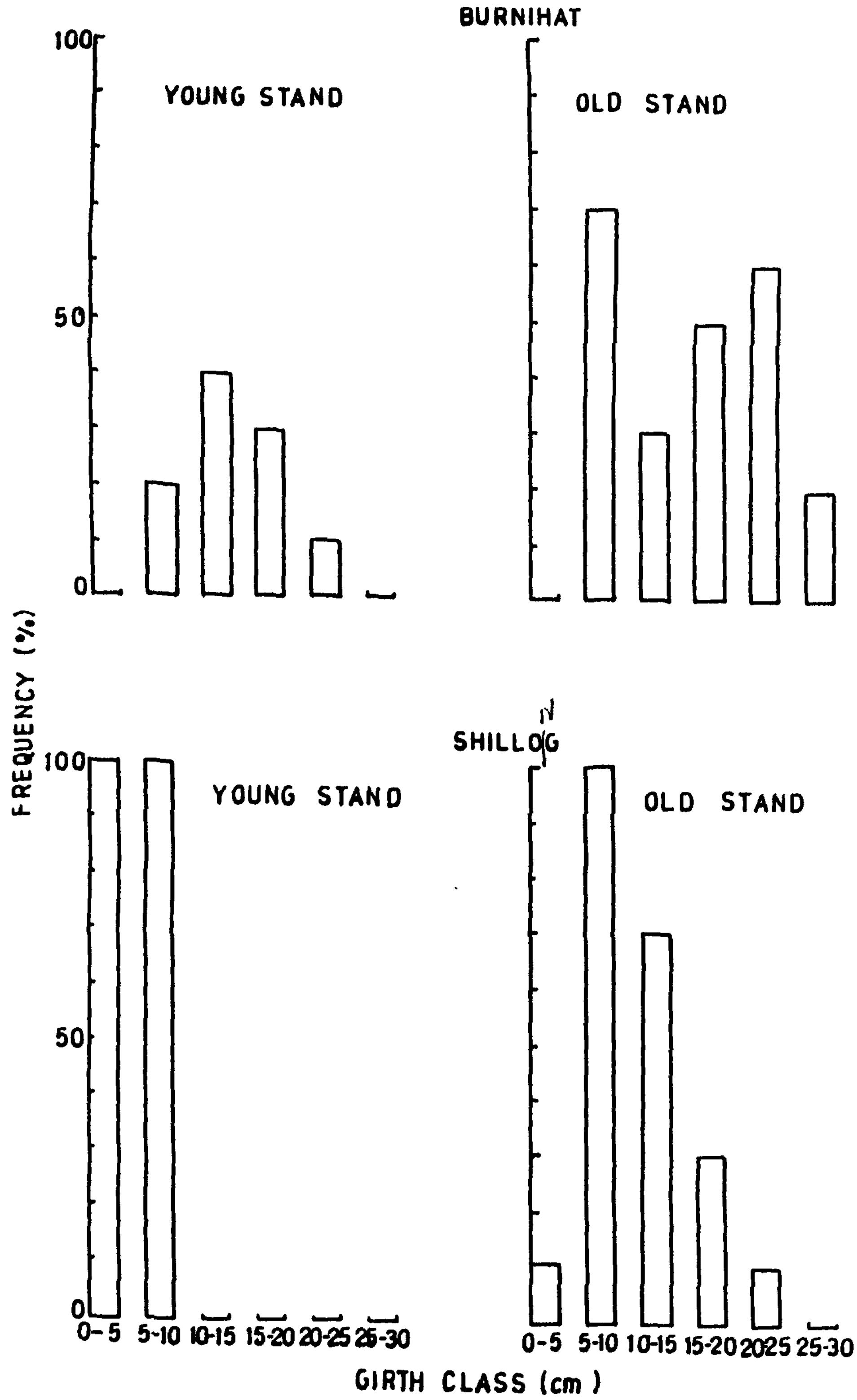

Figure 3.1. Frequency distribution of trees of different girth classes in the young and old forest stands.

stand frequency was high both in lower and higher girth classes. The frequency distribution pattern of trees at higher altitude was slightly different from that found at the lower altitude. The young stand was exclusively composed of trees upto 10 cm girth while in the old stand, though the frequency was maximum in 10-15 cm girth class, it declined in higher girth classes. Density-diameter histograms are given in Figure 3.2. The trend exhibited by density-diameter bars was almost similar to that of frequency in all the four stands.

Phenology of trees

The phenological behaviour of tree species at the lower altitude is shown in Figure 3.3. In most of the cases leaf fall occurred from September to January. In Holarrhena antidysentrica, Morus lavigata and Litsea monopetala leaf shedding started in June and continued upto December. Cassia fistula and Bauhinia purpurea showed leaf fall during October to April. At higher altitude leaf fall in Pinus kesiya occurred throughout the year. In other trees it started in June and continued upto March. Lyonia ovalifolia shed leaves during December to April (Figure 3.4).

Ground layer

Analysis of ground vegetation was carried out during peak growth period (July-August, 1987) prior to commencement

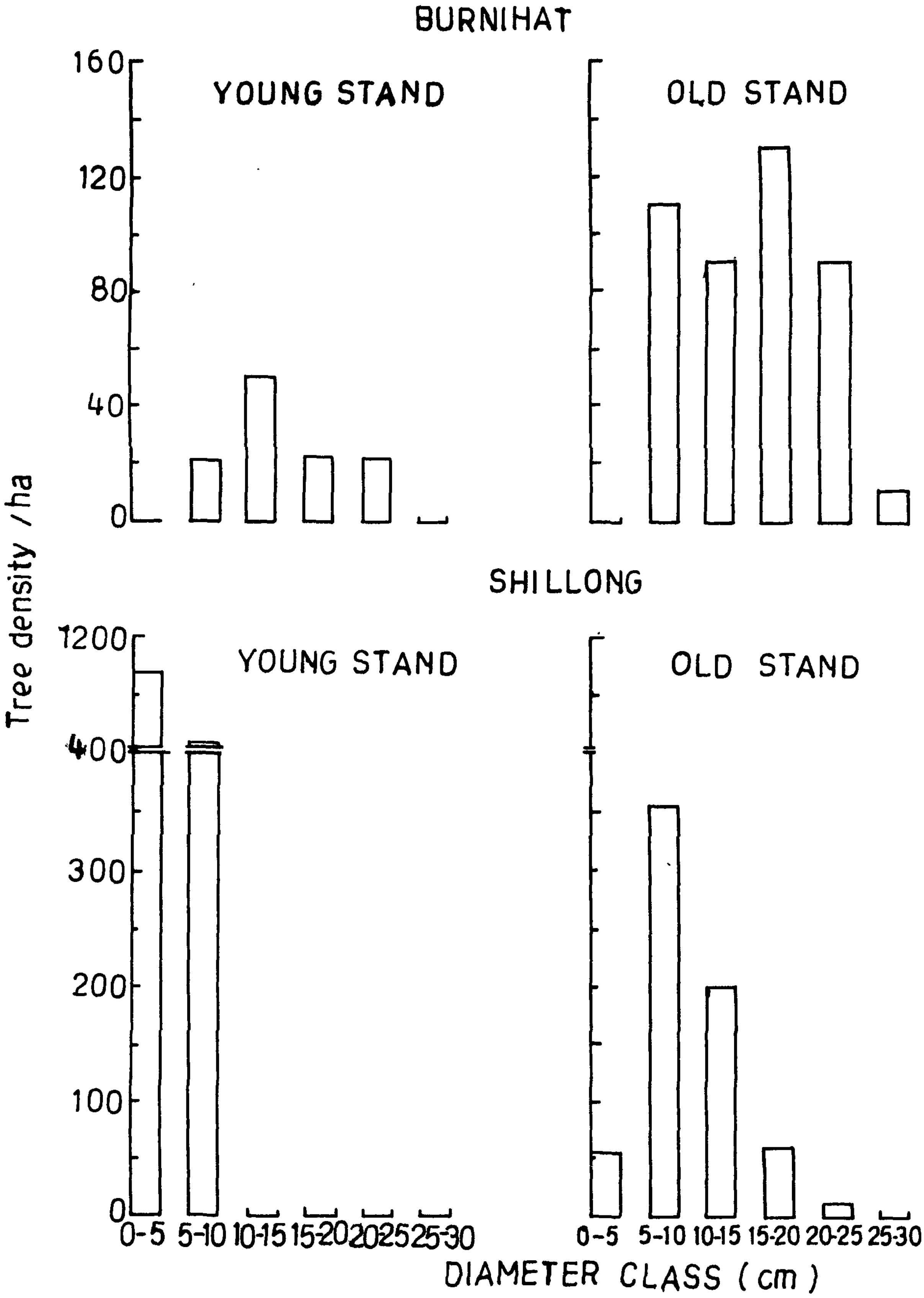

Figure 3.2. Density-diameter histogram of the trees in the young and old forest stands at the two study sites.

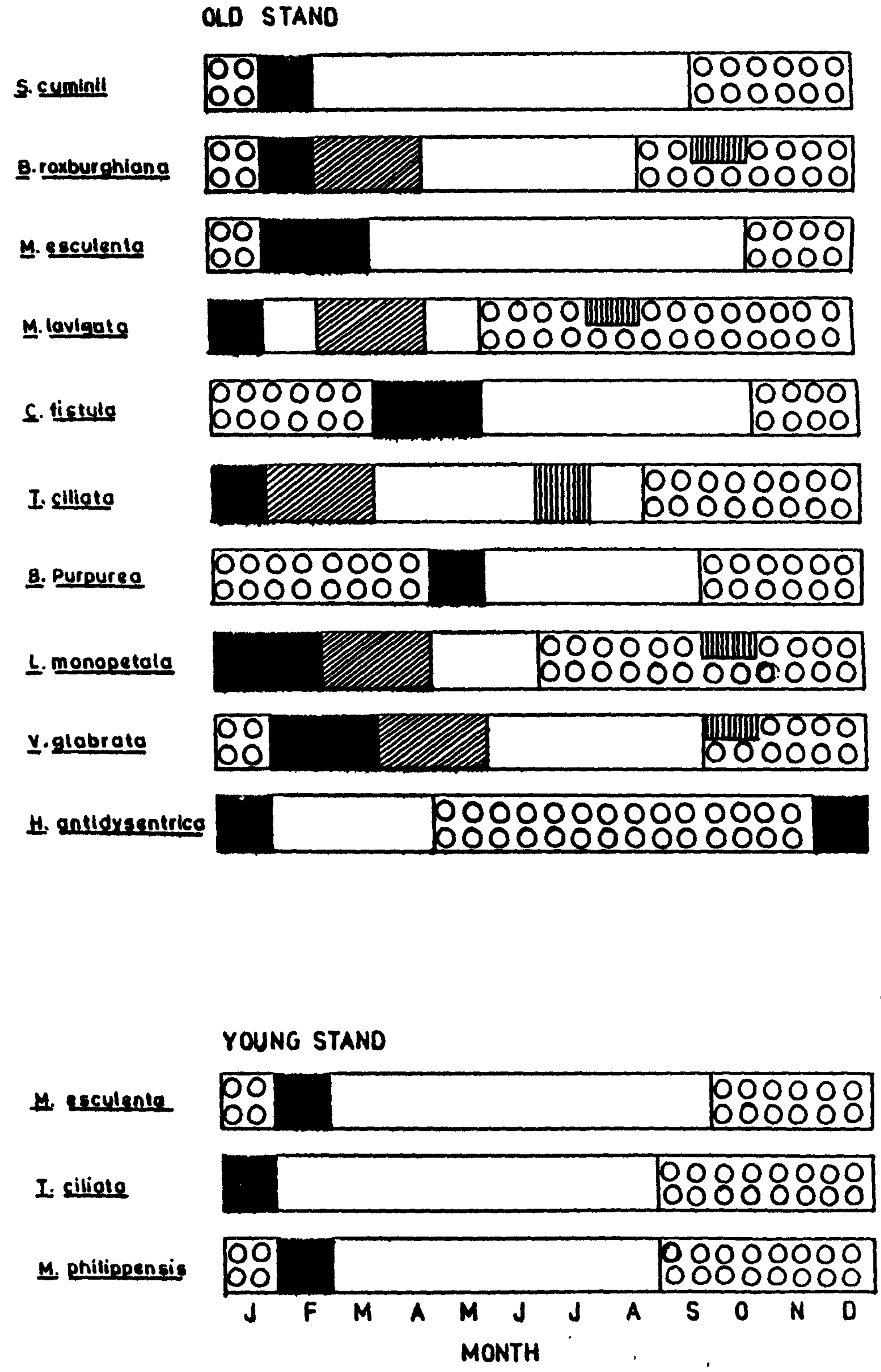

Figure 3.3. Phenological spectrum (leaffall 'O', flushing ■, flowering ▨, fruiting ▥) of tree species in the young and old forest stands at Burnihat.

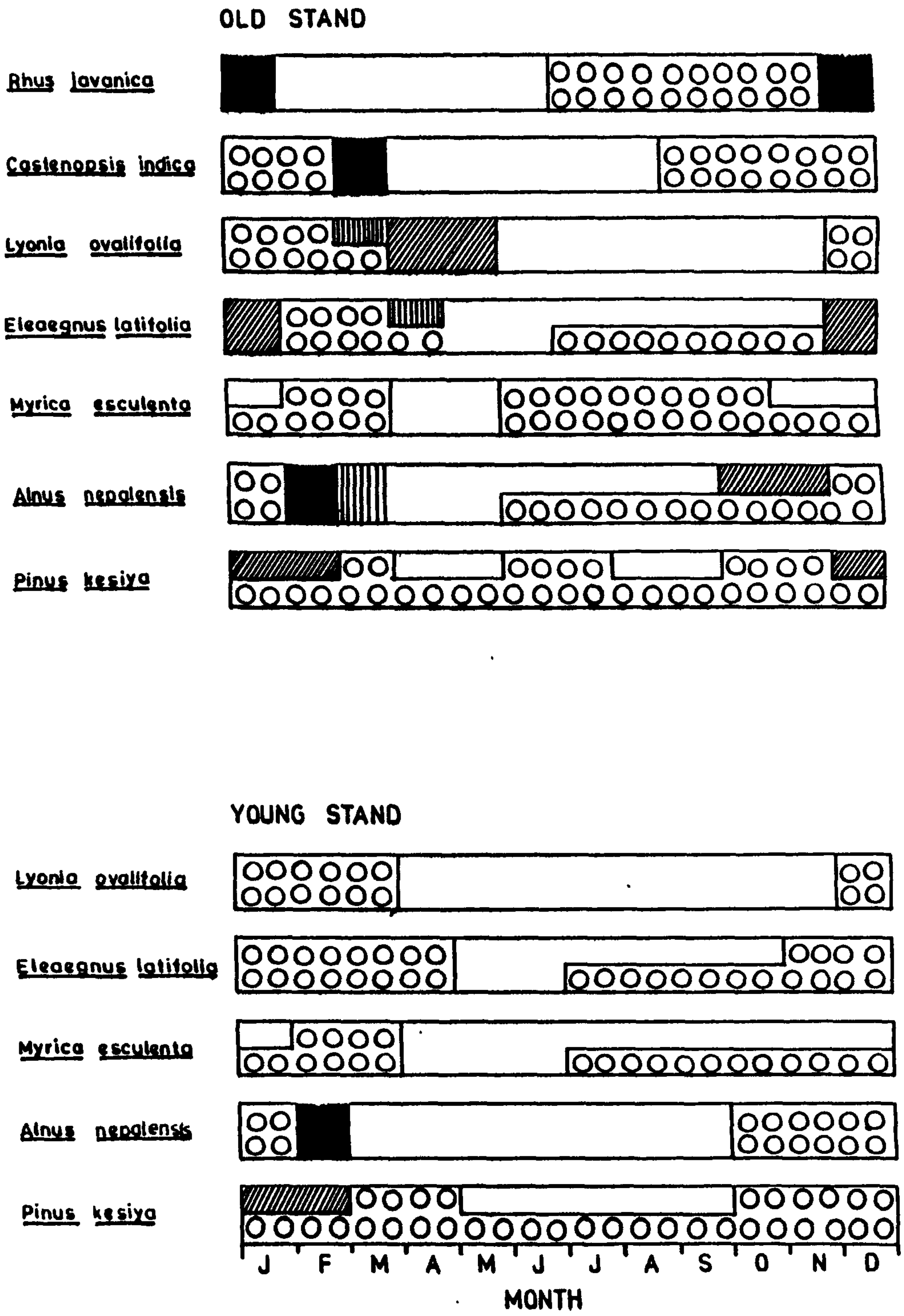

Figure 3.4. Phenological spectrum (leaffall 'O' flushing ▇, flowering ▨, fruiting ▥) of tree species in the young and old forest stands at Shillong.

of the study of litter dynamics. Frequency, density, cover and IVI values of important species in the young and old stands at the lower altitude are given in Table 3.5. *Ageratum conyzoides* and *Eupatorium odoratum* were dominant herbs in both the stands. At higher altitude ground vegetation in the two stands was dominated by *Pteris longipes* and *Eupatorium adenophorum* (Table 3.6). The ground flora was species poor and was not affected much by the stand age at both the altitudes. The species diversity, however, showed a declining tendency from the young to old stand. The dominance index followed a reverse trend. When both trees and ground flora were combined, an increase in the diversity index and decrease in the dominance index became more clear from the young to old stand (Table 3.3).

DISCUSSION

Results of frequency, density, species diversity and dominance presented in the foregoing pages show that the young and old stands of both the altitudes differ markedly from each other in tree species composition and community structure. The difference in species composition at the two altitudes are obviously due to the climatic variation. The seral stages of moist deciduous forest represented by the young and old stands at Burnihat had high species richness compared to their counterparts of similar ages of

Table 3.5. Frequency (%), density (Plant/m^2), basal cover (% x 10^{-3}) and IVI of important species of ground flora in the young and old forest stands at lower altitude (Burnihat)

Species	Young stand				Old stand			
	Frequency	Density	Cover	IVI	Frequency	Density	Cover	IVI
Ageratum conyzoides L.	100	6.8	7.0	119	60	4	2.8	121
Eupatorium odoratum L.	80	4.0	10.5	111	20	2	7.9	110
Mikania micrantha HBK	50	0.8	0.5	24.5	30	2	2.5	68.2
Mimosa pudica L.	80	2.1	0.8	45.5	-	-	-	-

Table 3.6. Frequency (%), density (Plant/m^2), basal cover (% x 10^{-3}) and IVI of important species of ground flora of the young and old forest stands at higher altitude (Shillong)

Species	Young stand				Old stand			
	Frequency	Density	Cover	IVI	Frequency	Density	Cover	IVI
Pteris longipies D. Don	40	0.6	6.7	73.45	30	0.3	4.7	105.58
Eurea japonica Thumb	10	0.1	0.3	12.77	10	0.2	0.8	35.01
Buddlya asiatica Lour.	20	0.2	1.0	27.39	10	0.1	0.5	24.55
Inula cappa DC.	20	0.2	0.6	24.59	-	-	-	-
Eupatorium adenophorum Sprang	40	0.5	5.8	83.63	30	0.31	3.1	77.11
Lantana camara L.	30	0.3	4.1	61.09	-	-	-	-
Rubus ellipticus Sm.	-	-	-	-	10	0.1	0.5	24.78
Imperata cylindrica L.	40	0.4	1.1	16.05	10	0.2	0.6	33.95

sub-tropical wet hill forest at Shillong. During the course of community development, although recovery in species richness was seen at both the elevations, it was more at Burnihat. This is the normal feature of the developing communities and has been reported by several other workers (Nicholson and Monk 1974, Peet and Christensen 1980) as well. Faster recovery at the lower elevation is in agreement with the findings of Kirkpatrick (1984) and Richerson and Lum (1980) in tropical forests.

Total tree density and basal cover in protected sub-tropical broad leaved climax forest at higher elevation have been reported to be 2134 tree/ha and 0.3% respectively (Khan 1986). At lower elevation the corresponding values in a 50 year old protected forest stand were 1058 tree/ha and 0.8% (Singh 1980). Density and tree cover of the young and old stands were calculated considering these values as control (100%) for the respective sites. It was found that density was about 10% and 40% and cover was 3% and 9% in the young and old stands, respectively at the lower altitude. At higher altitude the density was 63 and 32% and cover was 8 and 19% in the young and old stands, respectively. These values clearly indicate that recovery in the basal cover of the stand was more rapid at the lower altitude during forest regrowth. Relatively higher density in the young stand at upper elevation is attributed to greater sapling density of Pinus kesiya. Since the surrounding vegetation is mostly composed of secondary pine forest, large number of seedlings are recruited in the field after disturbance. Ellenberg (1956) has also emphasised the role of regional flora in colonization of newly created habitat and subsequent community development.

The values of diversity index at the lower altitude compare favourably with those ($\bar{H}$ = 0.1 - 2.58) reported by Singh and Ramakrishnan (1982) for 1-20 year old successional communities. Similar data is not available from higher altitude. In the tropical forest at Boro Colorado, Iseland, Panama, Knight (1975) has reported much higher value ($\bar{H}$ = 5 - 5.4) for young and old stand without specifying their age. Similar values ($\bar{H}$ = 2.52 - 4.15) have been reported for the tropical rain forest of the silent valley, India, by Singh et al. (1981). Compared to these, the values obtained in the four stands are much less. Dominance index was inversely related to species diversity at both the elevations. This is in agreement with the findings of Risser and Rice (1971) and Millinger and McNaughton (1975) who showed an increase in species diversity and decrease in dominance with progression of succession. In the ground flora concentration of dominance was less in the young stand and more in the old stand but diversity followed a reverse trend. Peet and Christenson (1980) have also reported that diversity of herbs decreased with progression of forest succession in experimental thinning treatment in Duke forest, North Carolina. This trend in species diversity was related to the reduction in light intensity on the forest floor due to gradual closing of canopy. However, when both trees and the species in the ground flora were considered together, diversity and dominance indices showed inverse relation during secondary forest succession at both the altitudes.

Phenological data show distinct seasonal pattern at both the altitudes. Winter season was characterized by leaf shedding by the majority of tree species. Leaf shedding was followed by flowering during spring (Feb-April) in most of them. Most of trees in the community were naked during peak winter period. Studies of Beard (1946), Madge (1965) and Frankie et al. (1974) showed that peak period of leaf fall correspond with relatively xeric condition of dry season. This is true in the present case also. However, slightly early leaffall at upper elevation may be attributed to severe winter. Here small amount of leaffall occurred throughout the year due to presence of Pinus kesiya in the stand. In showing extended period of leaf fall, the forest at lower altitude is similar to most of the low land tropical forest where leaf fall has been found to be maximum in dry season before the onset of monsoon (Hopkins, 1966; Fittkau and Klinge, 1973). Two flowering spells observed in the old stand at the upper altitude may be related to the climatic conditions as reported by Duke and Black (1953), and Frankie et al. (1974) and nature of the species. The production of mature fruit in majority of the species at lower altitude in post-monsoon season indicates that seeds require some resting period before their germination in next favourable season whereas at higher altitude fruit maturity occurred during March-April and seeds germinated immediately with the onset of rain in the month of May and June.

Leaf flushing showed a marked seasonality at lower altitude. Almost all the trees were naked between January and April. Similarly, at the higher altitude Alnus nepalensis, Castenopsis indica and Rhus javanica were leafless during January to March. At lower altitude flushing in Litsea monopetala, Toona ciliata, Morus lavigata and Beilschmidia roxburghiana occurred during March-April and fruits were mature during August to October. While in Toona cilata they matured slightly earlier (July). At higher altitude cones were borne in Pinus kesiya during December-February in both the stands but their maturity was not observed during the study period. Other species such as Alnus nepalensis, Eleaegnus latifolia and Lyonia ovalifolia flowered during March and May in the old stand only.

Phenological analysis of the four stands based on the number of species showing different phenophase in different seasons (Figure 3.5) reveals that number of species showing leaf fall, declined from January to May, thereafter it again increased and attained peak during October to December. Most of the species showed leaf flushing during winter season at both the altitudes, however, some species at the lower altitude exhibited extended leaf flushing period upto May. There were two flowering seasons at higher altitude, one during January to April (spring) and another during October to December (winter). Whereas at the lower altitude there was only one flowering season during February to April (summer). Observations on the fruiting behaviour of the trees made only during the second year of study revealed that most of the species produced fruits during July to November. Number of fruit bearing species increased from July to November.

The above account of analytic parameters of community and phenological behaviour of tree species clearly reveals that the species composition and community structure of the regenerating forest stands was markedly different at the two elevations of Meghalaya and both the stands were

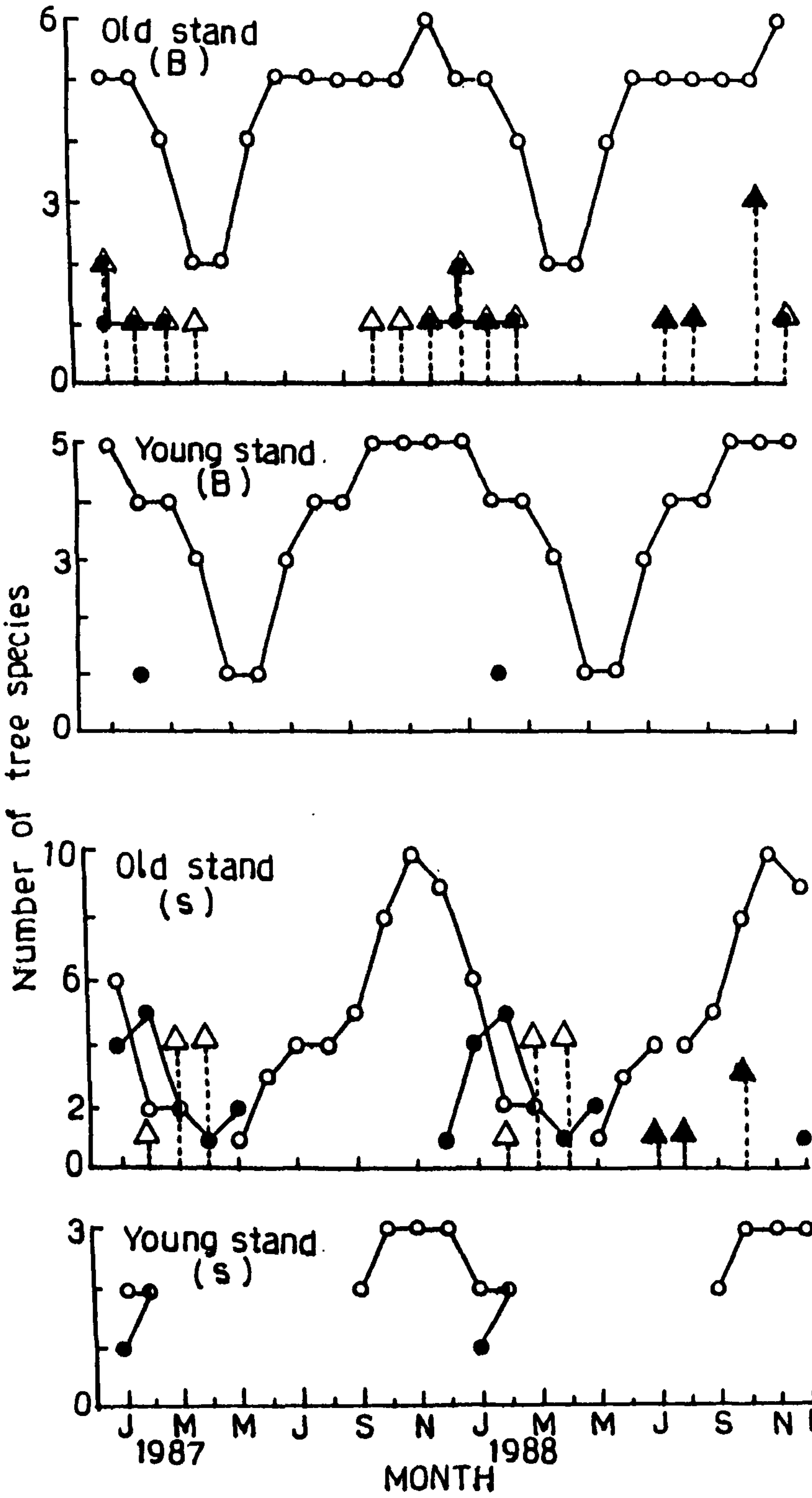

Figure 3.5. Phenological analysis (leaffall 'O', flushing '●', flowering 'Δ', fruiting '▲') of young and old forest stands at Burnihat (B) and Shillong (S).

characterized by low species diversity, basal cover and density.

CHAPTER 4

LITTER PRODUCTION

INTRODUCTION

Information on the amount and composition of litterfall is prerequisite for any study of nutrient cycling within the forest ecosystem (Ovington, 1965; Gosz *et al.* 1976, Swift *et al.* 1981). Litter production in forest ecosystem has been extensively studied all over the world and huge amount of data accumulated on this subject has been comprehensively reviewed by several authors (see Bray and Gorham 1964, Reichle 1981). In the tropics large number of studies on litter dynamics have been conducted in Africa (Laudelout and Meyer 1954, Nye 1961, Madge 1965, Bernhard-Reversat 1970) and in south central America (Jenny *et al.* 1949, Klinge and Rodrigues 1968, Ewel 1976, Klinge 1978, Tanner 1980, 1981). Similar studies in the tropical forests of south east Asia have been carried out by Edwards (1977) and Kira *et al.* (1967). In India litter production studies have been confined mainly to the tropical deciduous forests (Champion 1936, Puri 1953, Singh 1969, Gaur and Pandey 1978, Vyas and Garg 1984, Kapur *et al.* 1986). The moist deciduous and subtropical wet hill forests of north-east India have been investigated from this angle by Singh and Ramakrishnan (1982) and Boojh and Ramakrishnan (1981).

It is well known that a large number of factors affect production and composition of litter in forest ecosystem. Effects of climate, soil, forest type and physiography on litter production and its quality have been discussed in great detail by Bray and Gorham (1964), Swift (1977), Turnbull (1983) and Meentemeyer (1984). Relatively few studies have, however, assessed the variability in litterfall in successional forest communities (Swift et al. 1981, Muller and Martin 1983). The data for disturbed forests are still meagre (Richards 1952, Hall and Okali 1979) for proper evaluation of the effects of disturbance on litter dynamics and nutrient cycling in forest ecosystem.

This chapter deals with the monthly and seasonal variations in litterfall, litter standing crop on the forest floor and its composition during regrowth of disturbed tropical moist deciduous and subtropical wet hill forests of Meghalaya.

METHODS

Litter standing crop was determined at monthly intervals by randomly laying ten 1m x 1m size quadrats. Monthly litter production was determined in ten permanent quadrats of 1m x 1m size in each stand. This technique was adopted when sampling through litter traps failed to produce reliable data due to damage of the litter traps. Since the stand is located on the hill slope, the four arms of the permanent quadrats were kept about 10 cm high and they were positioned about 3 cm above the ground to minimize litter loss through run-off water. The permanent quadrats were laid along two - 20 m long line transects running across the hill slope. The litter samples were brought to the laboratory and the following fractions were separated.

a) Leaf litter - Specieswise leaves with petiole and foliar rachis.
b) Woody litter - The branches (> 4mm dia.) of all the species were considered in this fraction (Procter 1985).
c) Reproductive parts - It included flowers and fruits of angiospermous species and cones of P. kesiya at upper altitude.
d) Miscellaneous - This fraction included unrecognisable remains of leaves, thin branches (< 4m dia.) and fine particles.

The samples were dried at 60°C to a constant weight and weighed. The results have been presented on dry weight (g/m^2) basis. The data were statistically analysed employing ANOVA (Kapur and Saxena 1967).

Monthly variation in decomposition losses of leaf and total litter was estimated by the difference between the expected and observed values of the respective fraction on the forest floor according to the method outlined by Swift et al. (1979).

The annual litter turnover was calculated using the formula given by Olson (1963).

Turnover ratio $(K_L) = L/X_L$

Where, L = Annual litterfall,

X_L = Mean annual standing crop.

RESULTS

Litter production

Monthly values of leaffall by different species in the two stands at lower altitude are given in Tables 4.1, 4.2, 4.3 and 4.4. In the young stand M. philippensis was the only tree species which contributed to leaf litter production. In this species leaffall started in the month of August, attained peak in January and declined thereafter until March. The chief contributors to leaf litter production in this stand were herbaceous species like E. odoratum, M. micrantha and A. conyzoides. All of them showed maximum leaffall during winter and minimum during summer months. In the old stand, since specieswise separation of herbaceous

Table 4.1. Monthly leaf, woody and total litter production (g/m^2) in the young stand at Burnihat during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
M. philippensis	3.55 (1.05)	1.10 (0.26)	2.70 (0.57)	-	0.30 (0.10)	-	-	0.15 (0.05)	1.50 (0.41)	1.60 (0.35)	0.90 (0.19)	1.40 (0.31)
A. conyzoides	0.22 (0.03)	0.22 (0.03)	-	-	-	-	-	0.10 (0.02)	-	0.45 (0.06)	1.00 (0.12)	1.30 (0.13)
F. odoratum	0.63 (0.05)	0.60 (0.11)	-	-	-	-	-	0.30 (0.08)	2.50 (0.34)	3.02 (0.26)	2.55 (0.16)	2.90 (0.14)
M. micrantha	1.05 (0.14)	1.25 (0.15)	-	-	-	-	-	-	2.60 (0.33)	1.95 (0.35)	1.10 (0.13)	1.20 (0.10)
Woody litter	0.30 (0.06)	-	1.10 (0.92)	1.80 (0.29)	-	-	-	-	-	-	-	-
Miscellaneous	7.50 (0.29)	7.10 (0.52)	3.20 (0.31)	5.15 (0.27)	2.70 (0.11)	1.50 (0.07)	2.45 (0.07)	3.50 (0.18)	2.95 (0.25)	3.25 (0.21)	6.70 (0.24)	5.60 (0.26)
Total	12.80	10.27	7.00	6.95	3.00	1.50	2.45	4.05	9.55	10.27	12.25	12.40

Table 4.2. Monthly leaf, woody and total litter production (g/m^2) in the young stand at Burnihat during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
M. philippensis	2.40 (0.52)	1.10 (0.28)	1.00 (0.22)	-	-	-	-	0.20 (0.06)	1.70 (0.36)	1.20 (0.29)	1.50 (0.32)	1.30 (0.29)
A. conyzoides	0.30 (0.06)	0.20 (0.04)	-	-	-	-	0.20 (0.03)	0.20 (0.04)	-	0.60 (0.08)	0.80 (0.13)	1.30 (0.14)
F. odoratum	1.20 (0.10)	1.40 (0.09)	0.55 (0.07)	-	-	-	0.50 (0.06)	0.60 (0.07)	3.10 (0.26)	2.80 (0.11)	2.50 (0.14)	1.90 (0.12)
M. micrantha	1.30 (0.09)	1.45 (0.08)	1.05 (0.12)	1.20 (0.18)	0.90 (0.15)	-	-	0.20 (0.03)	2.80 (0.22)	1.00 (0.11)	1.40 (0.17)	1.40 (0.17)
Woody litter	1.40 (0.30)	0.80 (0.11)	0.85 (0.12)	2.00 (0.24)	1.10 (0.09)	1.00 (0.19)	-	-	-	-	-	-
Miscellaneous	6.75 (0.35)	4.40 (0.16)	4.70 (0.16)	4.00 (0.16)	1.70 (0.05)	1.60 (0.09)	2.50 (0.06)	3.50 (0.15)	2.90 (0.14)	2.70 (0.14)	6.20 (0.20)	5.50 (0.18)
Total	13.35	9.35	8.15	7.20	3.70	2.60	3.20	4.70	10.50	8.30	12.40	11.40

Table 4.3. Monthly leaf, woody and total litter production (g/m^2) in the old stand at Burnihat during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
H. antidysentrica	1.44 (0.21)	3.61 (0.53)	3.60 (1.01)	1.10 (0.31)	1.50 (0.25)	0.50 (0.16)	1.20 (0.11)	1.15 (0.19)	3.35 (0.53)	3.10 (0.44)	3.50 (0.50)	4.80 (0.57)
V. glabrata	14.40 (1.47)	6.50 (1.00)	1.20 (0.19)	0.20 (0.06)	0.60 (0.16)	-	-	1.10 (0.17)	2.35 (0.32)	2.40 (0.34)	1.90 (0.29)	2.75 (0.37)
B. purpurea	2.12 (0.49)	2.00 (0.51)	3.20 (0.79)	2.00 (0.35)	0.40 (0.09)	-	0.40 (0.09)	0.85 (0.19)	1.15 (0.35)	0.50 (0.16)	2.00 (0.41)	0.50 (0.13)
L. monoptala	1.35 (0.27)	7.60 (1.15)	3.30 (0.42)	1.70 (0.39)	1.80 (0.34)	0.45 (0.09)	1.20 (0.13)	0.55 (0.10)	1.20 (0.38)	1.70 (0.36)	2.10 (0.45)	2.10 (0.44)
C. fistula	7.15 (1.34)	2.55 (0.37)	3.50 (0.45)	-	-	-	0.10 (0.03)	0.20 (0.04)	0.45 (0.09)	0.90 (0.19)	1.90 (0.33)	2.10 (0.39)
B. roxburghiana	0.92 (0.22)	0.80 (0.25)	1.00 (0.32)	-	-	-	-	0.15 (0.05)	-	-	-	-
S. cuminii	-	0.40 (0.13)	-	1.70 (0.37)	-	-	-	-	-	0.50 (0.11)	0.45 (0.10)	0.55 (0.13)
M. esculenta	-	0.15 (0.05)	-	-	-	-	-	-	-	-	0.70 (0.13)	0.70 (0.16)
T. ciliata	-	1.60 (0.35)	-	-	0.40 (0.13)	-	0.35 (0.05)	1.05 (0.09)	-	-	-	-
Woody litter	0.40 (0.07)	0.30 (0.09)	-	-	-	-	-	-	1.65 (0.41)	0.70 (0.15)	1.37 (0.22)	1.90 (0.29)
Miscellaneous	2.55 (0.53)	4.60 (0.61)	10.60 (0.93)	6.80 (0.61)	7.90 (0.58)	2.85 (0.18)	2.10 (0.17)	1.95 (0.19)	2.80 (0.23)	7.15 (0.37)	12.15 (0.48)	9.70 (0.34)
Total	30.33	30.10	26.40	13.50	12.60	3.80	5.35	7.00	12.95	16.95	26.07	25.10

Table 4.4. Monthly leaf, woody and total litter production (g/m^2) in the old stand at Burnihat during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
H. antidysentrica	1.70 (0.31)	2.70 (0.44)	2.20 (0.37)	1.60 (0.29)	1.80 (0.24)	1.00 (0.15)	1.50 (0.20)	2.00 (0.31)	2.80 (0.34)	2.80 (0.37)	4.40 (0.54)	4.30 (0.54)
V. glabrata	12.70 (1.66)	5.10 (0.70)	2.70 (0.33)	1.20 (0.20)	0.90 (0.12)	-	-	1.20 (0.18)	2.30 (0.34)	2.00 (0.29)	2.30 (0.31)	2.90 (0.42)
B. purpurea	2.00 (0.33)	1.20 (0.28)	1.50 (0.30)	1.70 (0.23)	1.00 (0.19)	-	-	0.90 (0.19)	1.50 (0.27)	0.60 (0.14)	1.70 (0.31)	1.40 (0.31)
L. monopetala	3.50 (0.58)	7.00 (1.15)	3.50 (0.48)	2.00 (0.32)	1.40 (0.20)	0.80 (0.13)	1.00 (0.15)	1.20 (0.24)	0.90 (0.19)	1.30 (0.31)	1.40 (0.31)	2.70 (0.60)
C. fistula	5.80 (0.89)	1.40 (0.18)	1.50 (0.26)	0.20 (0.06)	-	-	0.40 (0.09)	0.50 (0.11)	0.70 (0.15)	0.80 (0.18)	2.30 (0.36)	2.00 (0.37)
B. roxburghiana	0.60 (0.18)	0.40 (0.13)	0.90 (0.19)	0.20 (0.06)	0.40 (0.06)	-	-	-	-	-	-	-
S. cuminii	-	-	-	-	-	-	-	-	-	0.30 (0.07)	0.50 (0.11)	-
M. esculenta	-	0.20 (0.06)	-	-	-	-	-	-	-	-	1.30 (0.23)	1.40 (0.30)
T. ciliata	-	1.10 (0.23)	-	-	-	-	0.80 (0.13)	1.10 (0.19)	-	-	-	-
Woody litter	1.20 (0.26)	0.50 (0.11)	0.60 (0.14)	0.10 (0.03)	0.50 (0.09)	2.20 (0.07)	1.70 (0.28)	1.80 (0.27)	2.30 (0.30)	0.50 (0.11)	1.50 (0.19)	2.00 (0.28)
Miscellaneous	2.60 (0.15)	2.80 (0.22)	4.10 (0.23)	7.80 (0.19)	5.50 (0.23)	2.00 (0.12)	2.60 (0.13)	1.30 (0.06)	4.05 (0.28)	5.60 (0.22)	14.10 (0.40)	9.70 (0.42)
Total	30.10	22.40	17.00	14.80	11.50	6.00	8.00	10.00	14.55	13.90	29.50	26.40

litter was not feasible, most of the leaves were kept in the miscellaneous fraction. Leaffall of important tree species, namely H. antidysentrica, V. glabrata and L. monopetala was almost synchronous. It occurred throughout the year, except during peak rainy season (June-July). November and December were the peak months for H. antidysentrica, January-February for V. glabrata and February-March for L. monopetala. In other tree species leaffall was confined either to November or April. This pattern of leaffall did not show any marked variation during two years of study period.

Specieswise monthly leaffall at higher altitude is given in Tables 4.7, 4.8, 4.9 and 4.10. In the young stand P. kesiya was responsible for major amount of leaf litter production. Leaffall in this species, although occurred throughout the year, the maximum was during April-May and minimum during July-August. In case of A. nepalensis and M. esculenta it occurred for about 5 months between September and January; the highest values were recorded in the month of September. Among the species of ground flora, P. longipes and I. cylindrica were important from the point of view of leaf litter production, whereas in case of P. longipes leaffall was recorded throughout the year, it was confined only to the winter season in I. cylindrica.

Table 4.7. Monthly leaf, woody and total litter production (g/m^2) in the young stand at Shillong during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	10.65 (0.48)	8.79 (0.96)	7.25 (0.72)	18.40 (1.30)	7.95 (0.58)	14.65 (0.59)	4.00 (0.18)	3.55 (0.25)	7.95 (0.46)	9.60 (0.42)	9.35 (0.44)	10.00 (0.45)
N. nepalensis	-	-	0.03 (0.01)	-	-	-	-	-	1.10 (0.15)	0.65 (0.13)	0.85 (0.05)	-
M. esculenta	0.32 (0.09)	-	0.02 (0.01)	-	-	-	0.15 (0.05)	-	2.30 (0.29)	1.60 (0.30)	1.80 (0.24)	0.45 (0.10)
E. latifolia	0.29 (0.06)	-	-	-	-	-	-	-	-	-	-	0.10 (0.02)
L. ovalifolia	0.05 (0.02)	-	-	-	-	-	-	-	-	-	-	0.25 (0.05)
P. longipes	0.11 (0.03)	0.50 (0.11)	1.60 (0.27)	1.10 (0.26)	0.50 (0.16)	0.55 (0.10)	1.15 (0.23)	1.40 (0.23)	2.25 (0.45)	1.25 (0.28)	0.40 (0.13)	- -
I. cappa	-	1.10 (0.03)	-	-	-	-	-	-	-	-	-	-
B. asiatica	-	-	-	-	-	-	0.20 (0.06)	0.25 (0.05)	0.30 (0.09)	0.40 (0.09)	-	-
I. cylindrica	1.47 (0.21)	2.20 (0.39)	2.37 (0.22)	-	-	-	-	-	-	-	-	0.75 (0.05)
Woody litter	1.65 (0.16	0.35 (0.27)	1.52 (0.18)	1.20 (0.38)	-	-	0.75 (0.13)	0.60 (0.09)	0.25 (0.08)	0.60 (0.19)	-	-
Reproductive parts	-	-	-	-	-	-	-	-	1.20 (0.38)	-	1.00 (0.31)	0.10 (0.03)
Miscellaneous	1.85 (0.16)	3.15 (0.24)	5.30 (0.27)	2.35 (0.15)	2.05 (0.11)	3.40 (0.22)	4.70 (0.36)	5.45 (0.40)	3.25 (0.74)	4.05 (0.21)	3.45 (0.19)	5.05 (0.28)
Total	16.39	15.09	18.09	23.05	10.50	18.60	18.15	16.85	18.60	18.15	16.85	16.70

Table 4.8. Monthly leaf, woody and total litter production (g/m^2) in the young stand at Shillong during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	8.90 (0.56)	9.00 (0.43)	6.40 (0.19)	12.00 (0.29)	14.10 (0.28)	17.30 (0.19)	3.60 (0.19)	3.70 (0.13)	7.60 (0.31)	9.30 (0.22)	8.90 (0.25)	11.90 (0.67)
A. nepalensis	-	-	-	-	-	-	-	-	0.90 (0.15)	0.95 (0.17)	0.80 (0.14)	1.20 (0.48)
M. esculenta	0.40 (0.08)	0.10 (0.03)	0.20 (0.04)	0.10 (0.03)	-	-	0.30 (0.07)	-	1.80 (0.29)	1.0 (0.18)	1.90 (0.27)	0.90 (0.20)
E. latifolia	0.25 (0.06)	-	-	-	-	-	-	-	-	-	-	0.30 (0.06)
L. ovalifolia	0.10 (0.03)	-	0.10 (0.03)	-	-	-	-	-	-	0.90 (0.15)	-	0.40 (0.06)
P. longipes	0.70 (0.13)	0.90 (0.20)	0.50 (0.16)	-	0.70 (0.15)	-	-	1.20 (0.18)	1.90 (0.23)	1.50 (0.29)	0.60 (0.19)	-
I. cappa	0.40 (0.19)	0.10 (0.03)	-	-	-	-	-	-	-	-	-	-
B. asiatica	-	-	-	-	-	-	0.40 (0.07)	0.30 (0.07)	0.40 (0.09)	0.60 (0.08)	-	-
I. cylindrica	2.30 (0.16)	2.00 (0.09)	0.90 (0.11)	-	-	-	-	-	-	-	-	0.50 (0.08)
Woody litter	0.80 (0.19)	0.30 (0.09)	1.10 (0.19)	2.10 (0.34)	1.30 (0.22)	0.90 (0.15)	1.30 (0.22)	0.40 (0.07)	0.90 (0.20)	1.40 (0.20)	-	-
Miscellaneous	4.50 (0.17)	3.10 (0.12)	8.90 (0.25)	7.30 (0.29)	4.80 (0.30)	4.20 (0.21)	4.70 (0.21)	5.10 (0.26)	4.40 (0.25)	4.60 (0.20)	2.70 (0.12)	5.70 (0.31)
Total	18.35	16.00	18.10	21.50	20.90	22.40	10.30	10.70	18.80	20.25	15.70	21.30

Table 4.9. Monthly leaf, woody and total litter production (g/m^2) in the old stand at Shillong during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
_P_. _kesiya_	10.90 (1.13)	3.19 (2.31)	3.69 (1.65)	3.21 (1.52)	9.80 (0.37)	6.95 (0.26)	3.25 (0.18)	3.15 (0.24)	5.60 (0.20)	3.75 (0.20)	5.75 (0.21)	7.55 (0.17)
_A_. _nepalensis_	9.00 (0.68)	2.30 (0.25)	3.40 (0.27)	0.90 (0.20)	1.00 (0.22)	0.80 (0.12)	6.65 (0.73)	8.90 (0.75)	7.25 (1.10)	2.35 (0.23)	1.65 (0.23)	1.80 (0.30)
_M_. _esculenta_	-	-	0.40 (0.09)	0.20 (0.06)	-	-	-	0.05 (0.02)	-	0.17 (0.04)	0.35 (0.07)	0.40 (0.07)
_L_. _ovalifolia_	0.90 (0.19)	0.40 (0.13)	1.05 (0.25)	0.30 (0.10)	-	-	-	-	-	-	-	0.70 (0.13)
_E_. _latifolia_	0.22 (0.03)	-	-	-	-	-	-	-	-	-	-	0.25 (0.05)
_R_. _javanica_	-	-	-	-	-	-	-	-	0.60 (0.19)	-	-	-
_P_. _longipes_	-	-	-	-	-	-	-	1.15 (0.21)	1.75 (0.31)	0.65 (0.11)	0.60 (0.11)	-
_B_. _asiatica_	-	-	-	-	-	-	-	-	0.80 (0.25)	0.30 (0.09)	0.20 (0.06)	-
_I_. _cylindrica_	0.01 (0.00)	-	0.01 (0.03)	-	-	-	-	-	-	-	-	0.50 (0.08)
Woody litter	3.07 (0.33)	1.10 (0.25)	3.40 (0.28)	5.05 (0.94)	0.70 (0.12)	0.70 (0.13)	5.35 (0.80)	3.60 (0.86)	-	-	-	1.40 (0.20)
Reproductive parts	0.25 (0.06)	1.20 (0.35)	1.35 (0.16)	2.00 (0.38)	7.60 (1.03)	2.80 (0.25)	9.40 (0.62)	1.00 (0.15)	-	-	-	1.15 (0.16)
Miscellaneous	3.21 (0.40)	8.54 (0.89)	12.05 (0.88)	5.00 (0.36)	5.05 (0.54)	3.70 (0.16)	7.35 (0.56)	3.00 (0.35)	6.42 (0.75)	4.80 (0.24)	5.80 (0.27)	6.30 (0.22)
Total	27.56	16.73	25.44	16.66	24.15	14.95	32.00	20.85	22.42	12.02	14.35	20.05

Table 4.10. Monthly leaf, woody and total litter production (g/m^2) in the old stand at Shillong during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	21.90 (0.34)	25.30 (0.35)	22.60 (0.42)	17.40 (0.22)	15.90 (0.25)	11.20 (0.26)	4.90 (0.17)	3.50 (0.19)	5.00 (0.25)	4.20 (0.29)	4.50 (0.16)	8.60 (0.25)
A. nepalensis	7.70 (0.49)	4.00 (0.40)	2.80 (0.33)	1.00 (0.15)	-	-	-	-	-	-	-	-
M. esculenta	0.20 (0.07)	0.30 (0.09)	0.50 (0.11)	-	-	-	-	-	-	0.30 (0.07)	0.90 (0.19)	0.50 (0.11)
L. ovalifolia	0.60 (0.11)	0.90 (0.13)	1.10 (0.13)	0.50 (0.11)	-	-	-	-	-	-	-	0.90 (0.19)
E. latifolia	0.20 (0.06)	-	-	-	-	-	-	-	-	-	-	0.50 (0.01)
R. javanica	-	-	-	-	-	-	-	-	0.40 (0.09)	-	-	-
P. longipes	-	-	-	-	-	-	-	1.70 (0.32)	0.60 (0.08)	0.50 (0.09)	0.70 (0.15)	-
B. asiatica	-	-	-	-	-	-	-	-	0.30 (0.10)	0.30 (0.07)	-	-
I. cylindrica	0.50 (0.11)	0.90 (0.15)	0.50 (0.11)	-	-	-	-	-	-	-	-	0.70 (0.12)
Woody litter	2.50 (0.32)	1.90 (0.16)	2.50 (0.22)	3.10 (0.33)	2.60 (0.30)	-	-	1.30 (0.26)	-	-	-	1.60 (0.24)
Reproductive parts	0.40 (0.07)	0.60 (0.16)	3.20 (0.15)	4.00 (0.44)	6.70 (0.32)	7.10 (0.28)	9.50 (0.71)	2.20 (0.32)	-	-	-	3.10 (0.32)
Miscellaneous	2.90 (0.17)	5.30 (0.18)	18.90 (0.45)	12.80 (0.36)	5.10 (0.17)	2.40 (0.11)	2.60 (0.29)	3.30 (0.22)	2.55 (0.16)	5.30 (0.13)	7.90 (0.27)	5.60 (0.20)
Total	36.90	40.20	52.10	38.80	30.30	22.50	20.80	18.50	13.75	12.70	15.60	23.60

Monthly variation in total leaf litter production in the two stands, both at the lower and higher altitudes, is given in Figures 4.1. and 4.2, respectively. At lower altitude the trend was more or less similar in the two stands. Leaffall was minimum during May and June, increased sharply and attained peak during September-October in the young stand and during January-February in the old stand, it declined thereafter to the minimum level in the month of May-June in both the stands. At higher altitude the two stands showed different monthly trends of litterfall. In the young stand, except for the rainy season (July-August) when litterfall was minimum, the values were almost uniform throughout the year. But in the old stand leaffall commenced from September, attained peak during winter (November - February) and then declined and reached to its minimum during June and July. Statistical analysis of data (Tables 4.5, 4.11) reveals that in all, except the old stand at higher altitude, monthly variation in leaf litter production was significantly different ($P < 0.05$).

Monthly values of woody litter production at the lower altitude are given in Tables 4.1, 4.2, 4.3 and 4.4. In the young stand production was confined mainly to drier months (November - December) but in the old stand the maximum value was found during pre-monsoon period (May-June). At

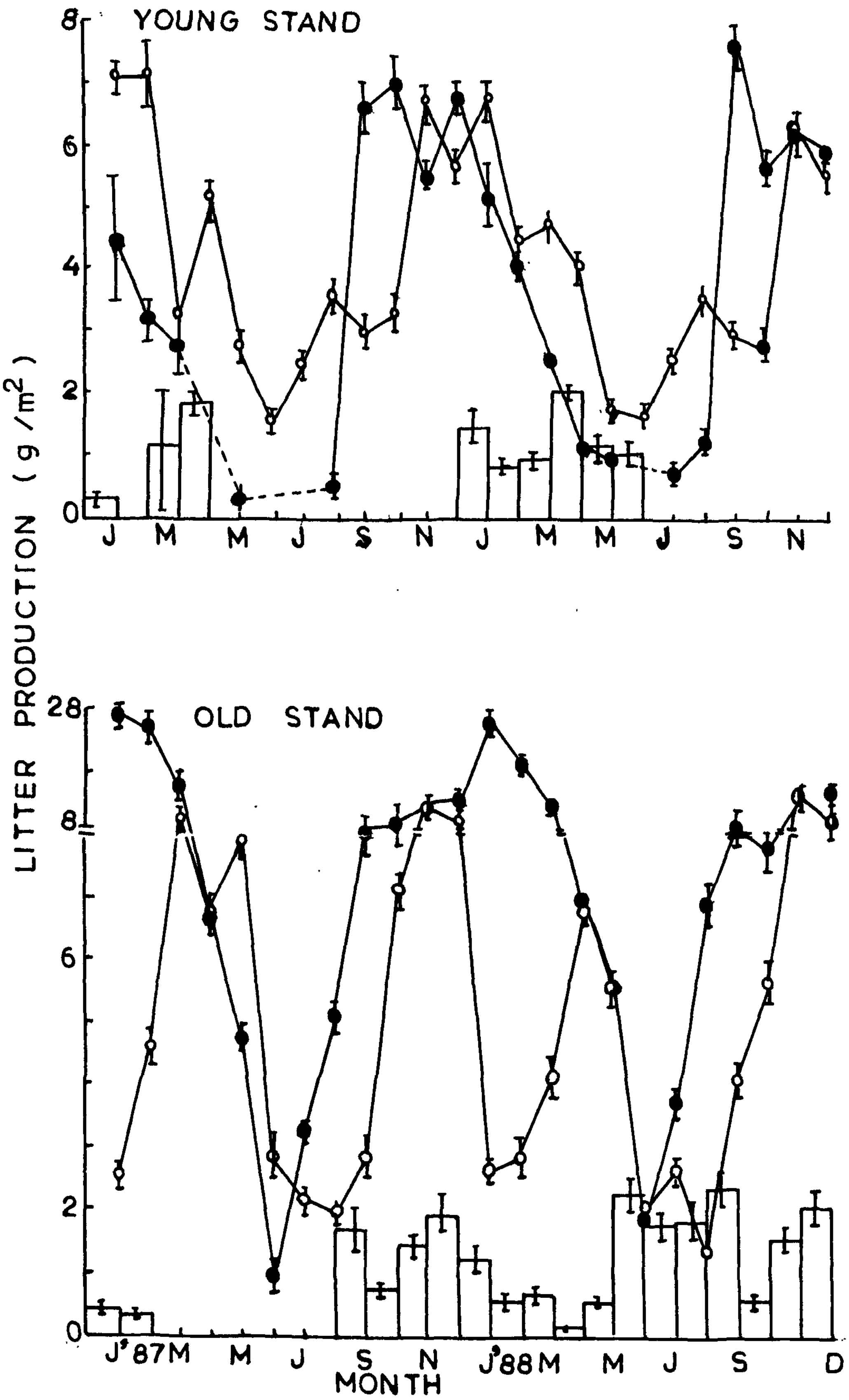

Figure 4.1. Monthly litter production (leaf 'O', woody '☐', miscellaneous '●' in the young and old forest stands at Burnihat. Vertical lines represent S.E., n = 10.

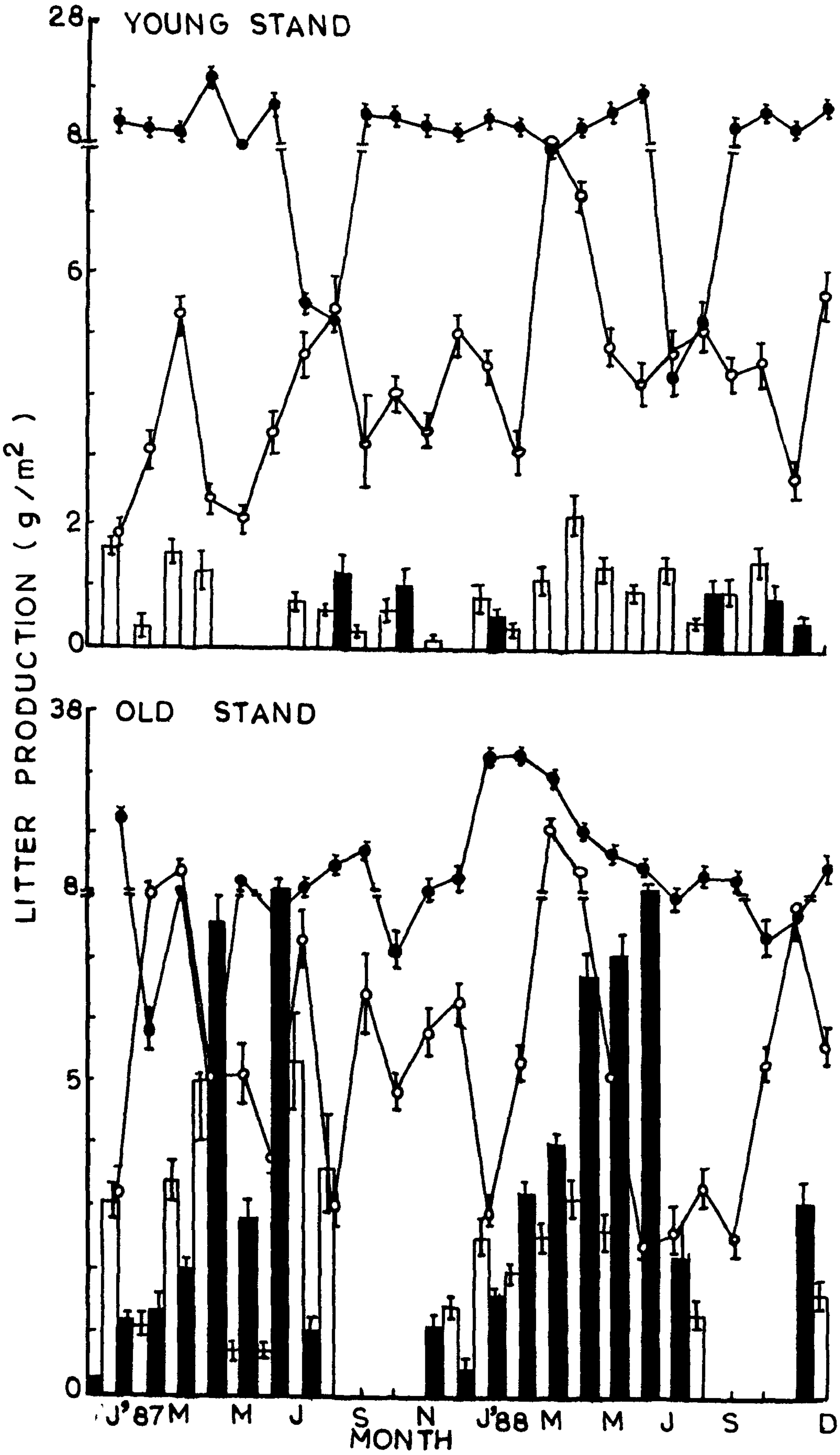

Figure 4.2. Monthly litter production (leaf 'O', woody '□', reproductive parts '■', miscellaneous '●') in the young and old forest stands at Shillong. Vertical lines represent S.E., n = 10.

Table 4.5. Analysis of variance of leaf litter production in the young and old forest stands at Burnihat during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	13.02	1.01^{NS}	111.11	1.24^{NS}
Month	11	131.88	10.24*	1420.43	15.87*
Year x Month	11	4.39	0.34^{NS}	97.15	1.09^{NS}
Error	216	12.88	0	89.50	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

Table 4.11. Analysis of variance of leaf litter production in the young and old forest stands at Shillong during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	10.62	0.38 NS	26204.40	0.86 NS
Month	11	168.37	6.06*	36803.90	1.209 NS
Year x Month	11	132.86	4.78*	33675.60	1.11 NS
Error	216	27.79	0	30444.30	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

the higher altitude small amount of woody litter was formed throughout the year in the young stand while in the old stand it was confined only during December to August (Figure 4.2). The maximum value was recorded in June and July. Reproductive parts followed the trend of woody litter in both the stands.

Total litter production (leaf + woody + reproductive parts + miscellaneous) showed significant ($P < 0.05$) monthly variation in all the stands (Tables 4.6 and 4.12). In moist deciduous forest at Burnihat it increased from August and attained higher values during November-January in both the stands while in the wet hill forest at Shillong, peak period of litter production extended from November to February; the rainy season was the period of minimum litter production in both the stands.

Mean daily leaf litterfall ($g/m^2/day$) and total production in different seasons are shown in Figure 4.3. At the lower altitude the rate was maximum in winter and minimum in summer in both the stands, but the differences among the seasons were more prominent in the old stands. At the higher altitude the rate of leaf litter production was different during 1987 and 1988. During 1987 in the young stand the seasonal trend was winter < summer > rainy, while in the old stand it was winter > summer < rainy. In 1988 minimum

Table 4.6. Analysis of variance of total litter production in the young and old forest stands at Burnihat during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	7.39	0.73^{NS}	21.77	0.43^{NS}
Month	11	293.2	28.78*	1557.66	30.58*
Year x Month	11	6.47	0.64^{NS}	91.87	1.80^{NS}
Error	216	10.19	0	50.94	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

Table 4.12. Analysis of variance of total litter production in the young and old forest stands at Shillong during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	48.89	1.04^{NS}	4.17	0.04^{NS}
Month	11	260.36	5.36*	3395.67	33.22*
Year x Month	11	66.44	1.42^{NS}	338.58	3.3*
Error	216	46.80	0	102.23	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

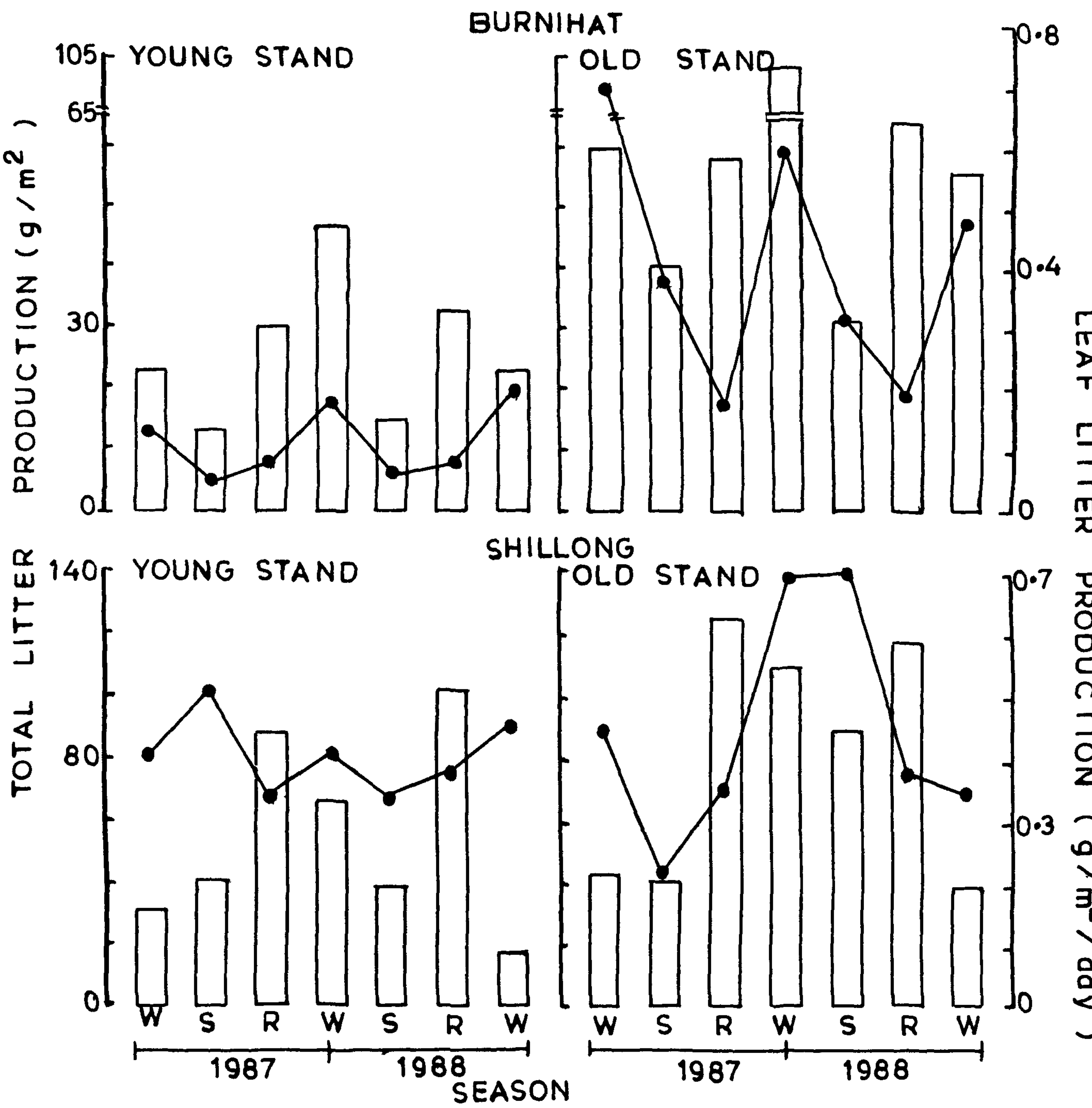

Figure 4.3. Seasonal total litter production (bar) and mean daily leaf litter production (line) in the three seasons (W-winter, S-summer, R-rainy) in the young and old forest stands.

litter production in the young stand was obtained in the summer season while in the old stand it was in the rainy season. When total seasonal litter production was taken into consideration the trend: winter < summer < rainy, was similar in all the four stands.

Annual production of leaf, woody and miscellaneous litter fractions showed a marked increase from the young to old stand, except the leaf litter which exhibited a declining trend from the young to old stand at higher altitude in 1987 (Table 4.13). Annual total litter production did not show significant difference between 1987 and 1988 (Tables 4.6 and 4.12). In the moist deciduous forest the values were 0.92 - 0.94 and 2.04 - 2.10 t/ha in the young and old stands, respectively. The corresponding values for the young and old forest stands at Shillong were 1.95 - 2.14 and 2.47 - 3.25 t/ha.

Litter standing crop

Monthly values of specieswise leaf, woody and total litter dry weight at the lower altitude are given in Tables 4.14, 4.15, 4.16 and 4.17. M. philippensis leaves were the main component among the tree leaf litter in the young stand. It showed highest value in the winter and lowest in the rainy season. Complete separation of leaf litter of herbaceaous species was not possible in this stand, therefore,

Table 4.13. Annual production of different categories of litter (t/ha) in the young and old stands of tropical moist deciduous forest at Burnihat and subtropical wet hill forest at Shillong

Year	Litter category	Burnihat		Shillong	
		Young stand	Old stand	Young stand	Old stand
1987					
	Leaf	0.38	1.33	1.41	1.25
	Woody	0.03	0.06	0.07	0.24
	Reproductive parts	-	-	0.02	0.27
	Miscellaneous	0.51	0.71	0.45	0.71
	Total	0.92	2.10	1.95	2.47
1988					
	Leaf	0.41	1.27	1.41	1.98
	Woody	0.07	0.15	0.10	0.16
	Reproductive parts	-	-	0.03	0.38
	Miscellaneous	0.46	0.62	0.60	0.74
	Total	0.94	2.04	2.14	3.25

- = Absent

Table 4.14. Monthly variation in litter dry weight (g/m^2) in the young stand at Burnihat during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
M. philippensis	7.40 (1.89)	-	4.00 (1.27)	2.00 (0.67)	1.60 (0.51)	-	-	1.30 (0.30)	1.10 (0.02)	1.45 (0.21)	4.40 (0.94)	7.80 (1.89)
A. conyzoides	0.32 (0.06)	-	-	-	-	-	-	-	-	0.50 (0.09)	1.20 (0.19)	2.05 (0.21)
E. odoratum	0.30 (0.07)	-	-	-	-	-	-	-	0.10 (0.07)	-	2.40 (0.28)	3.00 (0.31)
M. micrantha	0.54 (0.11)	-	-	-	-	-	-	-	-	-	1.30 (0.18)	2.50 (0.26)
Woody litter	4.20 (0.73)	5.30 (0.47)	8.50 (0.99)	16.20 (1.78)	3.40 (0.06)	4.90 (0.85)	1.70 (0.36)	4.10 (0.41)	6.90 (0.83)	7.40 (1.01)	-	3.40 (0.76)
Miscellaneous	51.90 (2.93)	54.22 (1.34)	18.70 (0.93)	15.80 (0.94)	10.90 (0.48)	11.50 (0.58)	6.90 (0.02)	8.10 (0.29)	11.30 (0.08)	16.80 (1.14)	24.90 (0.94)	39.50 (1.33)
Total	64.66	59.52	31.20	34.00	15.90	16.40	8.60	13.50	19.40	26.15	34.20	58.25

Table 4.15. Monthly variation in litter dry weight (g/m^2) in the young stand at Burnihat during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
M. philippensis	7.50 (1.29)	3.90 (1.23)	3.00 (0.69)	3.40 (1.08)	-	-	-	-	1.70 (0.38)	3.00 (0.63)	5.70 (0.92)	3.50 (0.65)
A. conyzoides	1.00 (0.09)	0.50 (0.06)	-	-	-	-	0.10 (0.02)	-	-	0.75 (0.09)	0.50 (0.09)	2.50 (0.21)
E. odoratum	1.90 (0.12)	2.00 (0.14)	0.70 (0.13)	-	-	-	0.70 (0.09)	-	3.80 (0.32)	1.90 (0.16)	3.40 (0.37)	1.80 (0.15)
M. micrantha	1.30 (0.13)	1.00 (0.16)	1.20 (0.16)	-	1.60 (0.24)	-	-	-	3.20 (0.23)	1.30 (0.13)	1.90 (0.31)	1.80 (0.23)
Woody litter	4.00 (0.62)	4.10 (0.68)	5.20 (0.63)	3.60 (0.64)	1.60 (0.29)	3.40 (0.74)	4.00 (0.67)	2.20 (0.27)	0.80 (0.18)	0.80 (0.17)	0.99 (0.20)	1.60 (0.30)
Miscellaneous	20.60 (1.02)	34.80 (1.13)	22.40 (0.83)	25.55 (1.13)	19.10 (0.54)	15.30 (0.64)	11.20 (0.44)	15.10 (0.45)	21.90 (0.46)	16.00 (0.55)	19.90 (0.72)	42.80 (1.10)
Total	36.30	46.30	32.50	32.55	22.30	18.70	16.00	17.30	31.40	23.75	32.39	54.00

Table 4.16. Monthly variation in litter dry weight (g/m^2) in the old stands at Burnihat during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
H. antidysentrica	3.20 (0.81)	3.15 (0.85)	4.00 (0.72)	2.40 (0.49)	8.90 (2.42)	1.90 (0.41)	3.95 (0.37)	-	0.70 (0.22)	4.10 (0.46)	10.80 (1.49)	11.90 (1.68)
V. glabrata	1.70 (0.31)	4.30 (0.77)	6.70 (0.64)	2.35 (0.42)	0.30 (1.10)	-	-	1.45 (0.23)	0.60 (0.19)	2.80 (0.35)	6.40 (1.06)	7.50 (0.88)
B. purpurea	-	1.85 (0.28)	1.30 (0.28)	1.70 (0.25)	-	-	0.45 (0.06)	-	-	2.00 (0.42)	1.15 (0.28)	3.20 (0.68)
L. monopetala	28.70 (4.65)	8.20 (1.95)	4.05 (0.65)	4.10 (1.16)	0.40 (1.08)	0.50 (0.13)	0.20 (0.06)	2.65 (0.28)	3.60 (0.83)	2.40 (0.43)	3.90 (0.83)	5.60 (1.24)
C. fistula	2.40 (0.61)	7.40 (1.21)	2.60 (0.44)	2.80 (0.38)	-	-	-	-	0.90 (0.21)	2.40 (0.45)	3.00 (0.39)	3.60 (0.58)
B. roxburghiana	-	2.95 (0.65)	0.05 (0.01)	-	-	-	-	-	3.10 (0.46)	-	1.00 (0.22)	-
S. cuminii	-	-	-	-	-	-	-	-	-	-	0.90 (0.28)	-
M. esculenta	-	2.40 (0.48)	-	-	-	-	-	-	-	-	0.70 (0.15)	2.40 (0.59)
T. ciliata	-	0.40 (0.13)	-	-	-	-	0.60 (0.09)	-	-	-	-	-
Woody litter	8.67 (0.94)	6.10 (0.79)	0.50 (0.16)	8.00 (1.56)	-	-	5.55 (0.78)	3.55 (0.48)	8.00 (1.15)	5.30 (1.02)	-	6.60
Miscellaneous	42.80 (1.89)	41.00 (2.19)	36.20 (0.96)	18.50 (0.64)	38.20 (1.39)	42.30 (2.01)	8.70 (0.25)	16.50 (0.67)	6.40 (0.44)	13.60 (0.89)	45.40 (0.59)	44.90 (0.96)
Total	87.47	77.75	55.40	39.85	47.80	44.70	19.45	24.15	23.35	32.60	73.25	85.70

Table 4.17. Monthly variation in litter dry weight (g/m^2) in the old stand at Burnihat during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
H. antidysentrica	10.60 (2.24)	7.40 (1.26)	5.80 (0.79)	5.40 (0.73)	5.50 (0.67)	3.20 (0.52)	4.20 (0.46)	2.90 (0.42)	2.70 (0.45)	3.50 (0.47)	11.30 (1.08)	11.80 (1.25)
V. glabrata	26.50 (3.48)	16.90 (2.53)	5.30 (0.74)	6.10 (0.88)	2.50 (0.50)	-	-	4.50 (0.68)	4.30 (0.65)	2.40 (0.35)	7.30 (0.71)	9.60 (1.38)
B. purpurea	-	2.50 (0.38)	0.50 (0.16)	1.10 (0.36)	-	-	-	1.20 (0.20)	2.60 (0.37)	2.00 (0.36)	1.10 (0.23)	1.30 (0.39)
L. monopetala	31.50 (4.24)	6.10 (1.06)	3.00 (0.39)	5.60 (1.03)	2.00 (0.36)	2.10 (0.29)	3.10 (0.67)	2.30 (0.31)	2.60 (0.50)	2.50 (0.41)	4.00 (0.66)	3.80 (0.70)
C. fistula	5.20 (0.86)	3.20 (0.54)	2.10 (0.35)	2.50 (0.43)	-	-	0.80 (0.16)	1.30 (0.35)	1.50 (0.32)	1.80 (0.29)	3.50 (0.64)	3.10 (0.60)
B. roxburghiana	-	2.30 (0.49)	2.70 (0.57)	1.30 (0.30)	1.50 (0.28)	-	-	-	3.10 (0.43)	-	1.30 (0.28)	-
S. cuminii	-	-	-	-	-	-	-	-	-	-	0.70 (0.08)	0.90 (0.14)
M. esculenta	0.80 (0.25)	-	-	-	-	-	-	-	-	-	0.90 (0.19)	0.80 (0.29)
Woody litter	3.70 (0.28)	3.00 (0.44)	3.30 (0.54)	3.20 (0.42)	1.70 (0.25)	4.80 (0.67)	3.60 (0.51)	2.20 (0.31)	6.00 (0.79)	4.70 (0.46)	2.20 (0.32)	4.10 (0.61)
Miscellaneous	3.60 (0.41)	42.0 (2.45)	27.80 (0.86)	27.80 (0.91)	36.00 (1.03)	34.30 (0.76)	16.60 (0.69)	16.80 (0.47)	5.60 (0.23)	13.20 (0.43)	45.10 (0.75)	45.50 (1.13)
Total	81.90	83.40	50.50	53.00	49.20	44.40	30.60	33.200	28.40	30.10	77.40	76.90

the miscellaneous fraction was composed mainly of the broken leaves of *A. conyzoides*, *E. odoratum* and *M. micrantha*. This fraction showed minimum value in July, which increased gradually through post rainy season and attained peak in February. The woody litter dry weight ranged between 1.7 and 16.2 g/m^2 without showing any definite seasonal trend.

In the old stand three important tree species viz., *H. antidysentrica*, *V. glabrata* and *L. monopetala* exhibited similar monthly variation in litter dry weight; the values were generally high during November-December and lower during June. The miscellaneous fraction which accounted for major portion of litter in this stand also exhibited a similar seasonal trend. The woody litter was comparatively less than the leaf and miscellaneous fractions but its monthly trend was similar to the other two fractions.

At the higher altitude although *P. kesiya* needles were present in the litter throughout the year (Tables 4.14 to 4.17)), the maximum leaf litter was recorded in January in both the stands. Monthly variation in leaf litter standing crop was found to be significantly ($P < 0.05$) different (Tables 4.18, 4.24) in all the four stands.

The miscellaneous fraction which was composed mainly of broken pine needles and leaves of the ground flora tended

Table 4.18. Analysis of variance of standing crop of leaf litter in the young and old forest stands at Burnihat during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	1099.97	6.54*	173.06	0.52^{NS}
Month	11	4026.73	23.96*	10755.40	32.21*
Year x Month	11	715.66	4.26*	318.42	0.21*
Error	216	168.09	0	333.64	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

Table 4.24. Analysis of variance of standing crop of leaf litter in the young and old stands at Shillong during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	2217.38	6.69*	9272.75	24.47*
Month	11	5426.88	16.39*	10463.00	27.61*
Year x Month	11	1179.95	3.56*	3591.74	9.48*
Error	216	331.05	-	378.99	-
Total	239	-	-	-	-

* = Significant at $P < 0.05$

Table 4.20. **Monthly variation in litter dry weight (g/m^2) in the young stand at Shillong during 1987 (values in parentheses are ± S.D., n = 10)**

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	62.30 (4.33)	60.60 (3.26)	24.60 (2.86)	64.40 (2.33)	35.20 (1.03)	42.30 (1.92)	28.30 (2.79)	15.60 (0.81)	33.35 (3.02)	28.10 (0.74)	26.90 (0.45)	29.10 (0.89)
A. nepalensis	-	1.32 (0.19)	1.90 (0.34)	-	-	-	-	-	-	-	2.10 (0.39)	-
M. esculenta	0.30 (0.07)	3.32 (0.45)	1.00 (0.23)	6.90 (1.09)	-	-	-	-	0.55 (0.17)	0.80 (0.14)	1.40 (0.45)	1.50 (0.32)
E. latifolia	-	0.07 (0.02))	-	-	-	-	-	-	-	-	-	0.02 (0.03)
L. ovalifolia	0.02 (0.06)	-	-	2.10 (0.44)	-	-	-	-	-	-	-	0.07 (0.14)
P. longipes	2.97 (0.48)	2.37 (0.06)	0.40 (0.09)	-	-	-	3.40 (0.49)	-	0.75 (0.16)	2.00 (0.34)	4.20 (0.60)	-
I. cappa	-	1.30 (0.41)	-	-	-	-	-	-	-	-	-	-
B. asiatica	-	-	-	-	-	-	-	1.10 (0.14)	0.60 (0.07)	-	-	-
I. cylindrica	5.60 (0.91)	2.16 (0.24)	3.25 (0.47)	-	-	-	-	-	-	-	1.30 (0.13)	1.50 (0.17)
Woody litter	3.45 (0.43)	1.20 (0.19)	5.80 (0.53)	-	2.80 (0.64)	1.70 (0.37)	2.05 (0.32)	4.50 (0.14)	5.95 (0.82)	5.80 (0.82)	3.90 (0.53)	6.20 (0.92)
Reproductive parts	0.03 (0.01)	0.05 (0.02)	-	-	0.40 (0.13)	-	-	-	0.70 (0.22)	1.80 (0.38)	3.60 (0.64)	3.50 (0.78)
Miscellaneous	36.50 (2.70)	29.00 (1.47)	67.00 (1.47)	50.90 (2.72)	47.30 (1.59)	40.10 (4.73)	53.70 (1.47)	29.90 (0.85)	60.50 (2.52)	51.10 (1.26)	61.70 (0.97)	58.40 (1.55)
Total	111.17	99.39	103.95	124.30	85.70	84.10	87.45	51.10	102.40	89.60	105.10	100.29

Table 4.21. Monthly variation in litter dry weight (g/m^2) in the young stand at Shillong during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	62.40 (1.65)	53.30 (2.12)	59.80 (1.24)	57.50 (1.34)	60.60 (1.23)	51.50 (1.01)	55.00 (1.12)	36.00 (0.42)	25.30 (0.59)	21.50 (0.39)	27.60 (0.57)	38.70 (1.15)
A. nepalensis	-	-	-	-	-	-	-	-	-	-	1.10 (0.23)	-
M. esculenta	0.50 (0.16)	2.20 (0.31)	1.60 (0.24)	0.60 (0.11)	-	-	0.70 (0.15)	-	1.70 (0.30)	1.60 (0.28)	1.60 (0.28)	2.50 (0.55)
F. latifolia	-	0.50 (0.11)	-	-	-	-	-	-	-	-	-	0.30 (1.10)
L. ovalifolia	-	1.00 (0.13)	-	0.90 (0.20)	-	-	-	-	-	0.90 (0.15)	-	0.60 (0.16)
P. longipes	2.60 (0.32)	0.80 (0.16)	1.90 (0.31)	-	1.40 (0.29)	3.30 (0.56)	1.20 (0.38)	-	1.90 (0.31)	2.00 (0.24)	4.50 (0.33)	-
B. asiatica	-	-	-	-	-	-	1.30 (0.26)	-	0.60 (0.16)	0.50 (0.11)	-	-
I. cylindrica	2.50 (0.20)	3.80 (0.13)	2.10 (0.19)	-	-	-	-	-	-	-	1.60 (0.09)	0.90 (0.15)
Woody litter	-	-	4.50 (0.37)	3.10 (0.34)	1.30 (0.22)	3.60 (0.62)	5.00 (0.61)	3.60 (0.44)	6.60 (0.69)	6.00 (0.60)	2.60 (0.37)	3.60 (0.44)
Reproductive parts	2.00 (0.43)	1.10 (0.20)	-	-	1.90 (0.42)	3.40 (0.72)	-	-	2.10 (0.34)	2.30 (0.32)	1.10 (0.35)	5.50 (0.78)
Miscellaneous	38.40 (1.25)	42.60 (1.45)	30.60 (0.64)	28.50 (1.07)	24.40 (0.82)	15.30 (0.32)	11.00 (0.35)	30.70 (1.21)	58.90 (1.97)	61.60 (1.11)	64.50 (1.33)	62.00 (0.70)
Total	108.40	106.20	100.50	90.60	89.60	77.10	74.20	70.30	97.10	96.40	104.60	114.10

Table 4.22. Monthly variation in litter dry weight (g/m^2) in the old stand at Shillong during 1987 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	101.00 (1.26)	65.55 (4.91)	62.80 (5.25)	20.00 (3.58)	21.05 (2.33)	26.00 (1.68)	22.50 (2.03)	23.00 (1.44)	15.25 (0.92)	38.30 (0.93)	41.80 (1.16)	48.00 (1.12)
A. nepalensis	7.05 (1.01)	7.70 (1.05)	9.20 (0.94)	2.40 (0.51)	4.40 (0.93)	3.30 (0.39)	3.00 (0.36)	10.65 (1.21)	0.50 (0.16	3.30 (0.54)	3.30 (0.45)	3.20 (0.53)
M. esculenta	0.10 (0.02)	-	0.15 (0.03)	-	-	-	-	-	0.25 (0.08)	1.40 (0.27)	1.70 (0.29)	2.50 (0.42)
L. ovalifolia	3.50 (0.52)	0.30 (0.07)	3.60 (0.53)	3.20 (1.01)	-	-	1.20 (0.29)	-	-	-	1.00 (0.15)	1.50 (0.26)
E. latifolia	0.15 (0.05)	-	-	-	-	-	-	-	-	-	-	-
R. javanica	-	-	-	-	-	-	-	-	1.60 (0.34)	1.20 (0.21)	-	-
P. longipes	0.67 (0.09)	-	-	-	-	-	0.70 (0.19)	0.95 (0.16)	0.65 (0.21)	1.50 (0.38)	1.80 (0.28)	-
B. asiatica	-	-	-	-	-	-	-	-	1.10 (0.14)	1.15 (0.19)	0.90 (0.11)	-
I. cylindrica	1.48 (0.16)	7.20 (0.05)	1.55 (0.51)	-	-	-	-	-	-	-	-	2.90 (0.28)
Woody litter	25.67 (2.37)	14.46 (2.10)	10.40 (0.94)	20.00 (1.78)	20.50 (1.96)	1.90 (0.26)	5.20 (0.63)	15.85 (1.65)	5.55 (0.66)	-	-	6.80 (1.01)
Reproductive parts	3.47 (0.60)	4.00 (0.46)	4.35 (0.61)	6.75 (0.83)	20.90 (2.86)	8.90 (0.75)	6.80 (0.86)	10.00 (1.21)	6.90 (1.32)	-	8.60 (1.11)	5.80 (0.61)
Miscellaneous	4.00 (0.21)	48.20 (3.61)	50.10 (1.94)	93.10 (4.29)	36.20 (1.73)	57.10 (1.76)	36.10 (1.87)	16.70 (0.92)	52.90 (3.12)	41.80 (1.33)	28.00 (0.43)	26.10 (0.96)
Total	147.07	147.41	142.15	145.45	103.05	97.20	75.50	77.15	84.70	78.65	87.10	96.80

Table 4.23. Monthly variation in litter dry weight (g/m^2) in the old stand at Shillong during 1988 (values in parentheses are ± S.D., n = 10)

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Leaf litter:												
P. kesiya	83.70 (0.97)	62.40 (1.09)	65.50 (1.05)	61.60 (0.76)	59.70 (1.15)	57.90 (1.29)	56.10 (1.30)	23.90 (0.99)	19.50 (0.54)	29.30 (0.51)	40.90 (0.52)	45.30 (0.83)
A. nepalensis	8.00 (0.91)	6.30 (0.64)	6.80 (0.92)	7.00 (0.58)	9.60 (1.14)	8.10 (1.14)	7.30 (0.17)	10.70 (1.33)	7.60 (1.23)	5.00 (0.67)	3.60 (0.61)	3.10 (0.57)
M. esculenta	0.50 (0.11)	0.50 (0.11)	0.90 (0.15)	0.70 (0.11)	-	-	-	-	0.30 (0.07)	1.80 (0.32)	1.90 (0.31)	1.40 (0.30)
L. ovalifolia	1.10 (0.19)	1.30 (0.18)	0.50 (0.16)	1.10 (0.25)	-	-	-	-	-	-	0.70 (0.15)	1.20 (0.29)
E. latifolia	0.20 (0.06)	-	-	-	-	-	-	-	-	-	-	-
R. javanica	-	-	-	-	-	-	-	-	0.80 (0.18)	-	-	-
P. longipes	0.80 (0.13)	-	-	-	-	-	2.30 (0.43)	1.30 (0.30)	1.20 (0.16)	2.10 (0.30)	1.80 (0.28)	-
B. asiatica	-	-	-	-	-	-	-	-	-	0.50 (0.11)	-	-
I. cylindrica	2.30 (0.09)	1.50 (0.07)	1.20 (0.10)	-	-	-	-	-	-	-	-	2.40 (0.23)
Woody litter	8.40 (0.85)	10.80 (0.84)	5.50 (0.61)	3.40 (0.51)	7.20 (0.75)	2.80 (0.48)	4.30 (0.48)	7.80 (0.77)	3.50 (0.40)	-	2.40 (0.41)	4.50 (0.69)
Reproductive parts	3.80 (0.24)	7.10 (0.68)	7.70 (0.71)	10.90 (0.90)	10.10 (0.06)	6.80 (0.72)	10.30 (0.60)	8.90 (0.82)	1.40 (0.27)	-	4.00 (0.33)	8.60 (0.55)
Miscellaneous	34.30 (1.03)	56.60 (1.60)	50.30 (6.78)	59.00 (1.18)	35.50 (1.44)	17.20 (0.34)	9.30 (0.22)	15.00 (0.86)	50.00 (1.05)	50.20 (1.06)	29.80 (0.69)	32.00 (0.28)
Total	143.10	146.50	138.40	137.70	122.10	92.80	89.60	67.60	84.30	88.90	85.10	98.50

to rise from September onwards until March and then declined in the ensuing months. The woody litter broadly followed this trend in both the stands during two years of the study. Its values were, however, generally low in the young and high in the old stand. Higher amount of reproductive parts in litter was recorded during November-December at the young stand and during April and May in the old stand.

Mean standing crop of leaf litter was more in the winter season in all the four stands. At the lower altitude the values declined from winter to summer and were minimum in the rainy season. At the higher altitude the values of summer and winter seasons were almost equal, the minimum remained in the rainy season (Figure 4.4).

Standing crop of total litter varied significantly in different months in all the four stands (Tables 4.19, 4.25) and exhibited definite seasonal pattern. At Burnihat (Tables 4.14 - 4.17) in both the stands higher values were recorded during December-January, declined thereafter upto July. At the higher altitude two peaks, one in December and the other in April were seen in both the stands. After April standing crop decreased upto August.

Annual mean standing crop of litter of different categories given in Table 4.26 tended to increase from the

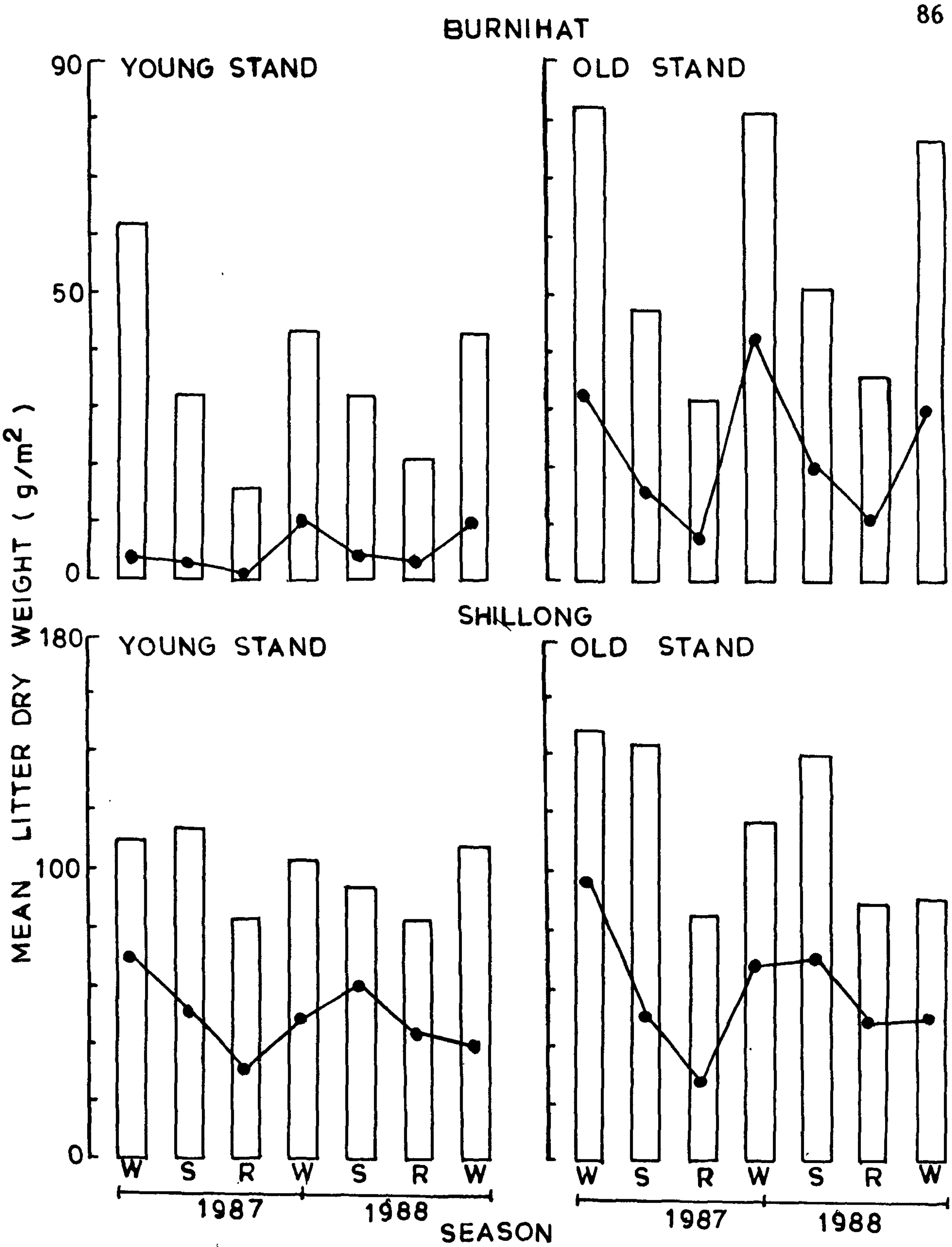

Figure 4.4. Mean standing crop of total litter (bar) and leaf litter (line) during three seasons (W=winter, S=summer, R=rainy) in the young and old forest stands at Burnihat and Shillong.

Table 4.19. Analysis of variance of standing crop of total litter in the young and old forest stands at Burnihat during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	1099.97	6.54*	173.06	0.52^{NS}
Month	11	4026.73	23.96*	10755.40	32.21*
Year x Month	11	715.66	4.26*	318.42	0.95^{NS}
Error	216	168.09	0	333.64	0
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

Table 4.25. Analysis of variance of standing crop of total litter in the young and old stands at Shillong during 1987-88

Source of variation	df	Young stand		Old stand	
		MSS	F ratio	MSS	F ratio
Year	1	408.50	0.16^{NS}	196.25	0.39^{NS}
Month	11	3261.66	1.29^{NS}	18295.30	38.37*
Year x Month	11	9234.52	3.65*	357.91	0.73^{NS}
Error	216	2532.14	-	493.19	-
Total	239	-	-	-	-

* = Significant at $P < 0.05$

NS = Not significant

Table 4.26. Mean annual dry weight of different categories of litter (g/m^2 ± S.D., n = 12) in the young and old forest stands at Burnihat and Shillong.

		Burnihat		Shillong	
Year	Litter category	Young stand	Old stand	Young stand	Old stand
1987					
	Leaf	3.77 ± 4.80	17.06 ± 12.16	42.09 ± 18.55	48.26 ± 29.07
	Wood	5.51 ± 4.11	4.36 ± 3.41	3.61 ± 2.09	10.53 ± 8.66
	Reproductive parts	-	-	0.84 ± 1.37	7.17 ± 4.87
	Miscellaneous	22.54 ± 16.76	29.54 ± 15.35	48.84 ± 12.57	41.33 ± 23.74
	Total	31.82 ± 19.32	50.96 ± 24.79	95.38 ± 18.14	106.85 ± 29.77
1988	Leaf	5.55 ± 4.37	23.81 ± 18.75	50.11 ± 14.88	60.10 ± 19.32
	Woody	2.69 ± 1.53	3.54 ± 1.23	3.33 ± 2.11	4.88 ± 3.20
	Reproductive parts	-	-	1.67 ± 1.69	6.63 ± 3.57
	Miscellaneous	22.05 ± 8.89	25.86 ± 14.43	39.04 ± 18.85	36.64 ± 16.76
	Total	30.29 ± 11.62	53.25 ± 21.41	94.09 ± 14.14	108.36 ± 28.34

- = Absent

young to old stand in both the forests. This trend is more clear in case of leaf litter than other fractions. Year to year variation in the mean standing crop was insignificant but it varied significantly between the two forest types.

Litter disappearance and turnover

Annual input, accumulation and disappearance of different categories of litter in all the four stands for the year 1987 and 1988 are given in Tables 4.27 and 4.28, respectively. Input of litter increased from the young to old stand at both the altitudes and the values were generally higher in the subtropical wet hill forest than the moist deciduous forest at Burnihat. The annual disappearance calculated as input (initial standing crop + annual production) minus final standing crop, indicates higher disappearance from the old stand at both the sites. All the four categories of litter followed the same trend.

The annual fractional weight loss (k) of different types of litter is given in Table 4.29. For leaf litter the values ranged between 5.2 and 9.5 at Burnihat and 2.6 and 3.3 at Shillong. Turnover rate of total litter varied between 4.1 and 2.8 at Burnihat and 2 and 3 at Shillong.

In general, turnover of leaf litter decreased while

Table 4.27. Annual balance-sheet of litter input, accumulation and disappearance in the young and old forest stands at Burnihat and Shillong during 1987

	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Initial litter standing crop (Jan '87) (g/m^2)				
Leaf litter	15.35	34.20	32.19	58.10
Woody litter	3.40	6.60	6.20	6.80
Reproductive parts	-	-	3.50	5.80
Miscellaneous	39.50	44.90	58.40	26.10
Total	58.25	85.70	100.29	96.18
Litter production ($g/m^2/yr$)				
Leaf	41.25	127.10	141.20	197.80
Woody	7.15	14.90	10.50	15.50
Reproductive parts	-	-	2.60	37.80
Miscellaneous	46.45	62.15	60.00	74.65
Total	94.85	204.15	214.30	325.75
Total litter input ($g/m^2/yr$)				
Leaf	59.56	161.30	173.39	255.9
Woody	10.55	21.50	16.70	22.30
Reproductive parts	-	-	22.90	85.40
Miscellaneous	85.95	107.05	118.40	100.55
Total	156.06	289.85	314.59	422.55

Table 4.27 (Contd.)

	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Litter at the end (Dec. '87) g/m^2				
Leaf	9.6	31.3	43.0	53.4
Woody	1.6	4.1	3.6	4.5
Reproductive parts	-	-	5.5	8.6
Miscellaneous	42.8	41.5	62.0	32.0
Total	54.0	76.9	114.1	98.5
Litter disappearance (g/m^2/yr)				
Leaf	49.96	130.0	130.39	202.50
Woody	8.95	17.4	13.10	17.80
Reproductive parts	-	-	17.4	76.80
Miscellaneous	43.15	65.55	56.40	68.75
Total	102.06	212.95	217.29	365.85

Table 4.28. Annual balance-sheet of litter input, accumulation and disappearance in the young and old stands at Burnihat and Shillong during 1988

	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Initial litter standing crop (Jan '87) (g/m^2)				
Leaf	8.56	36.00	71.19	113.95
Woody	4.20	8.67	3.45	25.67
Reproductive parts	-	-	0.03	3.47
Miscellaneous	51.9	42.80	36.50	4.00
Total	64.66	87.47	111.17	147.07
Litter production ($g/m^2/yr$)				
Leaf	38.14	132.58	140.95	124.84
Woody	3.20	6.32	6.92	24.37
Reproductive parts	-	-	2.30	26.75
Total litter input ($g/m^2/yr$)				
Leaf	46.70	168.58	212.14	238.79
Woody	7.40	14.99	10.37	50.04
Reproductive parts	-	-	2.33	30.22
Miscellaneous	103.05	113.95	80.55	75.22
Total	157.15	297.52	305.39	394.25

Table 4.28 (Contd.)

	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
Litter at the end (Dec '88) (g/m^2)				
Leaf	15.35	34.2	32.19	58.1
Woody	3.4	6.6	6.20	6.8
Reproductive parts	-	-	3.5	5.8
Miscellaneous	39.5	44.9	58.4	26.1
Total	58.25	85.7	100.29	96.8
Litter disappearance (g/m^2/yr)				
Leaf	31.35	134.38	179.95	180.69
Woody	4.00	8.39	4.17	43.24
Reproductive parts	-	-	1.17	24.42
Miscellaneous	63.55	69.05	22.15	49.12
Total	98.90	211.62	205.10	297.45

Table 4.29. Turnover coefficient (k) for different categories of litter in the young and old forest stands at Burnihat and Shillong during 1987-1988

Year	Litter category	Burnihat		Shillong	
		Young stand	Old stand	Young stand	Old stand
1987					
	Leaf	9.50	7.82	3.36	2.60
	Woody	0.50	1.50	2.33	2.18
	Reproductive parts	-	-	2.00	3.85
	Miscellaneous	2.21	2.37	0.92	1.73
	Total	2.87	4.11	2.05	2.31
1988					
	Leaf	6.83	5.29	2.82	3.30
	Woody	2.23	3.75	3.33	3.20
	Reproductive parts	-	-	1.50	6.33
	Miscellaneous	2.09	2.38	1.46	2.00
	Total	3.03	3.85	2.28	3.02

that of the total litter increased during forest regrowth at the two sites.

DISCUSSION

Litterfall, litter standing crop and disappearance data presented in the preceding pages for the moist deciduous and montane forests clearly indicates the effects of stand age, composition, phenology and climate on the above ecosystem characteristics. Seasonality in the litterfall is a characteristic feature of tropical and subtropical forests (Nye 1961, Laudelout and Meyer 1954, Klinge and Rodrigues 1968, Lam and Dudgeon Cousens 1988). And the role of climate on annual litter production in different forest types has been emphasized by several workers (Bray and Gorham 1964, Meentemeyer 1984). The leaffall in the moist deciduous forest at Burnihat occurred mainly during the period of relative drought which extended from November to February (Figure 4.1). This part of the year is characterized by low rainfall and low temperature (Figure 2.2). A minor variation in litterfall pattern observed in the two stands seems to be related to the differences in the species composition, their habit and phenological behaviour. Since in the young stand there were abundant herbaceous species, a significant amount of litterfall was also observed during the post-rainy season when most of the annuals were dead after completing their life cycles.

In the wet hill forest at upper altitude the overall seasonality in the leaf litterfall is similar to that of moist deciduous forest at Burnihat. The area receives much higher rainfall spreading over for about 5-6 months due to its special topography and has a relatively prolonged severe dry winter, with temperature generally touching the freezing point. This difference in climate at Shillong is manifested by litterfall pattern in the forest of the area. Here the period of relative drought (December-February) corresponds to the peak period of litterfall. Since the young stand is solely composed of pine and the old one represents a mixed coniferous stand, the period of peak litterfall in both the stands was extended upto April owing to the maximum needle fall during March-April. Several other investigators working in a variety of tropical forest types, both in India and abroad, have reported maximum leaffall during the driest part of the year (Madge 1965, Hopkins 1966, Singh 1969, Gordon 1974). This is true for the present forests also. However, a slightly extended period of litter-fall of about five months during dry winter in the montane forest is attributed to the phenological behaviour of the tree species, particularly *P. kesiya*.

The effect of age on leaf as well as total litter production is visibly clear in both the forests, indicating increase in litterfall during forest regrowth after disturbance at least upto 20 years of age. This increase from the young to old stand was, however, more (68%) in deciduous forest than in the montane forest (59%). This trend is closely related to the increase in species richness as described in chapter 3 of the thesis. Cooper (1981) while studying production during succession in Populus grandidentata stand on poor sites in Northern lower Michigan has reported that litterfall closely parallels with development of the canopy and during first 25 years annual litterfall increased to about 200 g/m^2. Our findings in these forest stands show an increase of 113 g/m^2 in moist deciduous and 24 g/m^2 in wet hill forest. Besides species richness, litterfall was also related to stand density and basal area. Both these community measures were directly related to stand age and litter production in the two forest types. A comparison between the forests at Burnihat and Shillong also reveals a positive relationship between litterfall and density and basal cover except in the old stand, where although density declined but litter production increased. Bray and Gorham (1964), Van Cleve and Noonan (1975), Turnbull (1983) and Prasad and Mishra (1985) have reported a positive relationship of litter production with density and basal cover. A slight variation was observed in the montane forest where density declined from the young to old stand but litter production showed about 40% increase mainly because of the abundance of young pine trees in the former stand. So far as the negative trend between litterfall and basal cover in the old stand of the two forest types is concerned, it is attributed to the abundance of low diameter trees in the old stand at Shillong which did not increase the basal cover significantly but contributed to higher litter production.

Annual litter production although increased during forest regrowth at both the elevations, the values are very low compared to other tropical and subtropical forests of the world (Table 4.30). Obviously this is related to the lower age and low density of the stands. The percentage contributions of different categories of litter to total production are, however, comparable to those reported for other forests of the tropics. The percentage of woody litter is however, low which may be due to the abundance of saplings and young trees in the stand (Christensen 1975). Ratio of wood to litter production ranged between 0.03 - 0.09 in the present study. These values are lower than many other workers (Jordan, 1971). This is again related to the stand age.

The annual litter production in the two forest types is related to rainfall and mean maximum temperature of the

Table 4.30. Total annual litter production and percentage contribution of different fractions in some tropical and subtropical forests of the world

Forest type	Altitude (m)	Age (yr)	Leaves (%)	Wood (%)	Flower/ Fruit (%)	Total (t/ha)	Author(s)
Semi evergreen young secondary forest, Ghana	150	40	66.67	33.33	-	10.5	Nye, 1961
Coniferous sub-alpine forest, Japan	1790	290	61.94	27.57	1.8	3.42	Kitazawa Y, 1974
Natural forest, Japan	720	120-443	49.55	36.91	-	0.89	Takashi Ando, *et al*., 1970
Equatorial forests Ivory coast	50	mature	69.06	21.75	9.19	11.86	Lemee G, (See Reichle 1981)
Equatorial forest, Ivory coast	70	"	74.09	14.98	10.93	9.61	Lemee G, (See Reichle 1981)
Tropical dry deciduous forest, India	350	66	83.46	-	-	6.78	Bandhu D, 1973
Tropical moist deciduous forest, India (Shillong)	296	50	76.78	22.8	-	5.5	Singh, 1980
Crop forest, Jamaica	1556	-	85.93	14.06	-	6.4	Tanner, 1980
Morridge forest, Jamaica	-do-	-	74.24	25.75	-	6.6	-do-

Table 4.30 (Contd.)

Forest type	Altitude (m)	Age (yr)	Leaves (%)	Wood (%)	Flower/ Fruit (%)	Total (t/ha)	Author(s)
Mull ridge forest, Jamaica	1556	-	90.55	3.45	-	5.8	Tanner, 1980
Wet slope forest, Jamaica	-do-	-	78.57	21.42	-	5.6	-do-
Montane forest, Shillong, India	1900	mature	63.28	27.9	8.7	8.96	Boojh, 1981
Tropical moist deciduous forest, Shillong, India							
Young	100	5	42.36	5.50	-	0.94	Present study
Old	-do-	15-20	62.68	5.15	-	2.07	-do-
Montane forest, Shillong, India							
Young	1500	5	69.23	4.23	1.19	2.04	-do-
Old	-do-	15-20	55.62	7.31	11.23	2.86	-do-

area. With the rainfall, litter production showed direct relation while with the mean maximum temperature it depicted a reverse trend. A positive relationship between annual litterfall and the rainfall is a established fact (Turnbull 1983, Meentemeyer 1984), which also holds good for the present study. But an inverse relationship with mean maximum temperature may be due to topographical difference between the two sites which is responsible for the high summer rainfall and low winter temperature.

The litter standing crop represents the balance between input by litterfall and output by decomposition. Since the climate of study area shows distinct seasonal cycle, litter production as well as decomposition closely follow a seasonal pattern. The net result of these two processes is clearly evident from the litter standing crop values. Winter season being favourable for litterfall and unfavourable for decomposition activity due to low temperature and soil moisture, showed higher litter on the forest floor. Reverse was true for the rainy season when the rate of litterfall was low and microbial activity was high due to favourable moisture and temperature conditions (Sharma 1981). This is further explained by the trends shown by observed and expected values of litter mass on the forest floor (Figures 4.5 to 4.8). The difference between expected

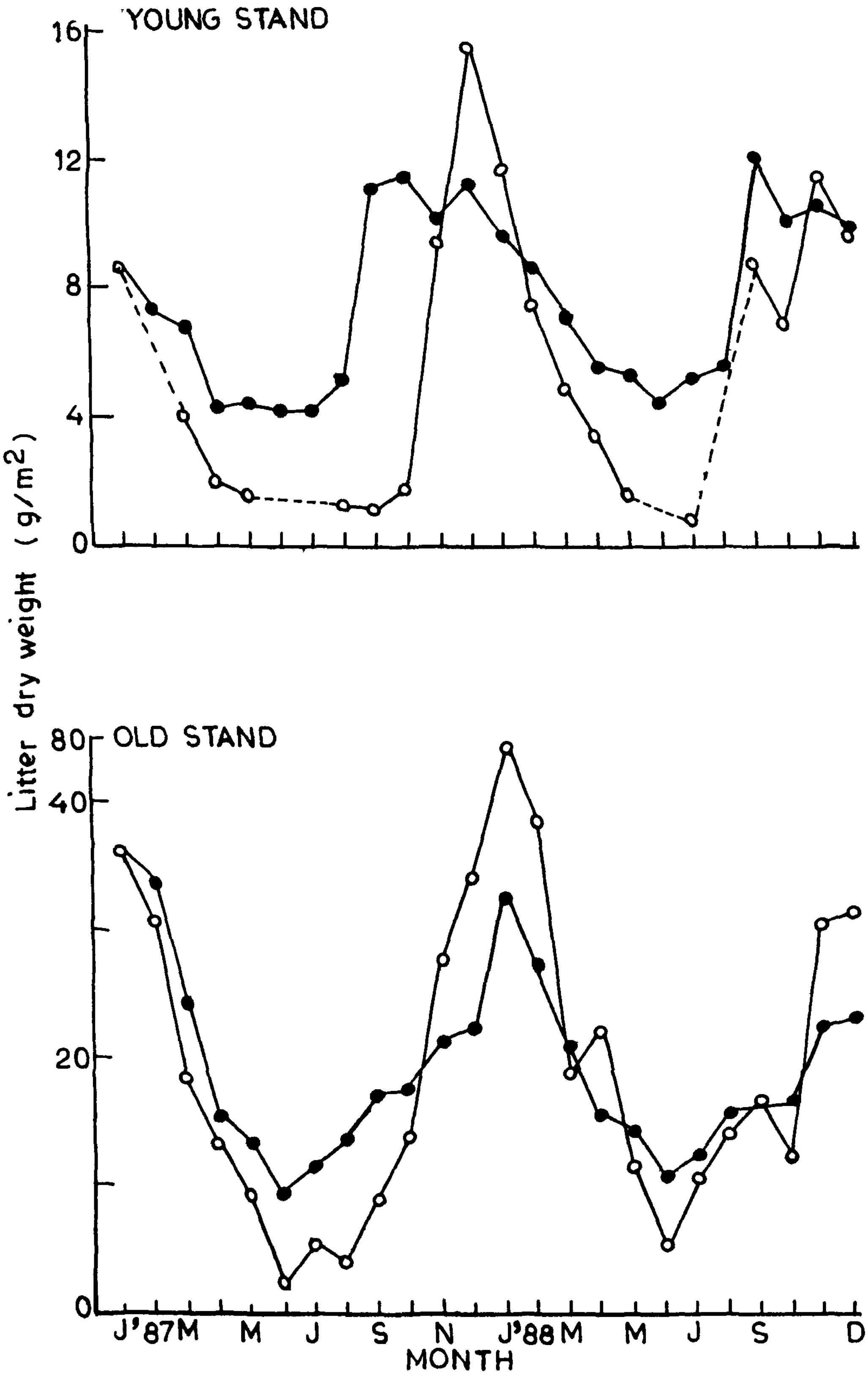

Figure 4.5. Monthly variation in standing crop of observed leaf litter (O) and the expected values (●) at Burnihat. The expected values have been computed according to Swift et al. (1981).

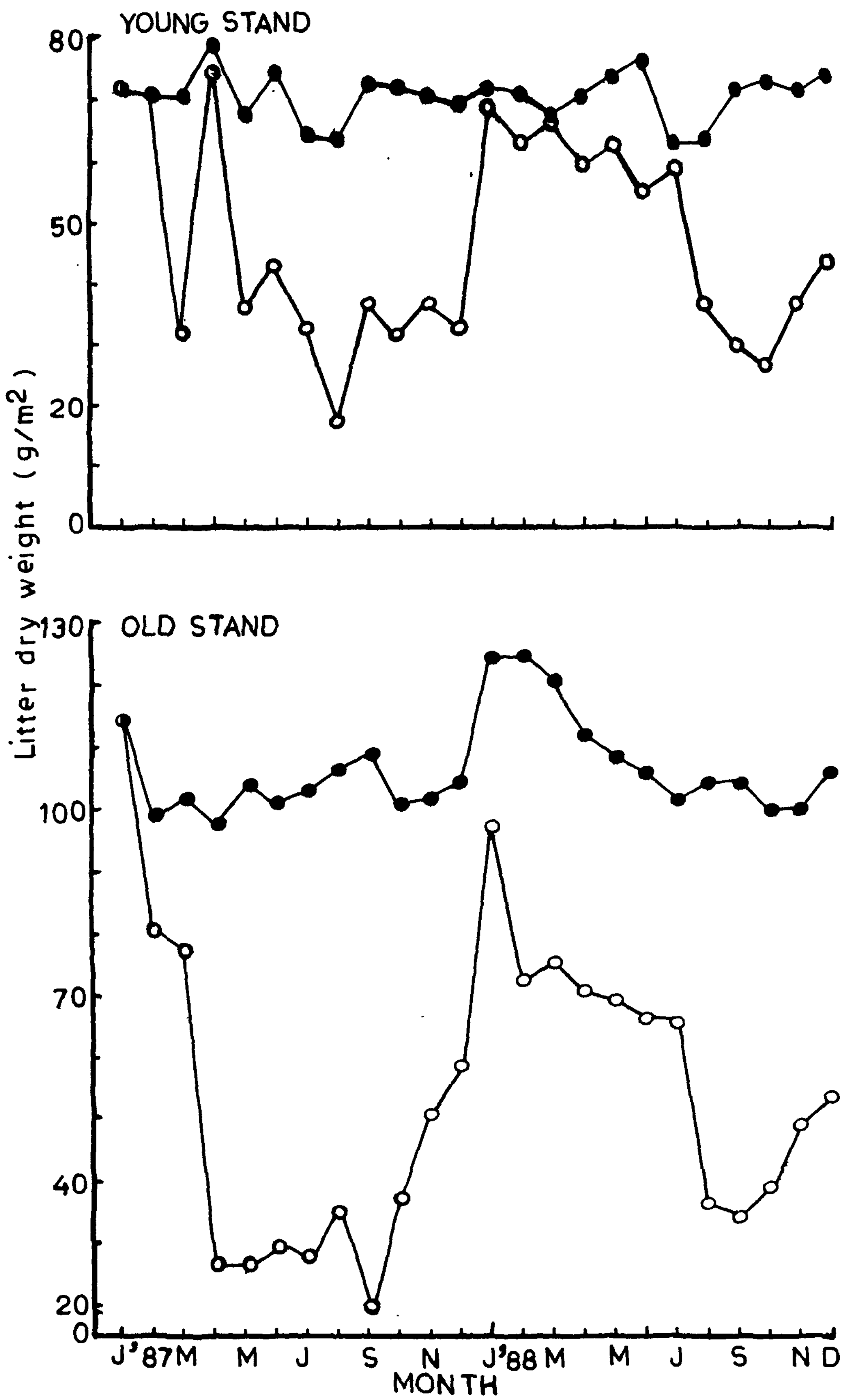

Figure 4.6. Monthly variation in standing crop of observed leaf litter (O) and the expected values (●) at Shillong. The expected values have been computed according to Swift <u>et</u> <u>al</u>. (1981).

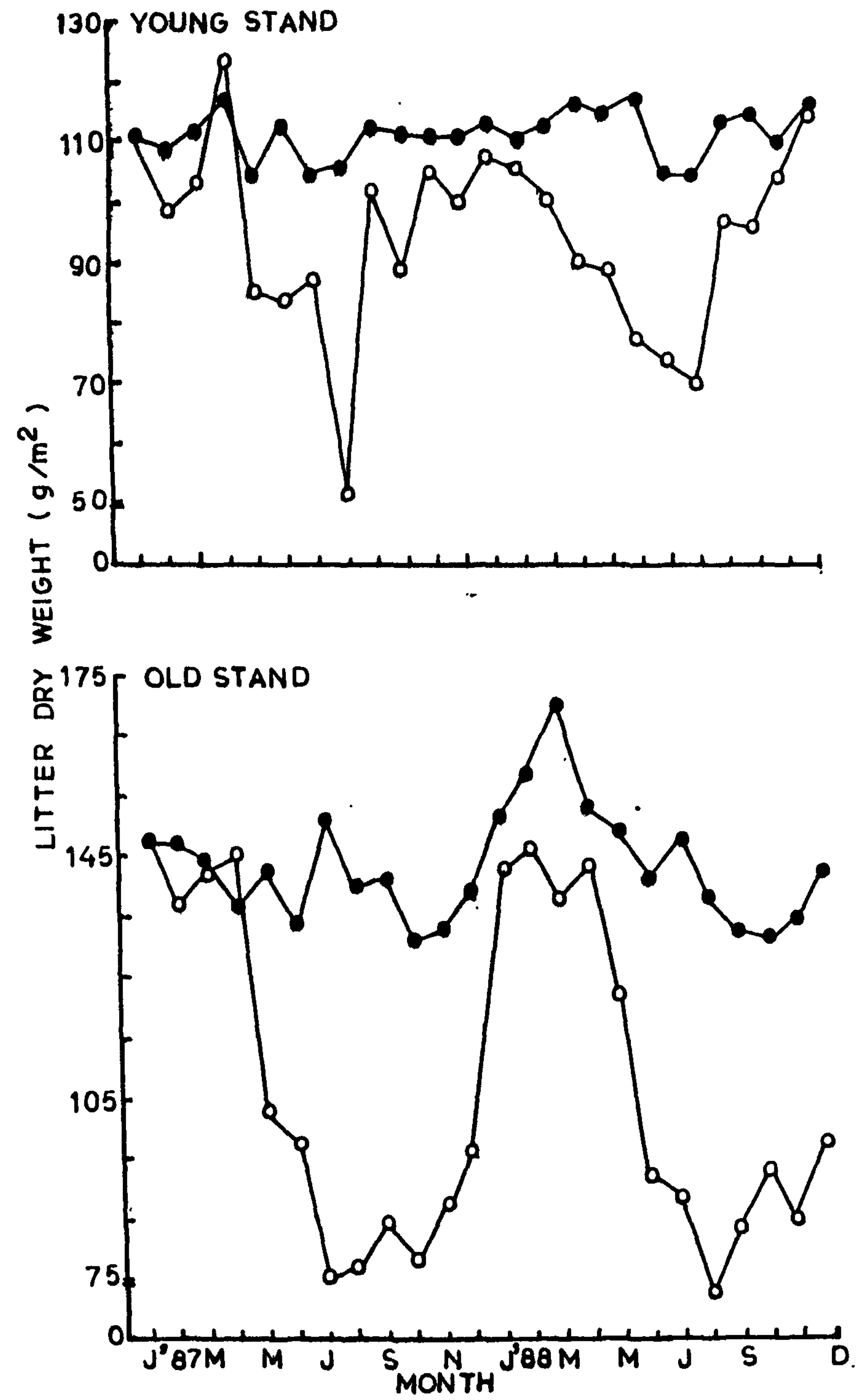

Figure 4.7. Monthly variation in standing crop of observed total litter (O) and the expected values (●) at Burnihat. The expected values have been computed according to Swift et al. (1981).

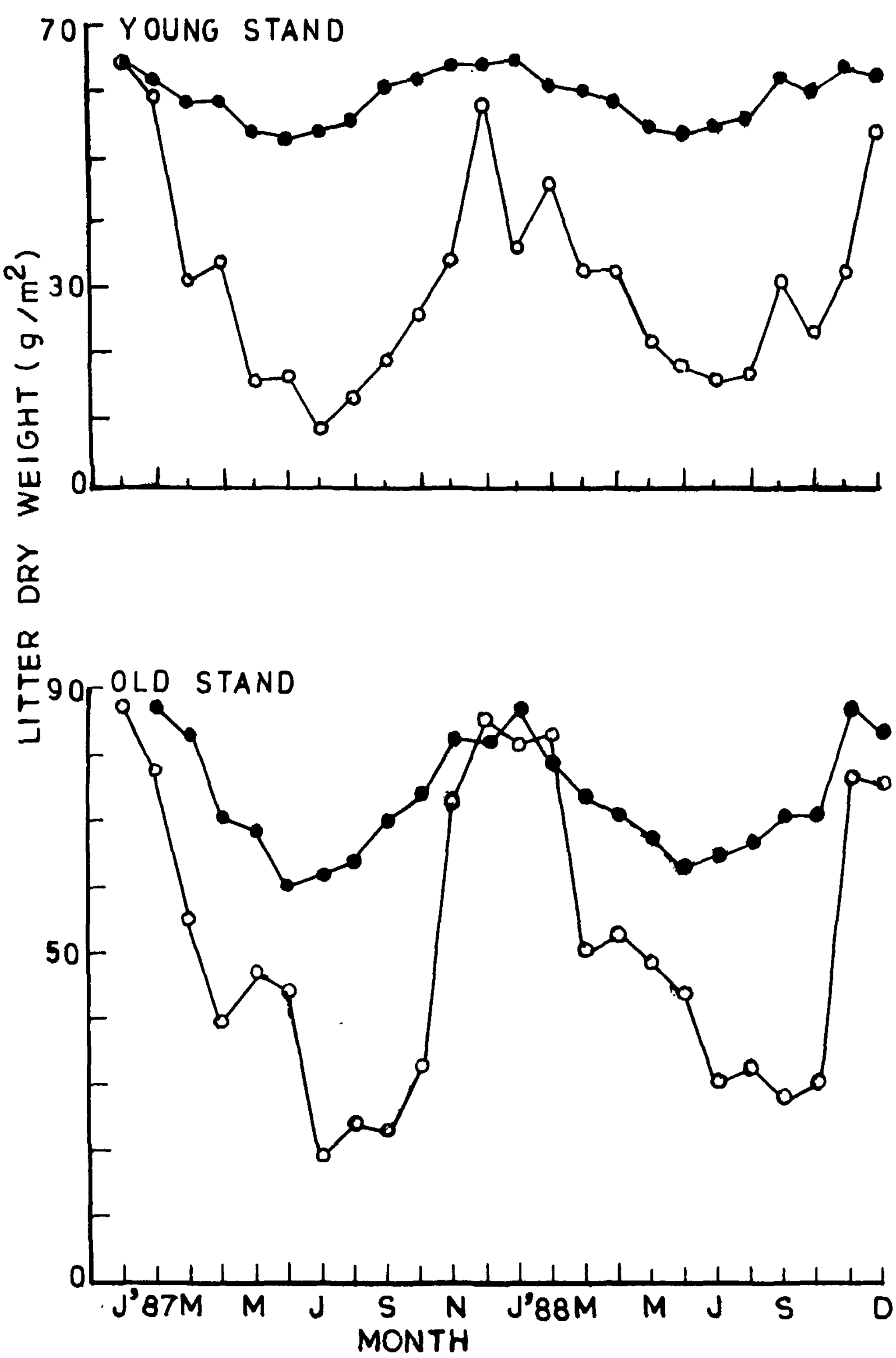

Figure 4.8. Monthly variation in standing crop of observed total litter (O) and the expected values (●) at Shillong. The expected values have been computed according to Swift *et al*. (1981).

and observed values shows net result of litterfall and decay; higher the difference lower the accumulation. Maximum difference during June-July indicated higher disappearance and low accumulation while the minimum difference during November-January shows the period of higher accumulation. Since all the stands are located on the hill slope, the possibility of litter loss with runoff cannot be ruled out. A critical examination of Figures 4.5 - 4.8 also indicates higher annual disappearance from wet hill forest than moist deciduous forest. The annual mean standing crop although showed an increasing tendency, it did not differ significantly from the young to old stand possibly due to overriding effect of climate over age. An increasing tendency in litter accumulation in secondary successional communities has also been observed by Pandey *et al*. (1980). Conversely, in the temperate climate Cooper (1981) has reported rapid litter accumulation during 25 years of succession in aspen forest at Michigan. The values of decay constant of different fractions of litter are within the range reported (0.7 - 6) for the tropical forests, indicating rapid breakdown of litter in these forests compared to their temperate counterparts (Swift *et al*. 1981). The other reasons for rapid litter turnover may be the favourable microclimate on the forest floor such as temperature, aeration and diurnal wetting and drying cycles due to incomplete canopy development in these stands. The role of microclimatic factors on litter decomposition and nutrient cycling has been emphasized by Lindsay and Monk (1981) in a regenerating Appalachian forest. The difference in decay constant (k) in the two forest types may be attributed to the variation in climatic conditions and quality of litter (Williams and Gray 1974). Exceptionally higher turnover of the litter in young stand at Burnihat may be attributed to the high proportion of herbaceous litter which tends to decompose more rapid (Jensen 1973) than tree litter. This aspect has been dealt with in the ensuing chapter.

CHAPTER 5

LITTER DECOMPOSITION, NUTRIENT INPUT AND RELEASE

INTRODUCTION

Nutrient input and release strongly influence the processes in the biogeochemical cycle of the forest ecosystem (DeCatanzaro and Kimmins. 1985). Basically, forest ecosystems are nutrient accumulating system in which elements combine in a variety of organic and inorganic compounds through its different components. Among the nutrient pools, litter plays an important role in regulating the structure and function of forest ecosystem in a variety of ways. Therefore, considerable emphasis has been given on the studies related to litter production and its decomposition in different parts of the world (Witkamp and Ausmus 1976). The large volume of information on this aspect has been reviewed by Ovington (1962), Olson (1963), Rodin and Bazilevich (1967), Swift et al. (1979) and Singh and Singh (1987). These articles reveal that most of the work on this aspect has been done in the temperate forests. In the tropical forests nutrient content of litterfall was determined by Laudelout and Meyer (1954), Nye (1961), Hopkins (1966), Bernhard (1970), Egunjobi (1974), Hains (1977) and Lamb (1985). Litterfall and decomposition are important processes through which major amount of mineral elements is transferred to the soil in the forest ecosystem. Intensive studies on nutrient cycling incorporating these aspects have been carried out by Likens and Bormann (1972), Fogel and Cromai (1977), Meentemeyer (1978), Birk and Simpson (1980), Cooper (1982), Lindsay (1988) and Staaf (1988). In India similar studies are available from central Himalaya and dry deciduous forests (Mehra et al. 1985, Upadhyay 1988, Singh K.P. 1968, 1969). Litter decomposition studies in the tropical moist deciduous forest of Meghalaya has been carried out by Singh (1984). Some studies on element dynamics in terms of C: element ratio in decomposing litter have been done by Park (1976). Recently it has been recognised as an important factor that affect nutrient release (Swift et al. 1979, Staaf and Berg 1982) during decomposition.

Disruption of forest structure by natural or human disturbances alters ecosystem processes which regulate retention and cycling of elements. Besides interruption in elemental uptake by vegetation, other processes such as decomposition, nitrogen transformation and soil physico-chemical properties are changed as well (Likens et al. 1978, Witkamp, 1979). These aspects have been emphasized in relation to succession (Odum 1969).

The data presented in this chapter describes the seasonal and annual variation in input, accumulation and release of N, P, K through litter in successional stands of tropical moist deciduous and subtropical wet hill forest after their disruption for shifting cultivation in the area. Experiments have also been conducted using litter bag technique to study the dry weight loss, changes in chemical composition and nutrient release pattern during decomposition of different categories of litter.

METHODS

Litter decomposition

The rate of litter decomposition and release of nutrients was studied by litter bag technique (Shanks and Olson 1961). The fresh litter was collected in February and leaf of the dominant and co-dominant species was sorted out. All the woody litter was kept together and remainder in the miscellaneous category. These were air dried for about 2 weeks in the laboratory. Depending upon the total amount of litter (g/m^2) present on the forest floor at the time of first sampling, 5 g litter samples were filled in the nylon bags of 6 x 12 cm size with 2 mm mesh size. Vatsauliya (1981) and Darlong (1984) have demonstrated that a mesh size of 2 mm was sufficient for the movement of mesofauna which are predominant in the litter layer of the secondary forest. Although, Arthropods and Annelids were also important litter feeders in the forests, but mesh size more than 2 mm was not selected, as bag with large mess size could not retain small pieces of litter. More than 36 bags for each category of litter were prepared and kept randomly on the forest floor in the month of February-March. Three bags of each category of litter were considered to determine oven dry weight before placing them on the forest floor. Monthly sampling was done for leaf & miscellaneous fractions and bimonthly samplings were done for woodylitter at Burnihat forest stands. At Shillong all the samplings were done at two months intervals. At each sampling time three bags of each category were brought to the laboratory carefully avoiding loss of material from litter bags. The extraneous matters over the litter were washed by tap water and dried at 60° C to a constant weight. Decay constant on dry weight basis was calculated following the formula given by Olson (1963).

$$\frac{dx}{x} = kdt$$

Where, dx = difference in weight

dt = time interval

x = initial weight

k = decay constant.

Chemical analysis of litter and soil

The dried and powdered samples were analysed for total carbon, nitrogen, phosphorus and potassium contents following the methods outlined by Allen (1974). Total carbon was determined by rapid titration method (Moore and Chapman 1986) using Barium Chloride and Barium Diphenylamine-Sulphate as indicators. Total nitrogen was determined by micro-Kjeldahl method using Copper Sulphate, Potassium Sulphate and Selenium Dioxide as catalyst. Mixed acid digestion method was followed for phosphorus and potassium analysis. Phosphorus was determined colorimetrically by Molybdenum blue method and potassium by flame photometer.

Nutrient input, accumulation and release

Monthly nutrient input through litterfall was computed using nutrient concentration and production values. Nutrient accumulation in litter was computed in similar fashion using standing crop and nutrient concentration values. ~~Nutrient accumulation in litter was computed in similar fashion using standing crop and nutrient concentration values~~. Rate of release of N, P, and K during decomposition was determined by weight loss and element concentration data of the samples obtained from litter bags.

Soil samples in five replicates were collected at bimonthly intervals from four depths 0-10, 10-20, 20-30 and 30-40 cm from each stand. The replicated samples from each depth were mixed together to give one composite sample after drying at 60° C. The samples were analysed for total nitrogen, available phosphorus and exchangeable potassium by the method given by Allen (1974). Nitrogen was determined by Kjeldahl method, phosphorus colorimetrically using molybdenum blue method and potassium was estimated by flame emission method after extracting exchangeable cations with 1 N Ammonium Acetate at pH 7.

RESULTS

Litter Decomposition

Weight loss

Decomposition rates of enclosed leaf litter of dominant and codominant species and other fractions are shown in Figures 5.1, 5.2, 5.3 and 5.4. The loss in weight occurred at a more rapid rates in the moist deciduous forest at Burnihat than the montane forest at Shillong. At Burnihat it took about 180 days for about 90-95% loss of leaf and miscellaneous materials from the litter bag. The woody litter, however, did not decompose completely even after 540 days of the setting of experiment in the field. At Shillong the decomposition was slow and all the four fractions of litter were retrieved from the bags even after 20 months.

The shape of weight loss curves for different types of litter did not differ markedly among themselves at Burnihat but at Shillong a sharp fall was noticed in case of

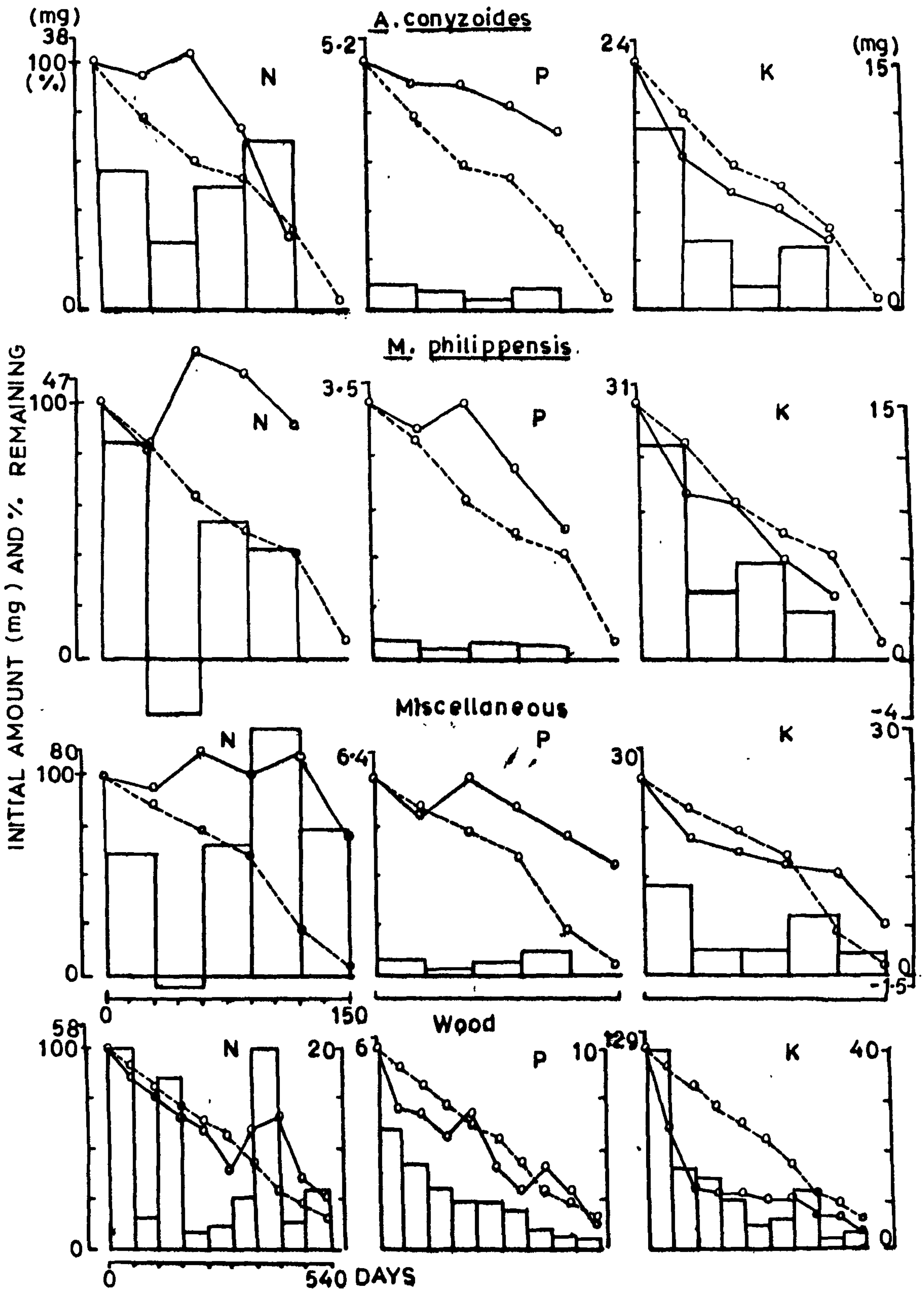

Figure 5.1. Changes in absolute amount of N, P, K (solid lines) and percent weight remaining (broken lines) of the litter mass enclosed in litter bags and placed in the young stand at Burnihat. The initial mass of nutrient is given on the top of left y-axis. The bars indicate the net change between the measurements (right y-axis).

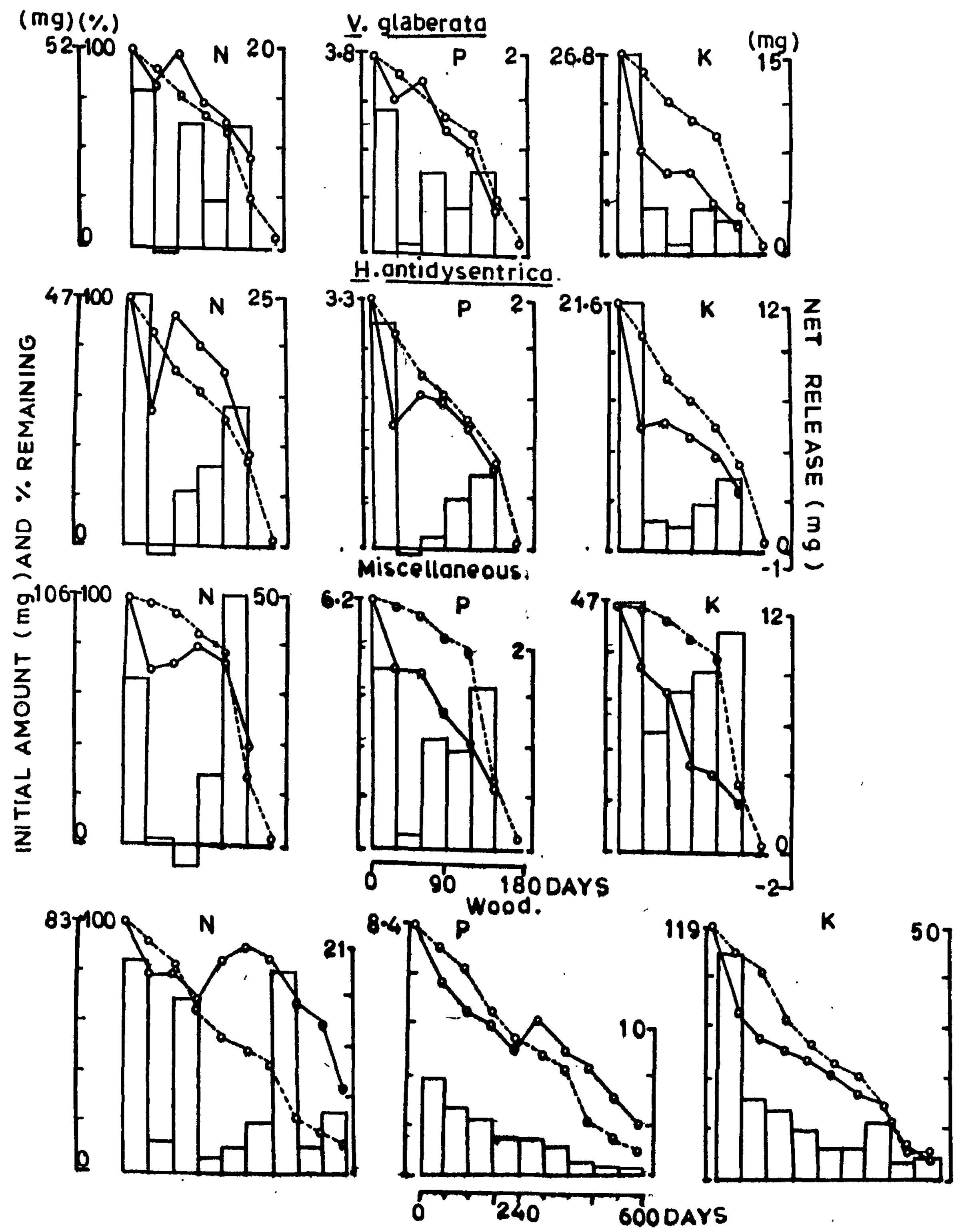

Figure 5.2. Changes in absolute amount of N, P, K (solid lines) and percent weight remaining (broken lines) of the litter mass enclosed in litter bags and placed in the old stand at Burnihat. The initial mass of nutrient is given on the top of left y-axis. The bars indicate the net change between the measurements (right y-axis).

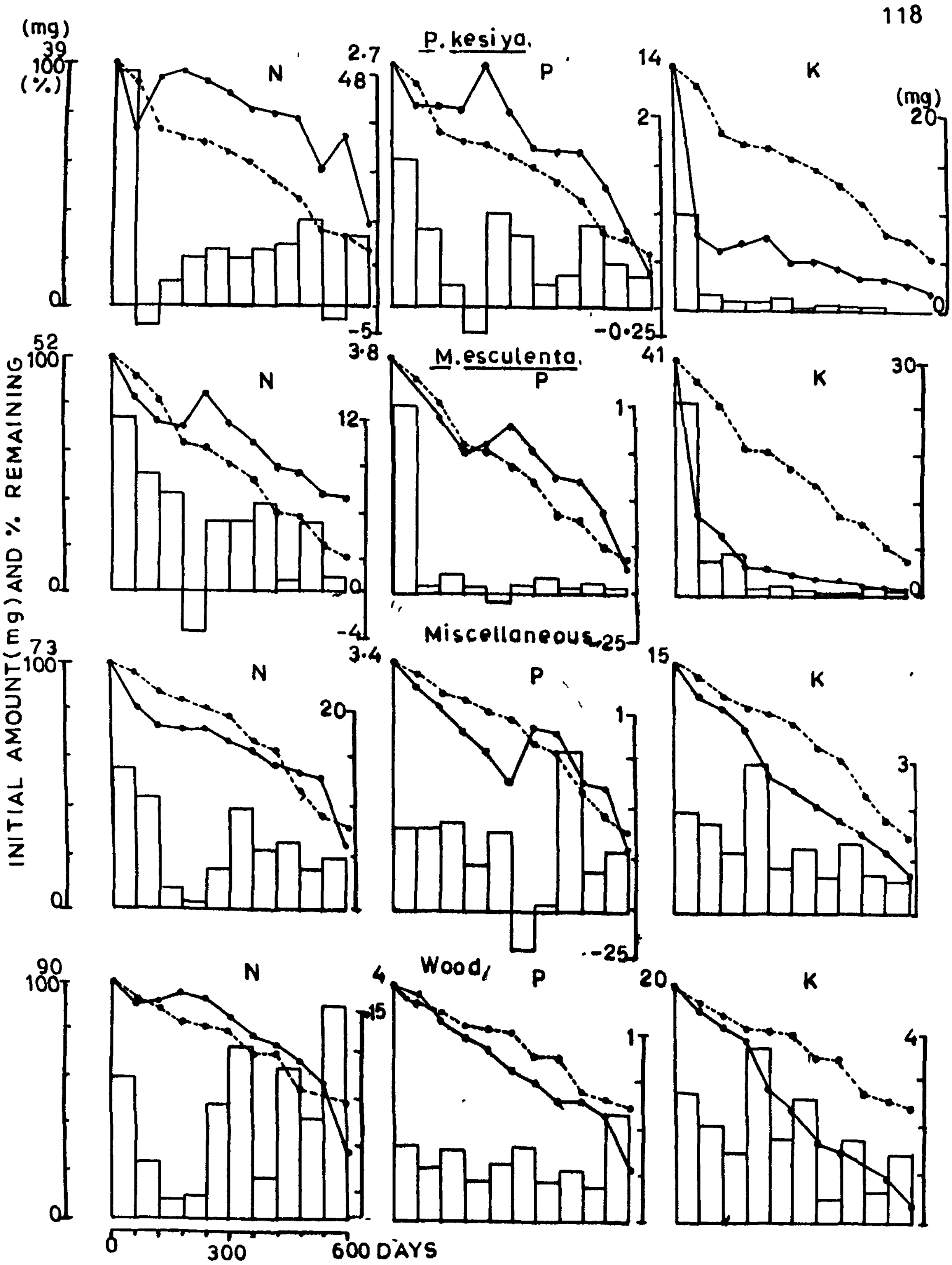

Figure 5.3. Changes in absolute amount of N, P, K (solid lines) and percent weight remaining (broken lines) of the litter mass enclosed in litter bags and placed in the young stand at Shillong. The initial mass of nutrient is given on the top of left y-axis. The bars indicate the net change between the measurements (right y-axis).

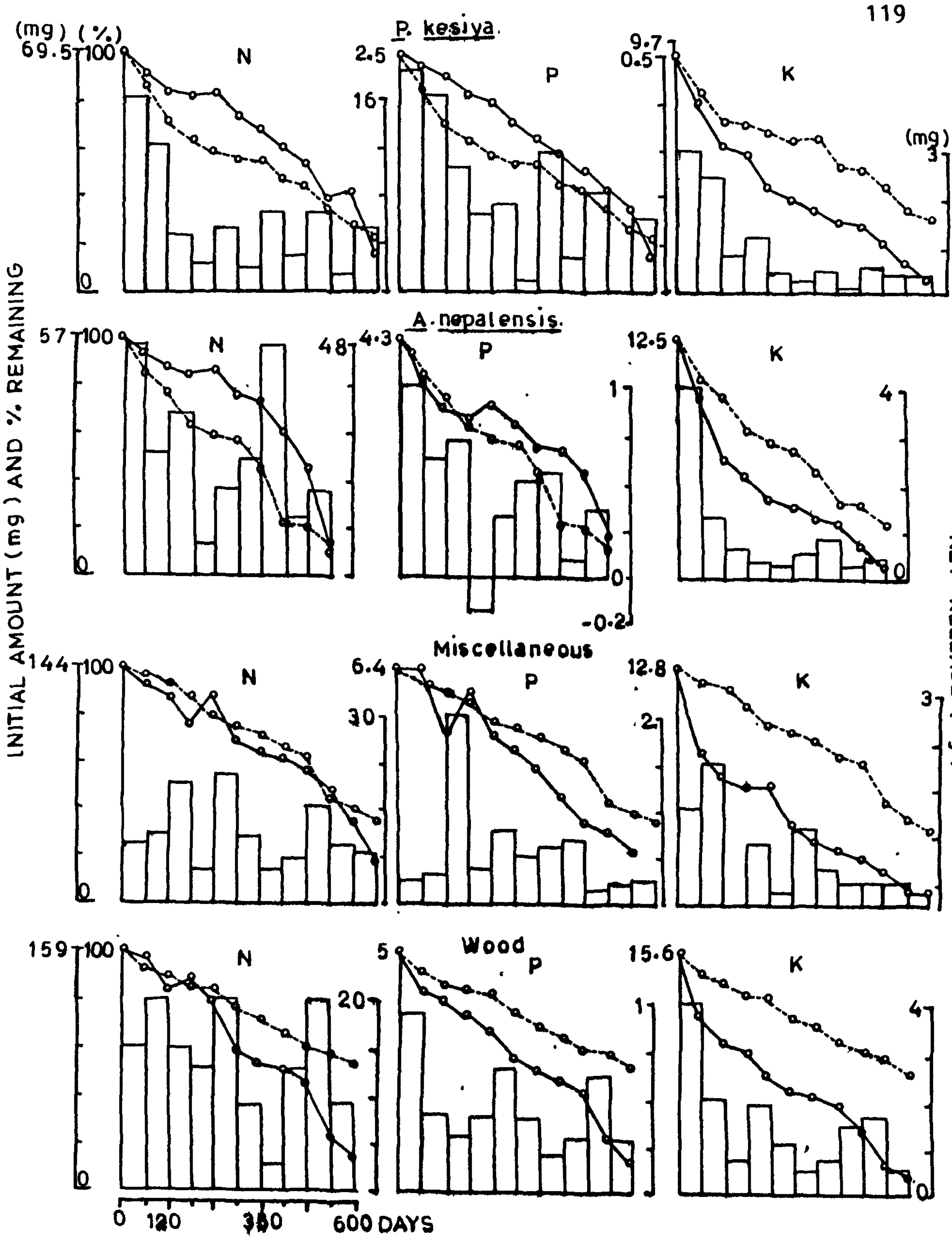

Figure 5.4. Changes in absolute amount of N, P, K (solid lines) and percent weight remaining (broken lines) of the litter mass enclosed in litter bags and placed in the old stand at Shillong. The initial mass of nutrient is given on the top of left y-axis. The bars indicate the net change between the measurements (right y-axis).

leaf litter of A. nepalensis and M. esculenta as compared to P. kesiya. The shapes of these curves further indicated that the age of the stand had little affect on litter loss in the two forest types.

Olson's decay constant (k) for different types of litter is given in Table 5.1. The values were generally higher in the moist deciduous forest at Burnihat than the montane forest at Shillong. The highest value (k = 2.6) was found for leaf litter of A. conizoides at Burnihat and the lowest (k = 0.46) for P. kesiya at Shillong. The values for angiospermic tree leaf litter were higher than pine needles. The k-value for woody litter was invariably the lowest. The decay constant for all the four types of litter declined from the young to old stand more markedly at Burnihat than at Shillong and the values were generally lower at the later site.

Nutrient release

Net release of N, P, and K from the enclosed litter during decomposition is shown by the bars in Figures 5.1, 5.2, 5.3, and 5.4. These figures show relatively higher amount of nutrient release during early stages of decomposition, irrespective of litter and forest types and stand age. The phase of rapid nutrient release was upto 60 days in the moist deciduous forest and 120 days in the montane

Table 5.1. Decay constant (k) and time required for the loss of one half of the original dry weight of different litter fractions in the young and old forest stands at Burnihat and Shillong

Stand	Litter categories	k	Half time (0.693/k)
Burnihat			
	Leaf		
Young stand	*A. conyzoides*	2.36	0.29
	M. philippensis	2.27	0.31
	Miscellaneous	2.35	0.29
	Woody	0.53	1.31
	Leaf		
Old stand	*V. glabrata*	1.76	0.39
	H. antidysentrica	1.96	0.35
	Miscellaneous	1.75	0.40
	Woody	0.58	1.19
Shillong			
	Leaf		
Young stand	*P. kesiya*	0.46	1.51
	M. esculenta	0.56	1.24
	Miscellaneous	0.42	1.65
	Woody	0.31	2.23
	Leaf		
Old stand	*P. kesiya*	0.46	1.51
	A. nepalensis	0.54	1.28
	Miscellaneous	0.34	2.04
	Woody	0.29	2.39

forest. After this phase of more rapid nutrient release, there was a distinct decline in the net release of N and P from the litter but K did not show any appreciable change with time. The weight loss was continued even after 60 days but the nitrogen content in remaining material showed an increase, thus yielded a negative value for the net release (Figures 5.1, 5.2, 5.3 and 5.4) in case of leaf litter of *M. philippensis*, *H. antidysentrica* ~~P. kesiya (young stand)~~, ~~M. esculenta~~ and miscellaneous litter at Burnihat. Similar situation at Shillong occurred after 120 days in leaf litter of *A. nepalensis*, *M. esculenta* and *P. kesiya* in the old stand.

Nutrient Input Through Litterfall

Nutrient concentrations in fresh litter - In tropical moist deciduous forest at Burnihat N concentration in leaf, woody and miscellaneous litter samples is shown in Figure 5.5. In the young stand the miscellaneous fraction generally showed higher concentration (1.4 - 2.7%) followed by leaf (1.2 - 2%) and woody (0.2 - 1.6%) litter. In the old stand leaf and miscellaneous fractions have almost similar values (1.4 - 2.1%) but the woody litter with slightly higher values (1.1 - 3.2%) showed wide seasonal variation.

In the young stand of montane forest (Figure 5.5) leaf (1.3 - 2.5%) and woody (1.7 - 3.6%) fractions did not

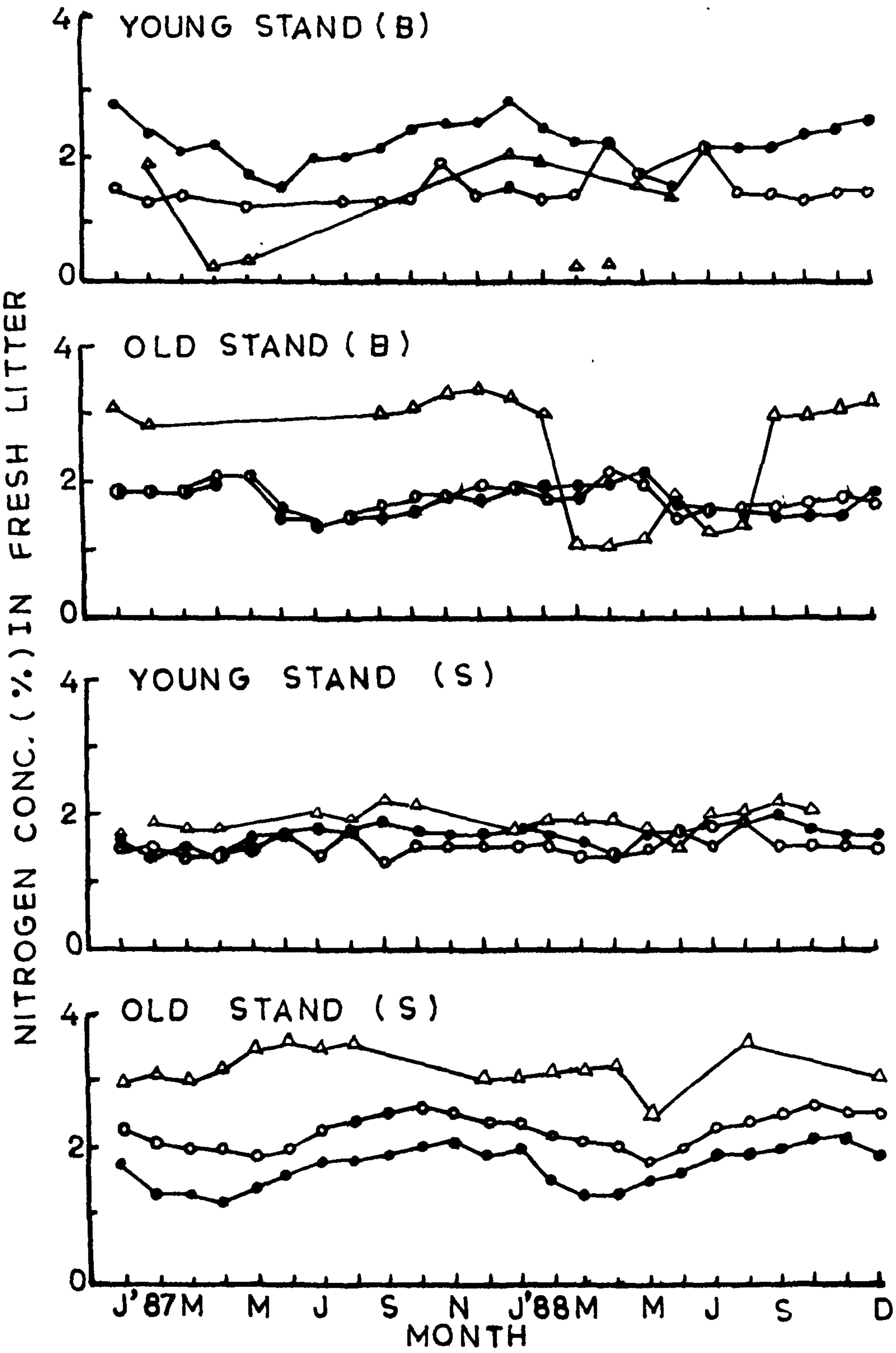

Figure 5.5. Variation in nitrogen concentration in fresh leaves 'O', woody 'Δ' and miscellaneous '●' litter samples collected at monthly intervals in the young and old *forest* stands at Burnihat (B) and Shillong (S).

differ much in N concentration but the difference was more clear in the old stand. The woody litter in the old stand showed higher values (2.5 - 3.6%) than the leaf and miscellaneous litter. Seasonality was indistinct in both the stands. Analysis of variance revealed significant ($P < 0.05$) effect of month on nitrogen concentration of woody litter only.

Phosphorus concentration (Figure 5.6) exhibited marked monthly and seasonal fluctuations. At Burnihat seasonality is more clearly seen than at Shillong. The values were generally low during summer and high during winter months in both the stands. In the wet hill forest similar seasonal trend was not evident and the values varied between 0.04 and 0.07% in different months. In this forest P concentration in the woody litter was minimum (0.04 - 0.05%) in the old stand. The leaf and miscellaneous litter depicted higher values (0.06 - 0.07). P concentration in woody and miscellaneous litter was significantly ($P < 0.05$) influenced by month.

Concentration of K in different types of litter is shown in Figure 5.7. At Burnihat, unlike P the value in the leaf and miscellaneous fractions did not show a marked seasonal variation, however, it was high in the leaf. The woody litter had the minimum (0.26 - 0.32%) concentration but an exceptionally high value (0.63%) was found in the month of June. At Shillong seasonality was more clear in the young

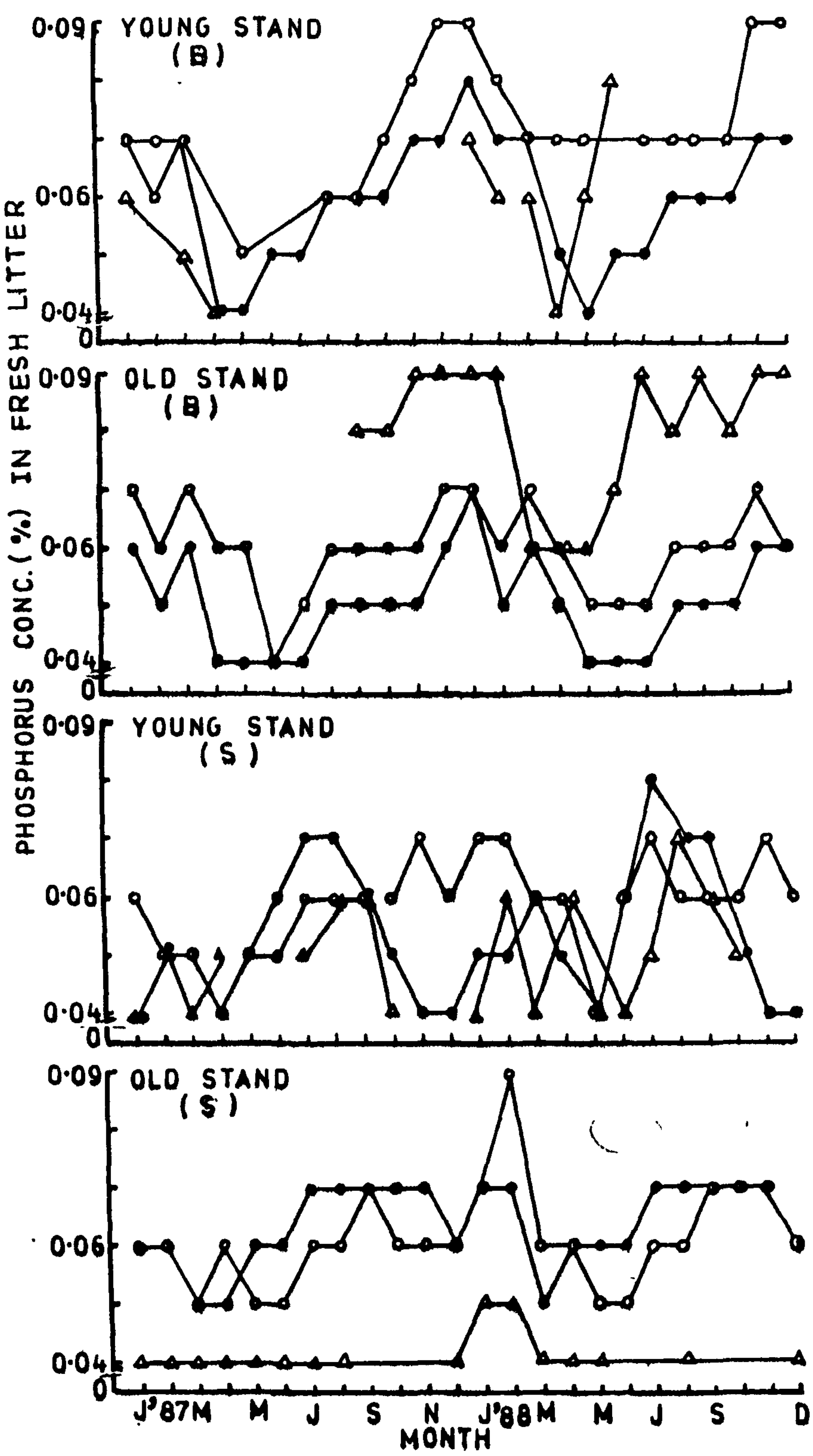

Figure 5.6. Variation in phosphorus concentration in fresh leaves 'O', woody 'Δ' and miscellaneous '●' litter samples collected at monthly intervals in the young and old forest stands at Burnihat (B) and Shillong (S).

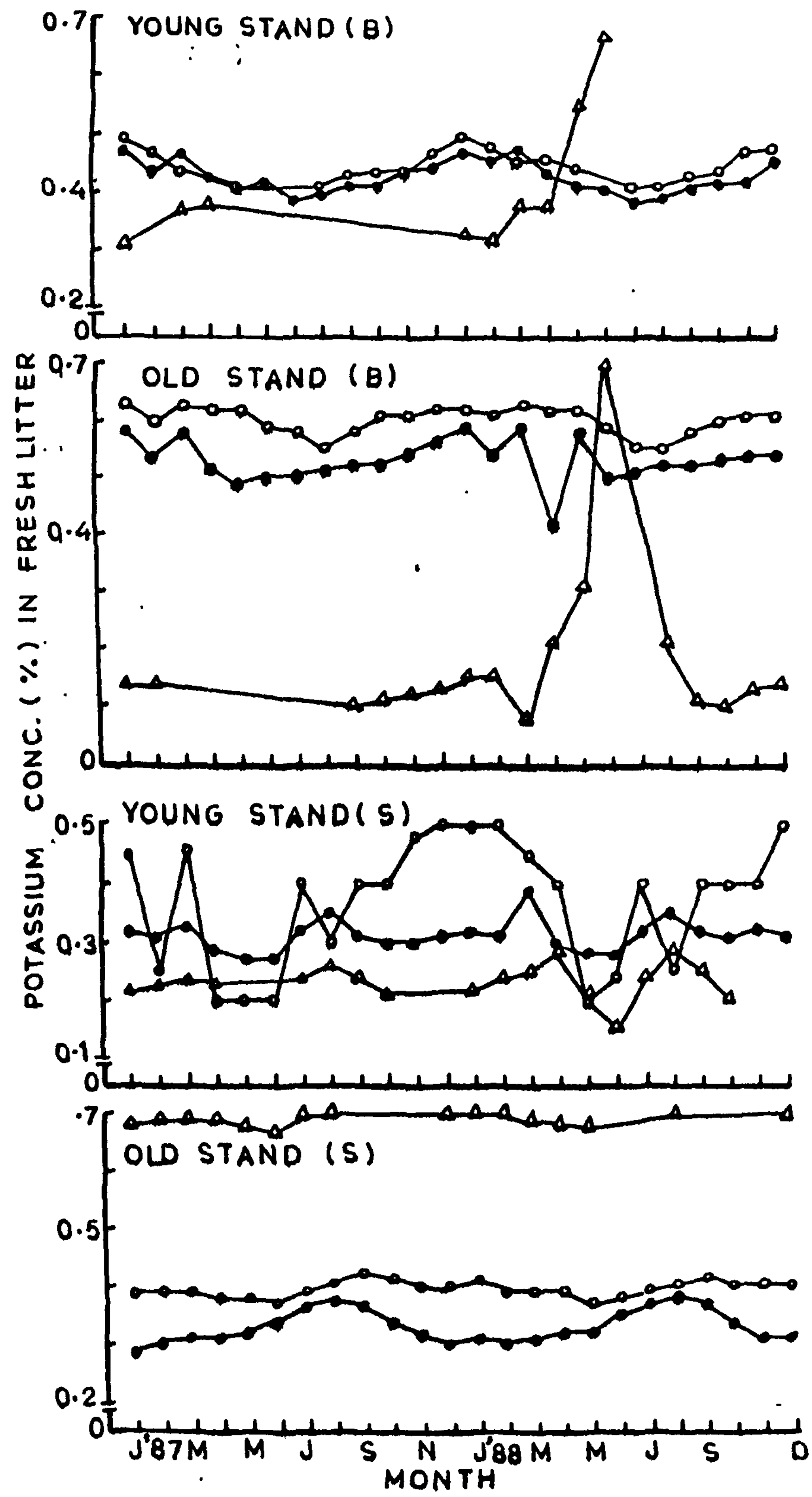

Figure 5.7. Variation in potassium concentration in fresh leaves 'O', woody 'Δ' and miscellaneous '●' litter samples collected at monthly intervals in the young and old forest stands at Burnihat (B) and Shillong (S).

stand than in the old stand. In both the stands higher (0.45 - 0.70%) values in leaf were found during January-February and lower (0.24 - 0.38%) during May-June. The miscellaneous and woody fractions have higher concentrations in August and lower during February and March. Potassium concentration in the woody litter at the old stand was more (0.67 - 0.72%) than the leaf and miscellaneous materials while it was lower than the other two categories in the young stand. Monthly and yearly variations in K concentration in different types of litter was found to be statistically insignificant.

Nutrient Input

Monthly input of N through litterfall is given in Table 5.2. In the young stand at Burnihat miscellaneous fraction constituted the major source followed by leaf and woody litter. In case of the old stand leaf litter became more important than any other fraction. Mean N input rate ($g/m^2/day$) by leaf and total litter during different seasons presented in Figure 5.8 reveals similar trend for both the fractions in the stands. The highest values were recorded for the winter and the lowest for the rainy season. At Shillong, although seasonality was less marked, it was slightly different from that seen at Burnihat. Here in the young stand, N return through total litter did not show much variation from one season to another but the value for leaf litter was high in winter, declined in summer and was minimum in the rainy season. The old stand followed almost the same trend. A comparison between the two stands indicates an increase in nutrient input rate through litterfall with increasing age.

Input of P through litterfall (Table 5.3) also varied widely in different months. In the young stand at Burnihat the miscellaneous fraction again contributed more than leaf and wood whereas in the old stand, leaf litter was the major source of P return to soil. With age, P input through all the three fractions of litter increased, however, it was more conspicuous in case of wood. The seasonal trend was similar to that of N (Figure 5.9), although the values were much less. In the wet hill forest the young stand showed higher input by woody litter compared to its counterpart at Burnihat. The leaf litter remained the major source of nutrient input. In the old stand P input by leaf as well as the woody litter increased from the young stand. The increase was, however, more in case of leaf than woody material. During winter season the rate was higher for both leaf as well as total litter in the young stand (Figure 5.9). In the old stand this trend was applicable only during the first year of study. During second year summer season exhibited peak for both the fractions.

The values for K input are given in Table 5.4. Both monthly and seasonal trends (Figure 5.10) were similar to that of N, but there was a quantitative difference between the two elements. The values were higher for N (31 - 162 $g/m^2/day$) and lower for K (10 - 32 $g/m^2/day$). Difference between the young and old stand was more at Burnihat than at Shillong.

Annual return of N, P, and K through litterfall, given in Tables 5.2, 5.3 and 5.4, respectively, show maximum value of N followed by K and P in all the four stands. Annual nutrient input through litter increased with stand age. At Burnihat increase was about 2.5 times for N and P and more than four fold in K. At Shillong increase from the young to old stand was less compared to Burnihat. Composition of N, P, K return with litter between the two forest types revealed higher values for wet hill forest at Shillong.

Nutrient concentration in litter mass

N, P, K concentration - N concentration in leaf, woody and miscellaneous fractions showed a definite seasonal pattern by having higher concentration during rainy season and low during winter (Figure 5.11). In the young stand at Burnihat N concentration in woody litter ranged between 1.7 and 2.8% and in miscellaneous material it varied from 1.3 to 2.2%. In the old stand this trend was changed and the woody litter has minimum concentration (1.3 - 2.1%) than leaf (1.7 - 2.7%) and miscellaneous (1.9 - 3.1%). Monthly difference in N concentration of woody and miscellaneous fractions was significantly different ($P < 0.05$) in both of them. At Shillong concentration in miscellaneous fraction was higher (2.9 - 3.7%) than leaf (2.4 - 3.3%) and woody litter (1.4 - 2.8%) in the young stand. But in the old stand leaf showed slightly higher values (2.8 - 3.6%) than other litter types. In both the stands monthly variation in woody and miscellaneous fractions was significant ($P<0.05$). N concentration seemed to be higher in the old stands both at Burnihat and Shillong.

Seasonality in concentration of P was more distinct than N (Figure 5.12) owing to higher values in the rainy season and lower figures during winter in all the four stands. The concentration in miscellaneous fraction was higher in both the stands at Burnihat followed by leaf in the young and woody litter in the old stand. At Shillong higher concentration was found in leaf litter in both the stands. Nonetheless, the values were high in the old stand. Mean P concentration in litter showed a rising tendency from the young to old stand at Shillong and a declining trend at Burnihat.

K concentration in leaf was higher than any other fraction in both the stands at Burnihat (Figure 5.13). The values were, however, low in the young stand, except in miscellaneous fraction which exhibited lower concentration.

Table 5.2. Monthly input of Nitrogen (mg/m^2) through litterfall in the young and old forest stands at Burnihat and Shillong

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	62	5	190	520	12	48	193	28	30	484	92	62
February	38	-	163	479	9	87	174	7	44	124	34	127
March	35	2	64	300	-	201	158	27	80	173	102	174
April	-	5	108	141	-	136	273	22	33	92	162	84
May	3	-	43	99	-	165	127	-	33	205	25	152
June	-	-	21	14	-	46	258	-	58	155	25	65
July	-	-	47	46	-	29	77	15	85	228	187	302
August	7	-	67	76	-	29	94	11	98	318	130	72
September	79	-	59	136	50	42	181	6	85	400	-	127
October	84	-	75	155	22	114	203	13	69	188	-	96
November	100	-	161	226	45	219	186	-	72	214	-	122
December	88	-	134	257	65	175	173	-	82	270	42	142

Table 5.2 (Contd.)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	73	27	182	500	40	49	196	14	77	746	75	66
February	50	14	101	344	15	50	182	6	58	691	59	104
March	34	2	99	221	7	78	113	20	134	578	78	287
April	25	5	84	145	1	156	169	40	102	378	99	218
May	14	17	27	110	6	116	222	23	77	286	65	177
June	-	14	22	27	37	32	294	14	71	260	-	152
July	14	-	50	56	22	39	65	26	85	200	-	230
August	16	-	70	110	25	20	99	8	51	281	47	105
September	99	-	58	131	69	61	202	20	91	280	-	51
October	67	-	59	133	15	84	214	28	78	192	-	111
November	81	-	143	250	47	212	183	-	56	193	-	166
December	77	-	132	265	64	175	228	-	98	333	48	165

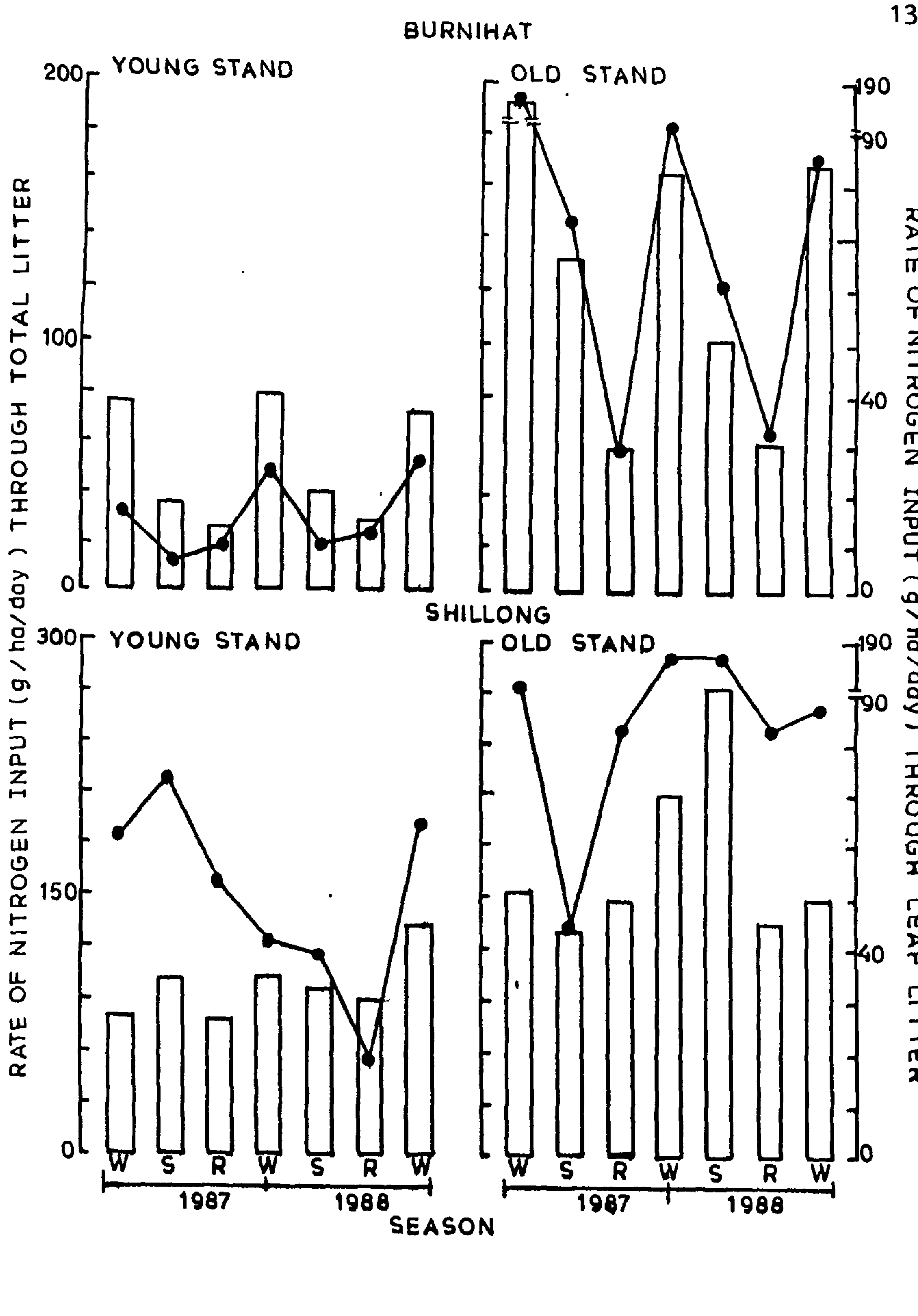

Figure 5.8. Rate of N - input through leaf litter (line) and total litter (bar) during three seasons (W=winter, S=summer, R=rainy) in the young and old forest stands at Burnihat and Shillong.

Table 5.3. Monthly input of Phosphorus (mg/m^2) through litterfall in the young and old forest stands of Burnihat and Shillong

Month	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	3	<1	5	19	<1	2	8	<1	1	13	1	2
February	2	-	4	15	<1	2	6	<1	2	4	<1	6
March	2	1	2	11	-	6	6	1	3	4	1	7
April	-	1	2	4	-	3	8	1	1	3	2	4
May	<1	-	1	3	-	3	4	-	-	5	<1	8
June	-	-	1	<1	-	1	8	-	2	4	<1	4
July	-	-	1	2	-	1	3	<1	3	6	2	12
August	<1	-	2	3	-	1	3	<1	4	8	1	28
September	4	-	2	5	1	1	8	<1	3	11	-	4
October	15	-	2	5	1	4	8	<1	2	4	-	3
November	4	-	5	8	1	6	9	-	2	5	-	4
December	6	-	4	9	2	6	7	-	2	7	<1	4

Table 5.3 (Contd.)

Month	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	5	1	5	18	1	2	9	<1	2	21	1	2
February	3	<1	3	11	<1	1	8	<1	2	28	1	5
March	2	1	3	9	<1	2	5	<1	5	17	1	11
April	1	1	2	4	<<1	4	7	1	4	11	1	10
May	1	1	1	3	<1	2	6	1	2	8	1	7
June	-	1	1	1	2	1	10	<1	3	7	-	6
July	<1	-	1	2	2	1	3	1	4	5	-	8
August	1	-	2	4	1	1	3	<1	4	7	1	4
September	5	-	2	5	2	2	8	1	4	8	-	2
October	4	-	2	5	<1	3	9	1	2	5	-	4
November	6	-	4	10	1	8	9	-	1	5	-	6
December	5	-	4	9	2	6	9	-	2	8	1	3

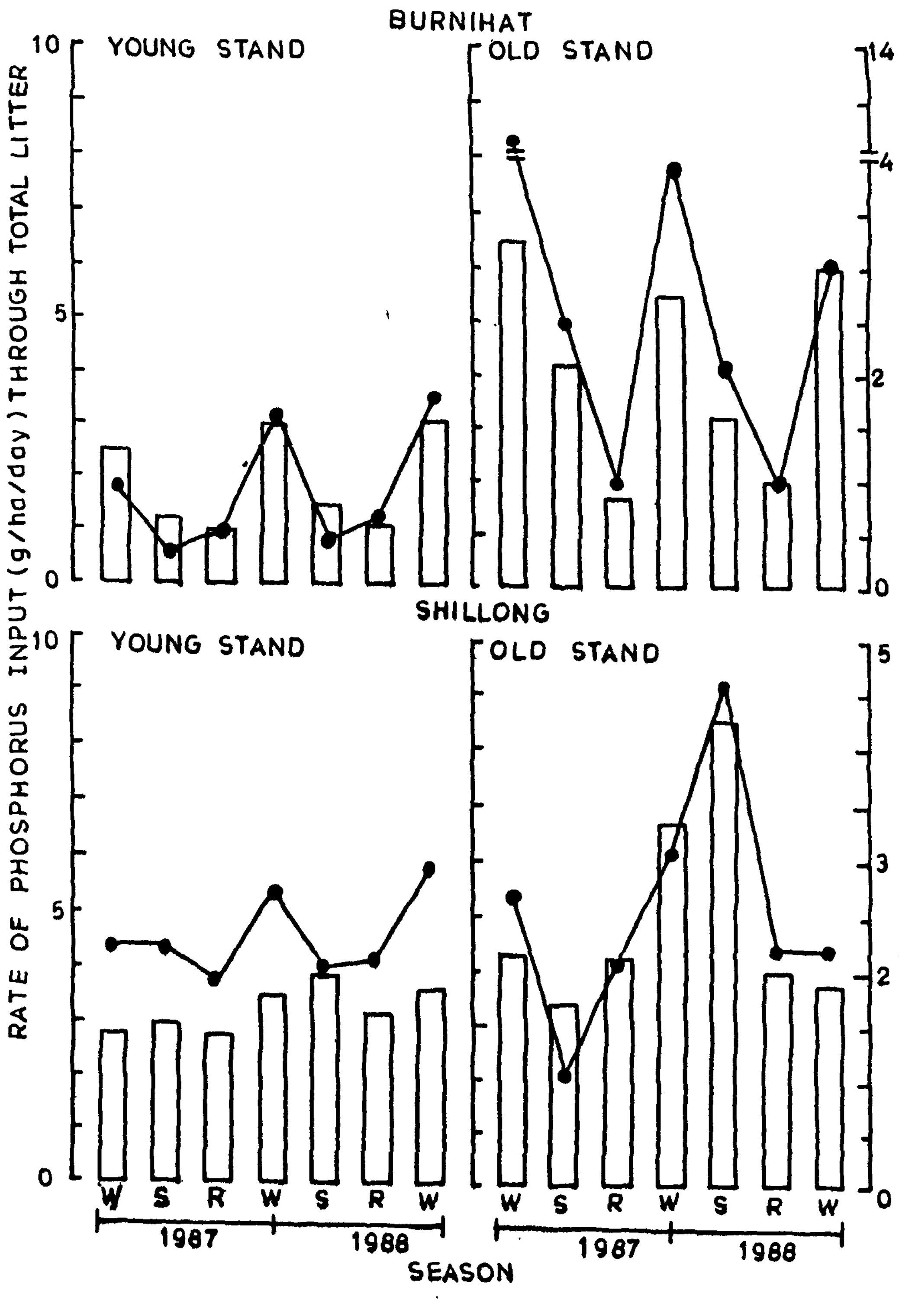

Figure 5.9. Rate of P - input through leaf litter (line) and total litter (bar) during three seasons (W=winter, S=summer, R=rainy) in the young and old forest stands at Burnihat and Shillong.

Table 5.4. Monthly input of Potassium (mg/m^2) through litterfall in the young and old forest stands at Burnihat and Shillong

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	19	1	30	172	1	15	58	4	59	82	21	10
February	13	-	28	151	<1	25	29	1	10	23	8	29
March	11	4	13	100	-	61	52	4	17	34	23	42
April	-	6	20	42	-	35	39	3	7	17	35	22
May	1	-	9	29	-	39	17	-	6	41	5	40
June	-	-	6	6	-	14	30	-	9	29	5	22
July	-	-	8	19	-	11	22	2	15	39	37	60
August	2	-	12	28	-	10	16	2	19	53	26	15
September	25	-	11	49	2	15	56	1	14	67	-	23
October	27	-	12	56	1	37	54	1	12	30	-	16
November	22	-	26	77	2	66	58	-	13	34	-	19
December	29	10	22	84	2	54	58	-	16	45	10	22

Table 5.4 (Contd.)

Month	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	23	4	29	166	2	15	65	2	15	128	18	10
February	18	2	18	117	1	15	61	1	11	122	13	21
March	11	3	20	77	<1	24	36	3	35	107	17	69
April	5	7	16	43	<1	33	48	6	21	70	27	54
May	4	6	6	34	2	32	30	3	13	59	23	38
June	-	6	6	11	16	10	42	1	12	49	-	33
July	3	-	9	20	9	13	17	3	15	34	-	45
August	4	-	12	38	4	7	13	1	18	47	9	40
September	29	-	11	48	3	21	50	2	14	46	-	9
October	22	-	10	47	1	30	57	3	14	30	-	18
November	27	-	24	85	2	76	49	-	9	31	-	24
December	25	-	23	90	<1	52	76	-	18	53	11	27

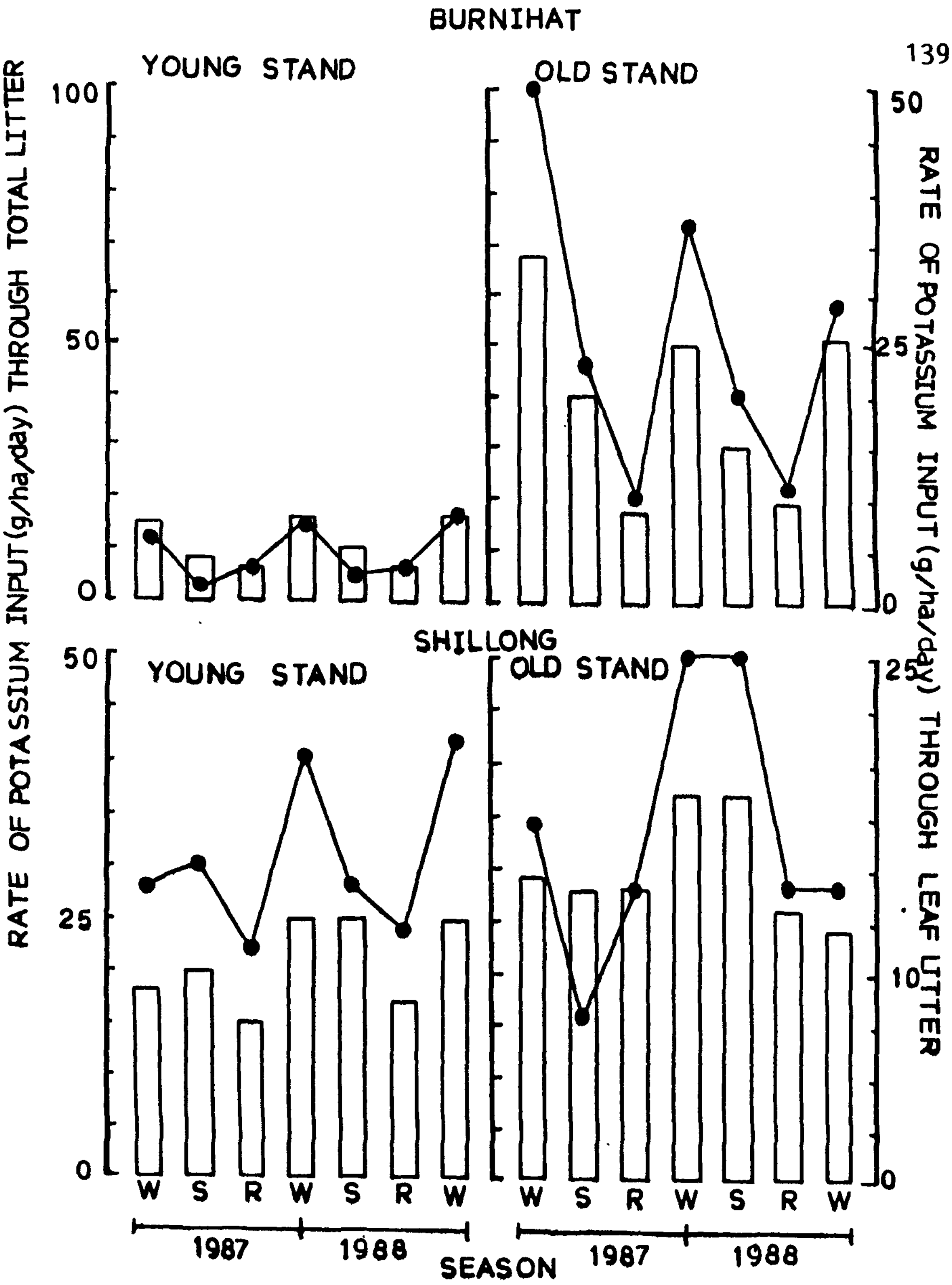

Figure 5.10. Rate of K - input through leaf litter (line) and total litter (bar) during three seasons (W=winter, S=summer, R=rainy) in the young and old forest stands at Burnihat and Shillong.

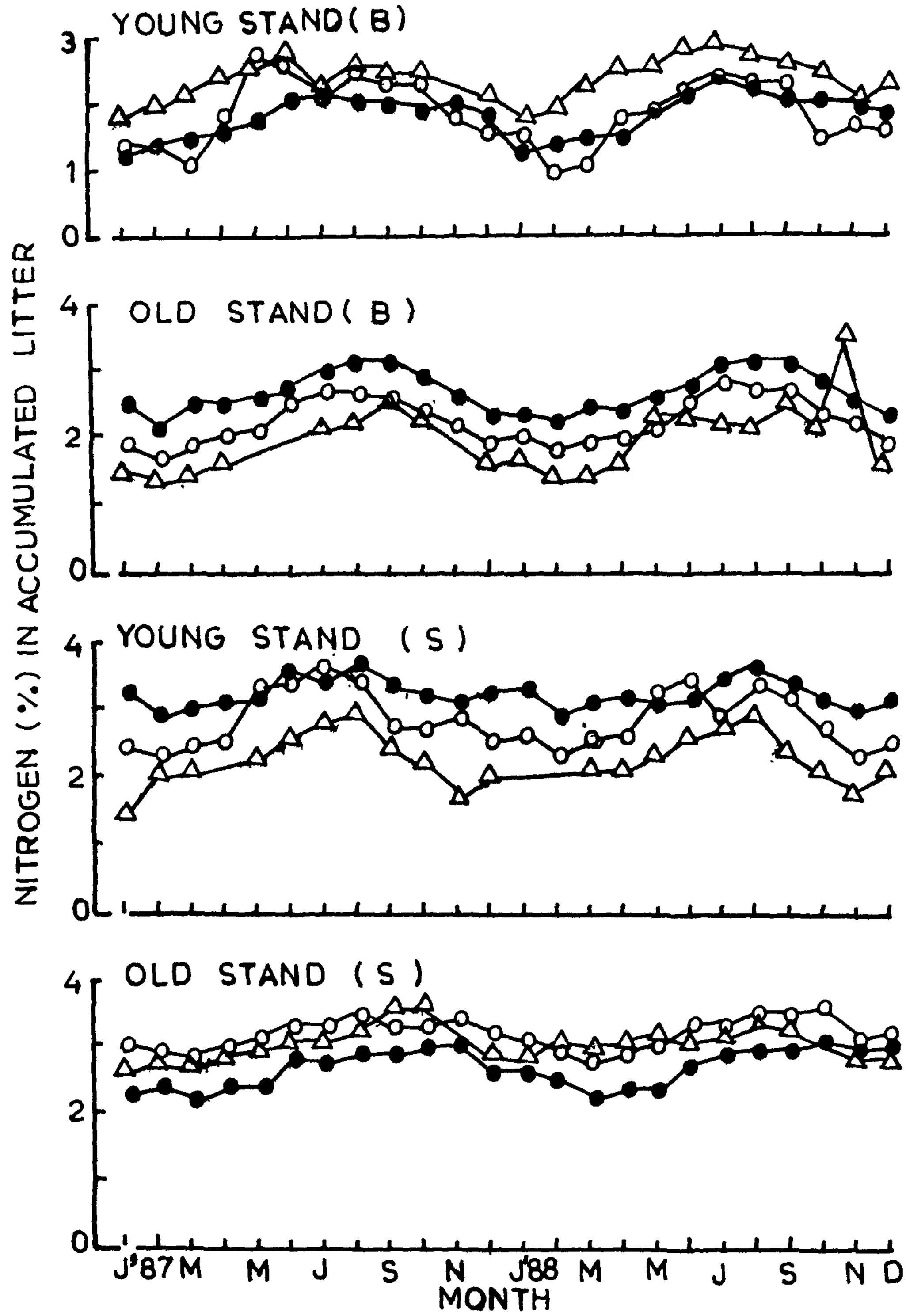

Figure 5.11. Monthly variation in nitrogen concentration in accumulated leaf (O), woody (Δ) and miscellaneous (●) litter in the young and old forest stands at Burnihat (B) and Shillong (S).

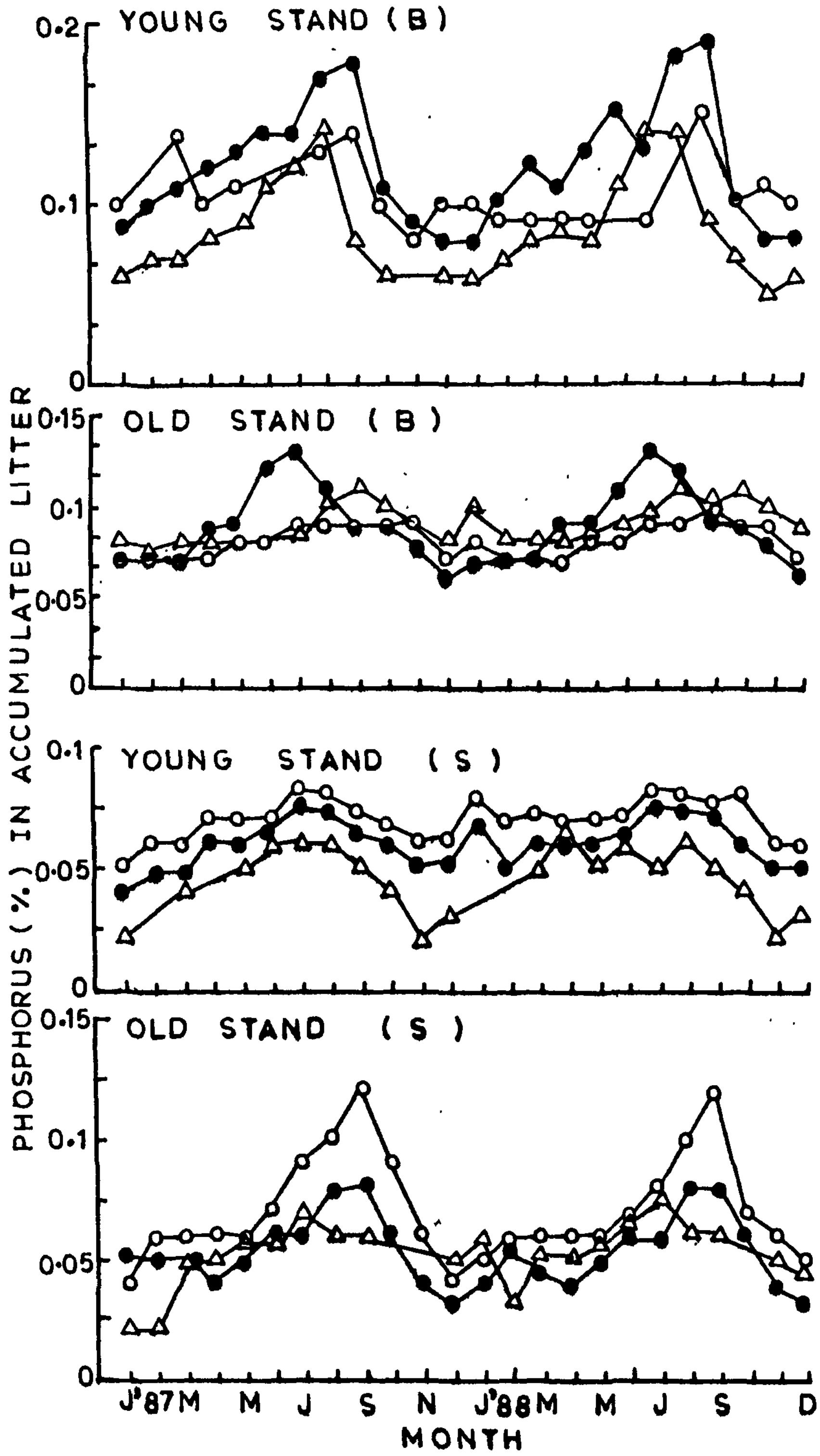

Figure 5.12. Monthly variation in phosphorus concentration in accumulated leaf (O), woody (Δ) and miscellaneous (●) litter in the young and old forest stands at Burnihat (B) and Shillong (S).

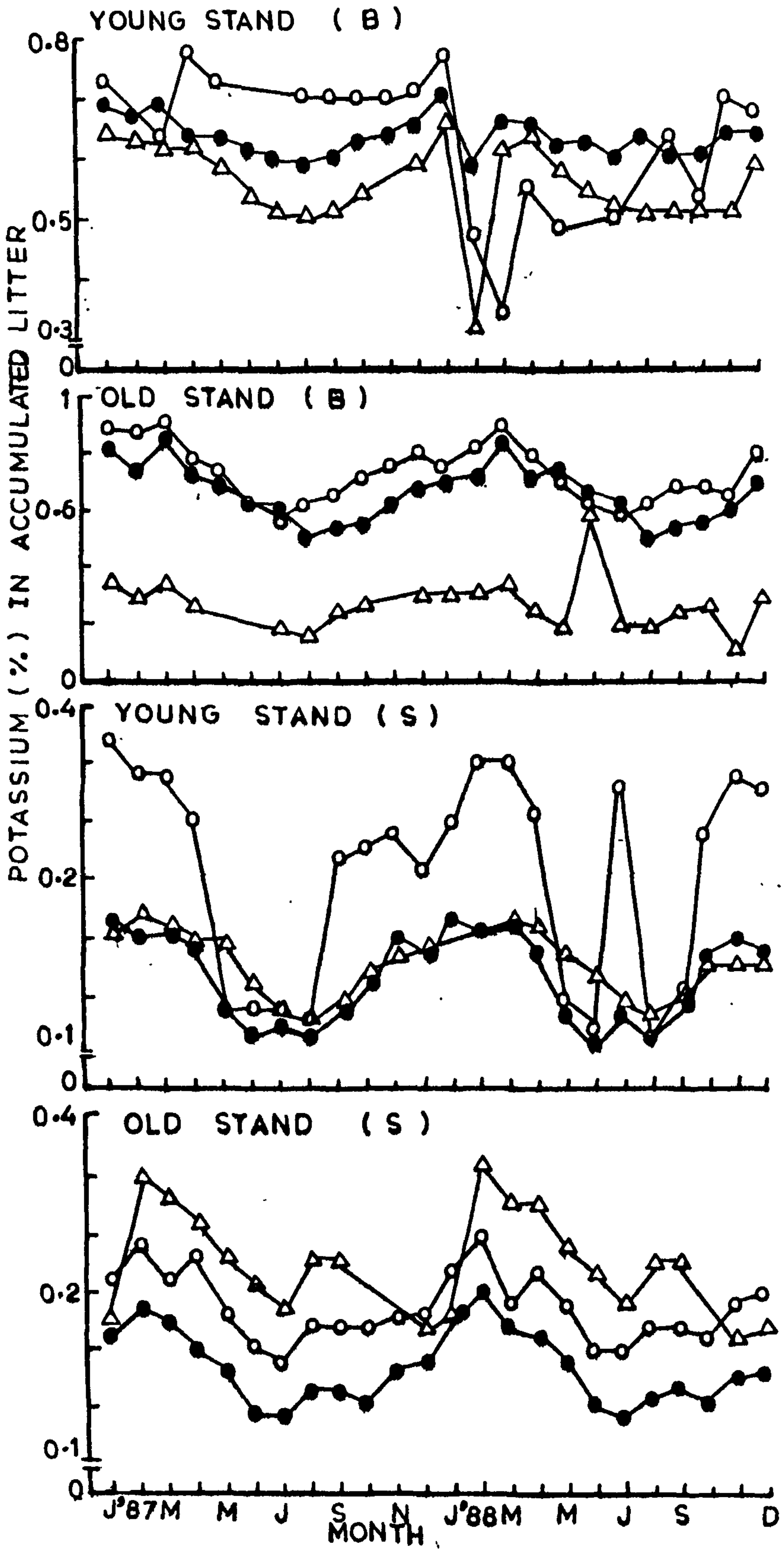

Figure 5.13. Monthly variation in potassium concentration in accumulated leaf (O), woody (Δ) and miscellaneous (●) litter in the young and old forest stands at Burnihat (B) and Shillong (S).

In the young stand of montane forest leaves had higher concentration than other fractions. In the old stand woody litter showed higher values (0.4 - 0.35%) than leaf (0.18 - 0.29%) and miscellaneous litter (0.14 - 0.25%). A distinct seasonal trend was visible in all the four stands, the values were higher during February and March and lower during June and July.

N, P, K accumulation

In the young as well as the old stand at Burnihat miscellaneous fraction accumulated major amount of N and leaf and woody materials were relatively less important (Table 5.5). All the fractions showed peak in winter and trough in the rainy season, except the woody material which accumulated maximum amount during summer in the young stand. In both the stands of montane forest accumulation in woody fraction was minimum. Miscellaneous fraction in the young stand and leaf litter in the old stand were of major importance from this point of view. The seasonal trend in the wet hill forest was similar to the moist deciduous forest but the total amount was higher in the former. P accumulation in different fractions of litter mass is given in Table 5.6. At Burnihat its allocation in different fractions was similar to that of N. At Shillong major amount (51 - 55%) was present in leaf in both the stands. As far as the

Table 5.5. Monthly variation in standing state of Nitrogen (mg/m^2) in litter mass in the young and old forest stands at Burnihat and Shillong

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	120	76	675	684	121	1070	1708	48	1169	3419	693	172
February	-	106	759	521	79	861	1590	24	842	2342	419	1253
March	44	179	280	355	7	905	748	122	2010	2164	291	1198
April	36	389	253	267	128	463	1835	-	1578	768	620	2396
May	29	85	196	202	-	993	1162	64	1526	789	615	1370
June	-	137	242	60	-	1142	1438	44	1404	967	59	1848
July	-	39	152	140	117	252	1141	57	1933	904	166	1287
August	33	107	170	111	78	512	568	131	1106	1211	539	828
September	33	166	226	233	208	198	952	143	2081	639	189	1854
October	33	178	319	329	127	394	834	128	1692	1216	-	1338
November	167	-	473	613	-	1180	1041	66	1959	1717	-	1098
December	246	71	711	650	106	1033	805	124	1981	1859	190	893

Table 5.5 (Contd.)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	164	68	276	1492	63	86	1768	-	1333	2995	235	1066
February	71	78	487	691	42	924	1438	-	1267	2088	324	1593
March	54	114	336	369	46	695	1635	95	949	2097	154	1276
April	61	90	383	440	51	667	1534	65	884	2042	102	1678
May	30	40	363	242	37	936	1984	30	815	2079	216	1094
June	-	95	321	133	110	926	1863	94	646	2178	87	672
July	19	116	269	291	79	498	1630	140	396	2168	138	568
August	-	59	332	383	48	520	1224	104	1136	1257	273	741
September	200	20	438	454	156	174	944	158	2013	1029	116	1593
October	104	19	320	281	108	370	716	126	1981	1393	-	1616
November	196	189	378	662	77	1128	837	44	1968	1516	67	1014
December	154	35	77	595	66	955	1075	76	2160	1709	1260	1137

Table 5.6. Monthly variation in standing state of Phosphorus (mg/m^2) in littermass in the young and old forest stands at Burnihat and Shillong

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	9	3	5	25	9	29	35	1	14	45	8	4
February	-	4	54	21	4	28	41	1	15	49	4	26
March	6	6	20	13	5	25	18	2	34	46	5	27
April	2	13	18	9	6	16	51	<1	31	15	10	40
May	2	3	14	8	-	34	25	1	29	15	12	29
June	-	5	16	2	-	51	30	1	28	21	1	46
July	-	2	10	5	5	11	25	1	43	25	4	26
August	2	6	14	4	4	18	13	3	24	35	10	21
September	2	6	20	8	9	6	25	3	43	23	3	48
October	2	4	18	12	5	12	22	2	32	33	-	25
November	7	-	22	25	-	36	22	1	33	30	-	15
December	15	2	32	24	5	27	19	2	31	23	3	10

Table 5.6 (Contd.)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
Month	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	12	2	16	60	4	3	54	-	20	48	5	15
February	7	3	35	27	2	29	44	-	26	43	3	38
March	4	4	27	14	3	19	46	2	18	45	3	29
April	3	3	28	15	3	25	41	2	17	42	2	28
May	1	1	25	9	1	32	43	1	16	42	4	23
June	-	4	23	4	4	38	38	2	13	46	2	14
July	1	6	15	9	3	22	47	3	9	53	3	12
August	-	3	27	13	2	20	29	2	31	36	5	19
September	13	1	42	17	6	5	21	3	73	35	2	41
October	7	1	16	11	5	12	24	2	45	27	-	30
November	13	<1	16	27	2	36	16	2	39	29	1	14
December	10	1	34	22	4	25	22	2	34	27	2	12

seasonal trend is concerned, maximum accumulation was seen during winter season and minimum during rainy season in both the forest types. Summer peak was, however, observed for the woody litter.

K content in litter standing crop is given in Table 5.7. It also exhibited the trend of N and P. The values were higher during winter and lower in rainy season. The total accumulation in litter mass also increased with the stand age at both the sites.

Annual data of mean standing state of N, P, and K in litter furnished in Table 5.8 showed that the miscellaneous fraction which was mainly composed of leaves and reproductive plant parts, accumulated highest proportion of nutrients on the forest floor. The data further indicated substantial enhancement in nutrient accumulation in litter from the young to old stand, the increase was, however, more in the deciduous forest.

Turnover rate

The turnover coefficient (k) for different elements accumulated in leaf and total litter is given in Table 5.8. The values were generally higher for leaf than total litter for all the three elements. A more rapid nutrient turnover in leaf litter was recorded in the young stand at Burnihat.

Table 5.7. Monthly variation in standing state of Potassium (mg/m^2) in litter mass in the young and old forest stands at Burnihat and Shillong

Month	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	63	27	358	320	29	347	263	7	77	296	56	16
February	-	33	363	273	18	299	235	3	58	234	51	125
March	26	54	129	168	2	308	106	12	13	201	34	120
April	16	102	101	104	21	133	220	-	92	72	62	200
May	12	20	70	69	-	271	49	5	67	59	57	103
June	-	26	71	15	-	262	59	3	48	59	5	92
July	-	9	41	31	10	52	44	3	70	49	12	60
August	9	21	48	25	6	83	20	6	36	76	44	43
September	8	35	68	59	19	34	95	8	86	43	16	96
October	20	40	106	97	14	73	87	10	70	81	-	63
November	65	-	159	212	-	281	104	7	131	116	-	66
December	109	20	25	244	19	310	84	12	111	134	15	61

Table 5.7 (Contd.)

Month	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.	Leaf	Wood	Misc.
January	90	26	144	522	11	26	204	-	89	261	19	88
February	35	13	205	311	9	30	219	-	92	216	39	160
March	17	32	148	175	11	239	229	9	65	180	18	128
April	19	23	166	174	8	197	183	7	54	190	11	147
May	8	9	118	83	3	259	93	2	37	166	21	87
June	-	18	95	33	29	213	71	6	21	132	8	36
July	4	20	67	61	7	101	192	8	15	131	10	27
August	-	11	95	88	4	82	43	5	37	79	22	38
September	56	4	131	114	14	30	47	10	90	65	10	87
October	38	4	96	84	13	71	77	11	115	81	-	75
November	81	5	127	199	2	271	124	5	131	117	5	61
December	65	9	274	250	12	290	142	7	122	134	10	73

Table 5.8. Annual N, P and K input (mean of 1987-88) through litterfall (Kg/ha), mean standing state in litter mass (Kg/ha) and their turnover rates in the young and old forest stands at Burnihat and Shillong (values in parentheses denote ± S.E.)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	N	P	K	N	P	K	N	P	K	N	P	K
Annual input:												
Leaf	5.23 (0.26)	0.30 (0.03)	1.60 (0.10)	23.69 (0.78)	0.83 (0.02)	7.93 (0.18)	21.31 (0.35)	0.82 (0.04)	5.16 (0.28)	36.32 (7.84)	1.02 (0.29)	6.34 (1.41)
Total	16.48 (0.07)	0.63 (0.03)	3.69 (0.12)	38.26 (1.16)	1.26 (0.09)	11.71 (0.29)	31.66 (1.75)	1.15 (0.10)	7.06 (0.58)	45.43 (7.77)	1.70 (0.26)	11.33 (1.50)
Mean standing state:												
Leaf	0.75 (0.15)	0.05 (0.01)	0.39 (0.07)	4.25 (0.66)	0.16 (0.03)	1.56 (0.25)	12.68 (0.86)	0.31 (0.03)	1.25 (0.15)	16.89 (1.45)	0.35 (0.02)	1.32 (0.15)
Total	5.46 (0.68)	0.33 (0.04)	1.83 (0.19)	8.23 (1.42)	0.43 (0.05)	3.56 (0.49)	27.99 (1.99)	0.62 (0.05)	2.03 (0.23)	31.56 (1.64)	0.63 (0.05)	2.39 (0.28)
Turnover rate:												
Leaf	6.94	6.23	4.10	5.58	5.16	5.08	1.68	2.61	4.14	2.15	2.93	4.80
Total	3.02	1.93	2.02	4.65	2.93	3.29	1.13	1.86	3.47	1.44	2.70	4.73

However, when nutrients in the total litter mass were considered, turnover rate was faster in the old stand. In the wet hill forest nutrient turnover rate both in leaf and total litter was higher in the old stand. A comparison of the two forest types reveals higher turnover rates for all the three elements in the moist deciduous forest at Burnihat.

N, P, K contents in soil

Total N, available P and exchangeable K in soil profile at all the four stands are shown in Figures 5.14, 5.15, and 5.16, respectively. The concentration of all the three elements was generally higher in the old stands of the two forest types and the difference between the young and old stands was significant at $P < 0.05$ (Tables 5.9, 5.10, 5.11). With higher values during July-August and lower during April, all the stands depicted a clear seasonal trend.

The mean standing states (kg/ha) of N, P, and K are given in Tables 5.12, 5.13 and 5.14, respectively. The amount of these elements was more in the old stand both at Burnihat and Shillong. At Shillong greater accumulation of P and K was found at 10-20 cm soil layer. Amount of N declined with increasing soil depth in all the stands. The young stand showed maximum nutrient accumulation in upper soil layer.

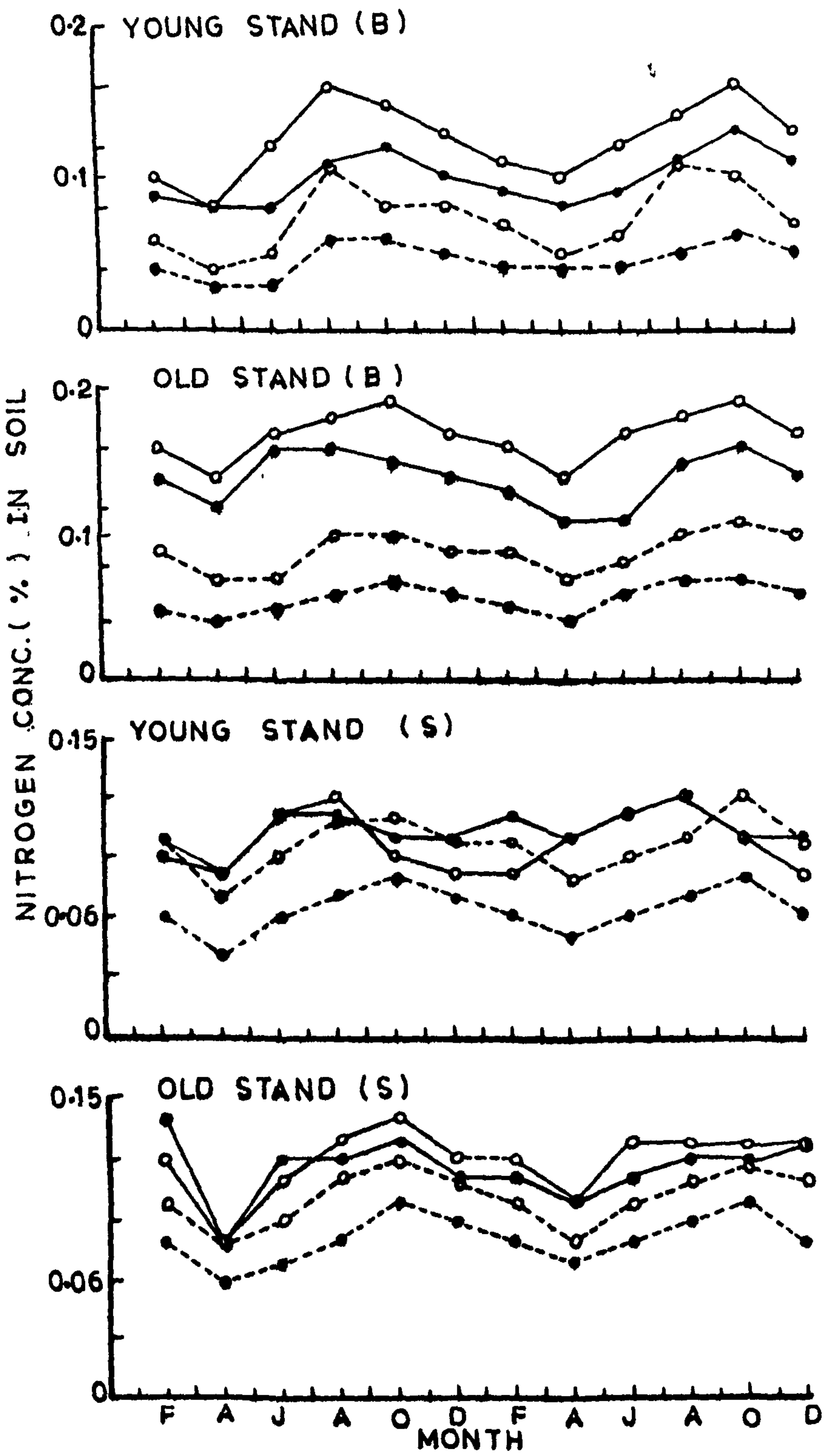

Figure 5.14. Seasonal variation in total soil N concentration in the young and old forest stands at Burnihat (B) and Shillong (S). Soil depths - 0-10 cm (—O—); 10-20 cm (—●—); 20-30 cm (--O--); 30-40 cm (--●--).

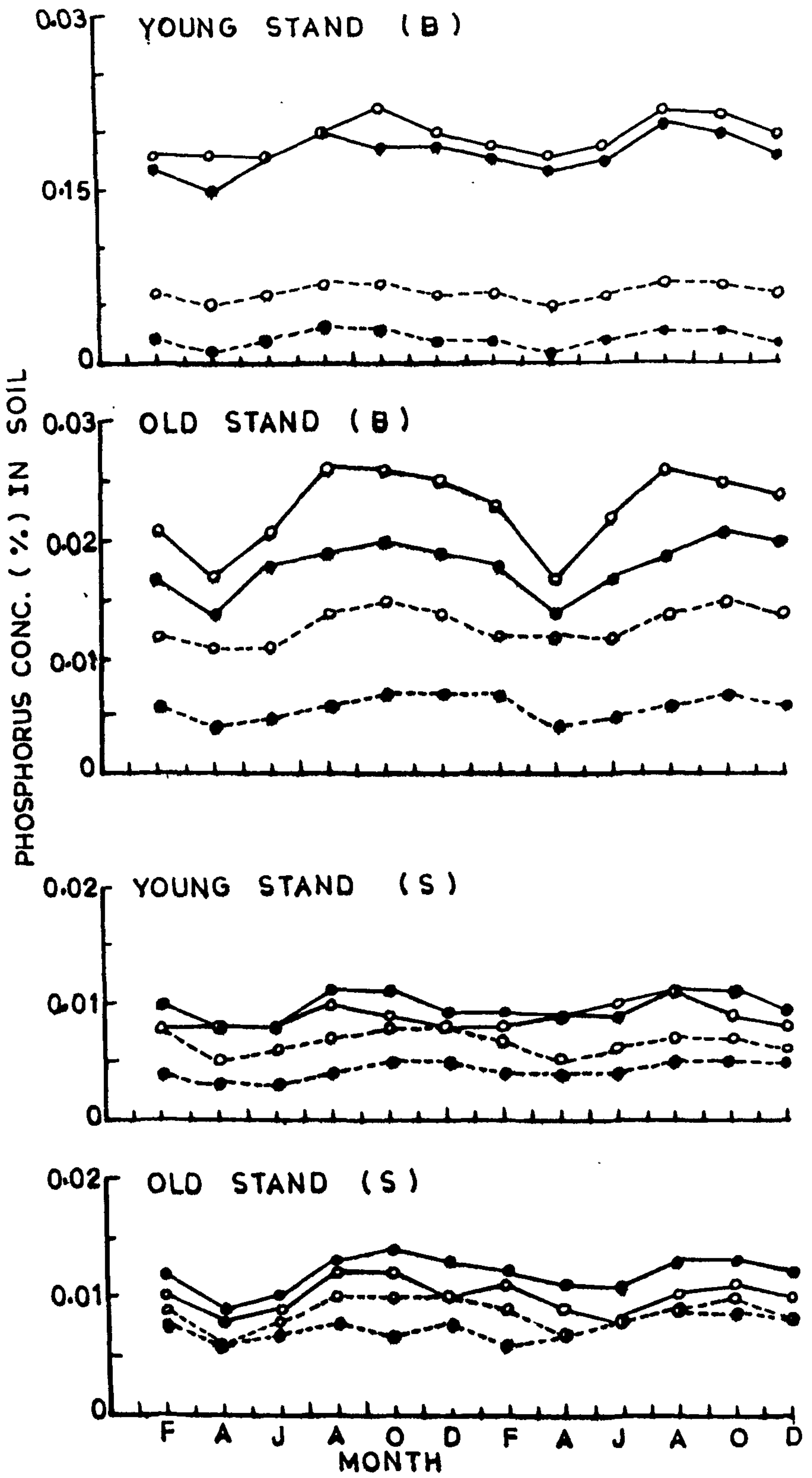

Figure 5.15. Seasonal variation in available soil phosphorus concentration in the young and old forest stands at Burnihat (B) and Shillong (S). Soil depths - 0-10 cm (—O—); 10-20 cm (—●—); 20-30 cm (--O--); 30-40 cm (--●--).

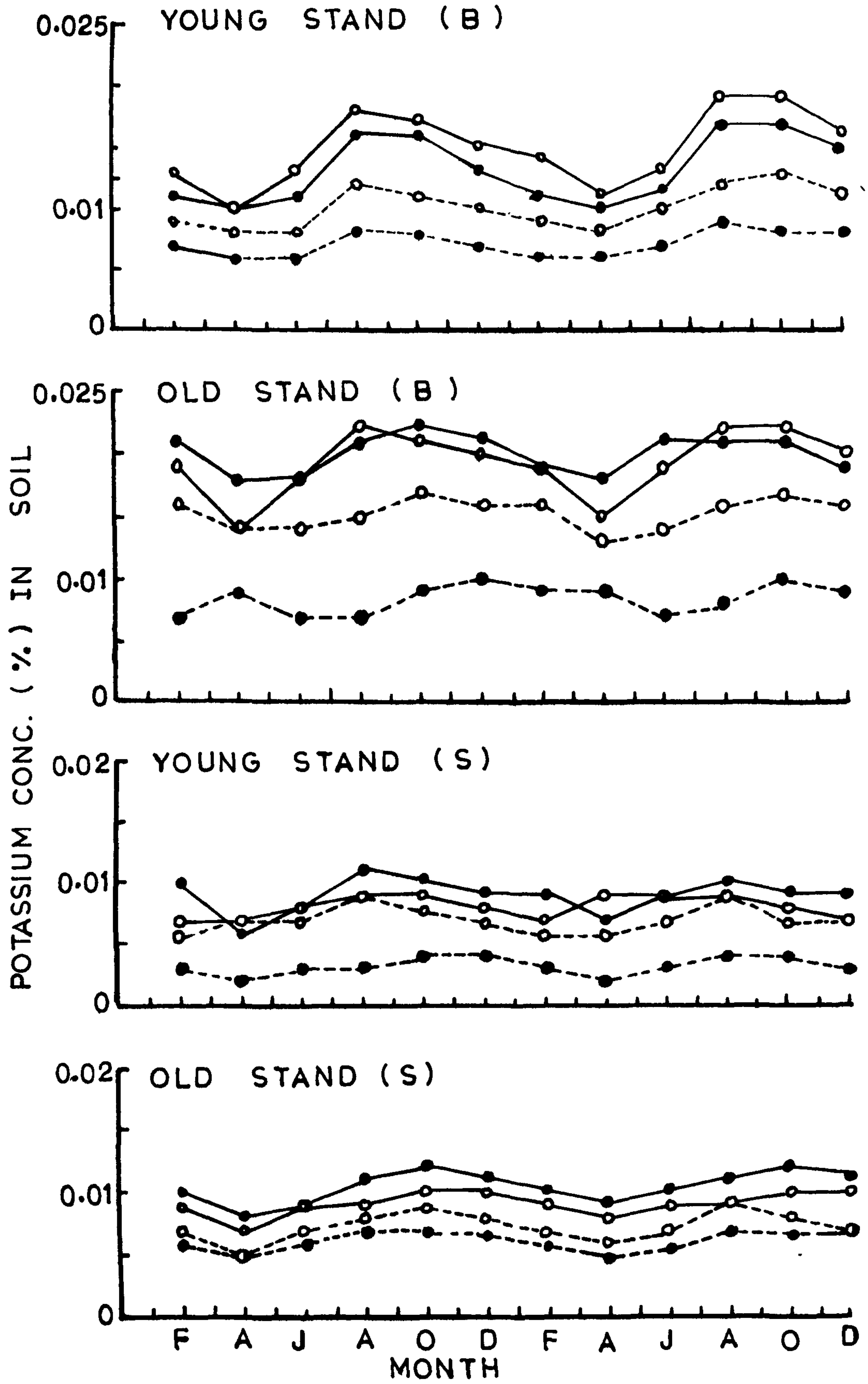

Figure 5.16. Seasonal variation in exchangeable soil potassium concentration in the young and old forest stands at Burnihat (B) and Shillong (S). Soil depths - 0-10 cm (—●—); 10-20 cm (--O--); 20-30 cm (—O—); 30-40 cm (--●--).

Table 5.9. Analysis of variance of total N-content in soil at Burnihat and Shillong

Source of variation	df	Burnihat		Shillong	
		MSS	F ratio	MSS	F ratio
Depth	3	0.1226	2962.77^{S}	0.0336	295.54^{S}
Stand	1	0.048	1165.65^{S}	0.1008	886.05^{S}
Month	11	0.00598	144.42^{S}	0.00230	20.217^{S}
D x S	3	0.00445	107.55^{S}	0.0363	318.99^{S}
D x M	33	0.0003	7.25^{S}	0.000274	2.407^{S}
M x S	11	0.00017	4.10^{S}	0.000191	1.68^{NS}
D x M x S	33	0.00019	4.59^{S}	0.000294	2.579^{S}
Error	192	0.0000414	-	-	-
Total	287	-	-	-	-

S = Significant at $P < 0.05$

NS = Not significant

Table 5.10. Analysis of variance of available P-content in soil at Burnihat and Shillong

Source of variation	df	Burnihat		Shillong	
		MSS	F ratio	MSS	F ratio
Depth	3	0.00569	34.886^{NS}	0.000312	300.49^{S}
Stand	1	0.00164	10.08^{NS}	0.00036	439.32^{S}
Month	11	0.000216	1.32^{NS}	0.0000223	27.17^{S}
D x S	3	0.000349	2.14^{NS}	0.0000144	17.52^{S}
D x M	33	0.000176	1.08^{NS}	0.00000181	2.2^{S}
M x S	11	0.000173	1.06^{NS}	0.00000148	1.81^{S}
D x M x S	33	0.000165	1.01^{NS}	0.00000103	1.25^{NS}
Error	192	0.000163	-	0.00000082	-
Total	287	-	-	-	-

S = Significant at $P < 0.05$

NS = Not significant

Table 5.11. Analysis of variance of exchangeable k-content in soil at Burnihat and Shillong

Source of variation	df	Burnihat		Shillong	
		MSS	F ratio	MSS	F ratio
Depth	3	0.00133	1352.98^{S}	0.000303	728.17^{S}
Stand	1	0.00149	1516.86^{S}	0.000003	367.46^{S}
Month	11	0.000066	67.71^{S}	0.0000189	45.46^{S}
D x S	3	0.00011	11.59^{S}	0.0000281	67.39^{S}
D x M	33	0.0000052	5.29^{S}	0.00000155	3.73^{S}
M X S	11	0.0000049	4.99^{NS}	0.00000068	1.63^{NS}
D x M x S	33	0.00000204	2.08^{S}	0.0000012	2.82^{S}
Error	192	0.00000048	-	0.000000417	-
Total	287	-	-	-	-

S = Significant at $P < 0.05$

NS = Not significant

Table 5.12. Total nitrogen content (Kg/ha ± S.D., n = 12) in soil at four depths in the young and old forest stand at Burnihat and Shillong

Depth (cm)	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
0 - 10	2100 ± 420	2822 ± 269	1629 ± 268	2016 ± 285
10 - 20	1680 ± 268	2251 ± 336	168 ± 17	1948 ± 269
20 - 30	1243 ± 386	1495 ± 218	588 ± 403	1730 ± 235
30 - 40	773 ± 185	957 ± 184	1058 ± 202	1377 ± 201

Table 5.13. Available phosphorus (Kg/ha ± S.D., n = 12) in soil at four depths in the young and old forest stands at Burnihat and Shillong

Depth (cm)	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
0 - 10	420 ± 336	386 ± 55	151 ± 17	168 ± 22
10 - 20	352 ± 252	302 ± 37	134 ± 56	201 ± 24
20 - 30	100 ± 12	218 ± 25	118 ± 17	393 ± 268
30 - 40	33 ± 12	84 ± 18	67 ± 13	134 ± 17

Table 5.14. Exchangeable potassium (Kg/ha ± S.D., n = 12) in soil at four depths in the young and old forest stand at Burnihat and Shillong

Depth (cm)	Burnihat		Shillong	
	Young stand	Old stand	Young stand	Old stand
0 - 10	252 ± 50	319 ± 50	134 ± 15	151 ± 16
10 - 20	218 ± 45	336 ± 24	151 ± 22	168 ± 20
20 - 30	168 ± 29	252 ± 21	117 ± 17	117 ± 19
30 - 40	117 ± 16	142 ± 20	50 ± 11	101 ± 12

DISCUSSION

The findings presented in the preceding pages clearly bring out the effects of climate, forest type, stand age and quality of litter on decomposition process. Since climatic conditions at the two sites did not show drastic change, litter decomposition pattern was broadly similar in the two forest types. Nevertheless, relatively high temperature and favourable moisture conditions through major part of the year at Burnihat were responsible for more rapid decay of enclosed litter in the moist deciduous forest than at wet hill forest, where low temperature for about six months provided unfavourable conditions for decomposition. Since the rainfall was sufficiently high at both the sites, it appears that temperature, rather than the rainfall, played a more significant role in litter decay. Mikola (1955) in the temperate forest at Finland has also shown a decisive influence of climate, particularly temperature on litter decomposition. Another factor that regulated temperature within the forest stand was the development of tree canopy. The young stand with an open canopy generally had higher soil surface temperature and might be experiencing wide fluctuations in diurnal temperature and wetting and drying cycles (Lindsay, 1988). These microclimatic differences contributed to the rapid decay of litter in the young stand at Burnihat where there was practically no fully grown tree in the stand. Among other things, decomposition rate is also influenced by properties of litter (Jensen, 1974). The mechanical nature and chemical composition of plant tissues are important factors which determine decomposition rate. Faster decomposition in the young stand at Burnihat may also be due to these attributes of leaf and miscellaneous fractions which were mainly composed of herbaceous litter. Relatively rapid decomposition rate of angiospermous tree leaf litter as compared to pine needle is also attributed to the difference in the chemical composition of the two types of litter. Relatively slow decomposition of coniferous litter has also been reported by Staaf and Berg (1983).

The decomposition rate of litter can be explained in terms of carbon : element ratio. Plant materials with high C:N ratio tend to decompose more slowly than those having low ratio (Jensen, 1929; Brady, 1974, Wieder et al. 1983). C:N ratio in all litter fractions was more in the wet hill forest at Shillong than the deciduous forest at Burnihat (Tables 5.15, 5.16, 5.17, 5.18 and 5.19). This was yet another reason for slow decomposition in the montane forest. Slower decomposition in the old stand at Shillong, except the pine needle, may also be attributed to the difference in C:N ratio.

Table 5.15. Changes in C/N, C/P and C/K ratios during decomposition of confined leaf litter from litter bag in the young forest stand at Burnihat

Days	*A. conyzoides*			*M. philippensis*			Miscellaneous		
	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K
Initial	29	341	75	21	554	62	39	614	130
30	27	282	91	22	519	79	40	550	143
60	21	173	73	18	298	53	21	300	95
90	19	120	55	11	217	46	12	175	53
120	19	54	30	6	175	41	5	100	33

Table 5.16. Changes in C/N, C/P and C/K ratios during decomposition of confined leaf litter of important species from litter bag in the old forest stand at Burnihat

	H. antidysentrica			*V. glabrata*			Miscellaneous		
	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K
Initial	38	549	83	40	550	77	36	571	81
30	62	974	144	45	706	140	47	799	98
60	32	698	125	30	472	137	43	740	106
90	36	680	135	36	560	111	31	772	100
120	31	624	119	31	549	157	28	867	124
150	15	232	50	90	2475	619	13	328	59

Table 5.17. Changes in C/N, C/P and C/K ratios during decomposition of woody litter from litter bags in the young and old forest stands at Burnihat

	Young stand			Old stand		
Days	C/N	C/P	C/K	C/N	C/P	C/K
Initial	68	614	31	51	500	35
60	69	760	45	58	586	48
120	62	640	73	50	616	51
210	63	675	68	46	517	44
270	61	460	56	36	540	43
330	76	667	57	27	399	40
390	36	697	47	26	399	40
450	29	400	46	23	351	33
510	40	465	39	19	340	32
570	44	700	64	23	353	37

Table 5.18. Changes in C/N, C/P and C/K ratios during decomposition of confined leaf litter of important species and total woody litter from litter bag in the young forest at Shillong

	Leaf litter											
	P. kesiya			*M. esculenta*			Miscellaneous			Woody litter		
Days	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K
Initial	52	750	141	40	550	50	47	1025	227	38	891	170
60	66	862	436	45	683	128	58	1167	263	40	930	182
120	53	886	550	46	617	154	61	1145	266	39	930	190
180	43	742	411	42	658	174	59	1275	264	34	971	184
240	45	599	360	34	638	291	55	1349	350	32	769	236
300	43	680	486	37	500	333	53	1521	356	32	967	250
360	44	800	457	39	558	351	55	933	350	33	999	311
420	42	750	506	36	550	275	64	900	386	31	998	300
480	29	501	398	31	455	257	40	802	266	25	752	299
540	43	732	437	35	569	337	37	700	280	27	771	339
600	33	1066	533	30	1425	760	39	805	298	32	1000	500
660	48	1445	497	-	-	-	-	-	-	-	-	-

Table 5.19. Changes in C/N, C/P and C/K ratios during decomposition of confined leaf litter of important species and total woody litter from litter bag in the old forest stand at Shillong

	P. kesiya			*A. nepalensis*			Miscellaneous			Woody		
Days	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K	C/N	C/P	C/K
Initial	58	805	205	34	456	158	27	600	300	23	741	239
60	50	791	233	35	474	200	27	585	358	22	784	285
120	30	765	278	33	497	188	29	571	444	24	792	317
180	28	764	277	31	517	281	35	828	517	24	787	307
240	25	731	330	27	402	311	24	566	485	26	851	378
300	28	784	356	28	432	326	27	599	529	27	901	375
360	27	750	375	23	418	300	28	609	560	25	833	312
420	30	877	400	23	336	243	23	562	575	24	859	343
480	29	833	357	30	400	348	23	656	656	25	837	420
540	33	845	417	47	945	945	19	585	466	39	1236	800
600	23	720	500	-	-	-	18	473	473	52	1336	1200
660	58	1442	1442	-	-	-	27	533	816	-	-	-

In addition to the above factors, litter decomposition is also influenced by soil reaction. Rapp (1971) reported that vegetation replacement is associated with an acidification of soil, a reduction in cation exchange capacity and the pool of exchangeable cations and transformation of mull humus to mor humus type. It has also been shown that low pH retards decomposition of litter by influencing the activity of decomposer organisms (Sanchez. 1976). Thus, acidic soil at Shillong might have been another important cause for slow decomposition.

The overall effects of physical conditions, litter quality and nature of soil substratum on decomposition have been evaluated through determination of decay constant (k). In general higher values indicate rapid litter decay. The values obtained in the present study are comparable to those of tropical forests (Swift et al. 1979; Singh 1980; Anderson and Swift 1983) and are higher than those reported from the temperate region (Olson, 1963).

Nutrient release during the initial phase of decomposition was similar in all the litter types. Rapid release of nutrients as observed in the present study has also been reported by Singh and Ramakrishnan (1982) from decomposing leaf litter in tropical moist deciduous forest. Upadhyay and Singh (1989) while working in the central Himalayan forest, have also reported similar trend of nutrient release. Similar trend was found by Likens and Bormann (1972) in beech and sugar maple leaves. The net release of any element during decomposition is directly related to the availability of that element to the decomposer organisms (Swift et al. 1979). Carbon is usually in plentiful supply during the early stages of decomposition while N and P are present in much lower amount. As the decomposition proceeds mineral elements along with carbon are released rapidly and their supply become limiting to the decomposers during the later stages of decomposition (Jensen 1929). At Shillong high C:N ratio in the beginning, followed by a rapid decline, indicate the possibility of N and P being limiting for the growth of microorganisms, which, in turn, was probably responsible for slow nutrient release during later stages of decomposition. Negative values of net N and P release after 60 days at Burnihat and 180 days at Shillong do not rule out this possibility. This finding is in conformity with that of Schlesinger (1985) who reported net accumulation of N and P during second phase of litter decomposition. The micro-organisms involved in the immobilization have the ability to immobilize nutrients within their biomass in higher concentrations than found in litterfall (Vogt 1985). In the young stand total N and P immobilization in an annual cycle was 6.00 and 0.30 kg/ha, respectively in the wet hill forest and 1.6 kg/ha N only in the deciduous forest. This amount in the old stand was 0.50 kg/ha for N in the deciduous forest and 0.20 kg/ha for P in the forest at Shillong. The total amount of N immobilized in these forests was less compared to that reported by Upadhyay and Singh (1987) in the mixed oak-pine forest of central Himalaya. N and P immobilization occurred in *M. philippensis*, *H. antidysentrica*, *V. glabrata*, *A. nepalensis*, *M. esculenta* and *P. kesiya* only in the young stand. Upadhyay and Singh (1985), although reported immobilization in few species of the community only, but they have also underlined the importance of other species in nutrient dynamics within the ecosystem. This may be true in these forests also. Comparatively higher nutrient immobilization at the forest floor in the young stand of both the forest types might serve as potential nutrient pool for subsequent community development.

Nutrient input through litterfall and its accumulation on the forest floor in litter mass are largely determined by climate and vegetation (Anderson *et al*. 1983). Both the forests exhibited seasonality in these ecosystem processes. In general, winter season was the favourable period for nutrient input and accumulation while the rainy season was characterized by low accumulation and faster nutrient loss from litter. Obviously this seasonal trend is mainly related to the litterfall pattern and climatic conditions that influenced both decomposition and accumulation.

Annual nutrient return through litterfall and its mean standing state in litter mass increased with increasing age of the stand. Contribution of leaf litter to total nutrient input was more in both the stands while the amount of nutrient returned through woody material was less. Lower nutrient input through woody litter is attributed to its low production owing to the abundance of young trees in the stands at both the sites and generally lower nutrient concentration. Conversely, high nutrient concentration and larger production of leaf litter could be held responsible for higher nutrient return through leaf and miscellaneous fractions. The percentage increase in nutrient input in the old stand through litterfall was N - 138%, P - 90% and K - 217% at Burnihat. The corresponding values for Shillong were 87, 42 and 59%, respectively. The increase in nutrient accumulation in litter mass was N - 20%, P - 14% and K - 30% at Burnihat and N - 6%, P - 2% and K - 8% at Shillong. Similar trend in N, P, K input through litterfall and accumulation in standing dead biomass on forest floor during the vegetation development from shrub stage (5 yr old) to mature balsam poplar stand in boreal forest has been reported by Van Cleave and Viereck (1981). They have also reported

3, 4 and 5 fold increase in N, P and K contents, respectively in the standing dead biomass in the forest floor. A comparative account of N, P and K return through litterfall in some tropical and subtropical forests is given in Table 5.20. The values obtained in the present study are low compared to other places. Lower stand age, poor stand density and basal cover could be the probable reasons for lower nutrient return through litter (Gorham et al. 1979). Apart from these, translocation of nutrients from leaves and leaching of soluble organic and inorganic materials before senescence also affects nutrient return to the forest floor (Tukey 1970). Since a senescent leaf in humid condition of tropical rain forest has a rich phylloplane flora (Ruinen, 1961), the extent of decomposition of standing dead biomass before falling on the forest floor is a factor of considerable importance which might have also influenced the amount of nutrients returned through litter.

The relationship between nutrient input through litterfall and mean standing state on the forest floor has been widely used to compare turnover rate of nutrient. The tropical forest generally have turnover values greater than one suggesting turnover within a year while values less than one indicate a turnover time that may vary from few years to several decades (Jenny et al. 1949, Olson 1963),

Table 5.20. Amount of mineral nutrients returned through litterfall in some tropical, sub-tropical and temperate forest

Vegetation	Location	N	P	K	Author(s)
Mixed tropical	Zaire	154 - 224	7.9	48 - 87	Laudelout and Meyer (1954)
Mixed tropical	Kade Ghana	199.4	7.2	68.3	Nye (1961)
Mixed moist evergreen	Ivory Coast	104 - 107	4.2 - 13.6	26 - 81	Bernhard (1970)
Amazonian tropical rain forest	Brazil	106	2.1	13	Klinge and Rodrighes (1968)
Tropical deciduous forest (Gutmala)		169	5.8	20	Ewel (1976)
Mixed tropical deciduous forest	Varanasi (India)	18 - 54	1 - 28	6.31	Singh (1968)
Mixed tropical forest	Meghalaya (India)	41.36	25 - 26	21.21	Singh (1980)
Tropical moist deciduous forest					
Young		16.48	0.68	3.69	Present study
Old		38.26	1.26	11.71	-do-
Sub-tropical wet hill forest					
Young		31.66	1.15	7.06	-do-
Old		45.43	1.7	11.33	-do-

a characteristic feature of temperate and alpine climates. In general, higher values of N, P and K turnover indicate their rapid transfer from litter to soil compartment within the ecosystem. But, behaviour of these three elements was not similar with respect to litter category, stand age and forest type. Generally, turnover was faster for leaf nutrients than total litter fraction in all the four stands. As far as age is concerned, turnover was more rapid in the old stand. A wide variation in the behaviour of N, P and K was also noticed in the two forest types. In the moist deciduous forest the trend was N > K > P while in the wet hill forest, it was K > P > N. The trend obtained in the mixed broad leaved forest at Shillong is in conformity with temperate coniferous, temperate deciduous and mediterranean forests (Cole and Rapp, 1981). Faster turnover of N at Burnihat indicates higher requirement for this element in deciduous forest than in the mixed broad leaved forest at Shillong. Higher annual requirement for N in deciduous species compared to the coniferous species has been demonstrated by Cole and Rapp (1981). They also noted that the coniferous forest floor has longer turnover period than the deciduous forest floor. Similar information about K and P is apparently limited, however, the importance of these elements in developing communities cannot be overemphasized (Heitman and Gessel 1963; Madgwick et al., 1970 and Fagerstrom and Lohm 1977).

The annual balance sheet illustrating nutrient movement from aboveground vegetation through litter to soil compartment is given in Table 5.21. It is apparent that the relationship between nutrient input and turnover is changing during the forest regrowth after disturbance. This kind of trend in a series of plantations of varying ages from early stages of development to fully mature *Pinus sylvestris* stand has been reported by Ovington (1957). Besides, relatively high N return in the wet hill forest may be attributed to the presence of *P. kesiya*, since gymnospermous species retain more N before needlefall compared to the deciduous species which translocate significantly more nutrients from older foliage (Nihlgard, 1972 and Cole *et al*. 1978).

A positive balance of N, P and K in soil at deciduous forest and a negative values, extent K in the old stand of wet hill forest, could be one of the major causes for relatively slow recovery of the forest at Shillong. Hilly topography, high rainfall and coarse soil texture all contributed to the impoverishment of soil substratum which had low pH, exchangeable cations and showed relatively high nutrient accumulation in sub-soil layer. In spite of above incongenial edaphic conditions, wet hill forest has a marked advantage over the moist deciduous forest having colonized

Table 5.21. Annual balance sheet (Kg/ha) of nutrients input through litterfall, accumulation in litter mass and soil upto 40 cm depth and release during litter disappearance (values are mean of 1987-88)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	N	P	K	N	P	K	N	P	K	N	P	K
Initial standing state:												
Litter (a)												
Leaf	1.20	0.09	0.63	6.84	0.25	3.20	17.08	0.36	2.63	34.14	0.46	2.96
Total	8.69	0.58	4.48	9.12	0.65	6.96	29.26	0.51	3.47	42.83	0.57	3.69
Soil	1255	180	168	1848	235	264	714	299	109	1445	164	134
Annual input through litter fall (b):												
Leaf	5.23	0.30	1.60	23.69	0.83	7.93	21.31	0.82	5.16	36.33	1.02	6.34
Total	16.48	0.63	3.69	38.26	1.26	11.71	31.66	1.15	7.06	45.43	1.70	11.33
Total input (a + b):												
Leaf	6.43	0.39	2.23	30.53	1.08	11.13	38.39	1.17	7.79	70.51	1.48	9.31
Total	25.17	1.21	8.17	47.38	1.91	18.66	60.92	1.66	10.53	38.26	2.27	15.01

Table 5.21 (Contd.)

	Burnihat						Shillong					
	Young stand			Old stand			Young stand			Old stand		
	N	P	K	N	P	K	N	P	K	N	P	K
Final standing state:												
Litter												
Leaf	1.54	0.10	0.65	5.95	0.22	2.50	10.75	0.22	1.42	17.08	0.27	1.34
Total	1.97	0.45	3.49	16.15	0.51	5.53	53.11	0.57	2.70	29.72	0.41	2.17
Soil	1312	193	203	1874	268	346	672	277	104	1390	161	147
Release through litter:												
Leaf	4.89	0.29	1.58	24.59	0.87	8.63	27.65	0.95	6.38	53.43	1.21	7.97
Total	23.21	0.77	4.69	31.24	1.41	13.14	27.81	1.09	7.83	58.54	1.86	12.85
Gain/loss in soil	57	13	35	26	33	82	-42	-22	-5	-55	-3	13

by *Alnus nepalensis*, a nitrogen fixer, sometimes after about five years of stand growth. This species might have played a significant role in the annual nutrient budget of the stand.

CHAPTER 6

GENERAL DISCUSSION

During early stages of vegetation regrowth on abandoned jhum fallow at Burnihat, herbaceous species such as A. conyzoides and E. odoratum were dominant in the community whereas pine. being the main element of surrounding vegetation, its seedlings were abundant among the early colonisers at Shillong. As the succession progressed, species content in the tree layer increased but it tended to decline in the ground layer. Reduction in light intensity on the forest floor due to gradual closing of overhead canopy and accompanying changes in micro-environmental factors as reported by Peet and Christensen (1980) appear to be the reasons for this trend. The overall increase in species diversity and decrease in dominance with the progression of succession is in agreement of Risser and Rice (1971) and Millinger and McNaughton (1975). The density increased from the young to old stand except in the young stand at Shillong on account of high seedling density of P. kesiya. The increase in basal cover from the young to old stand was 78% in the moist deciduous forest and 73% in the wet hill forest. Litter production in both the forests was related to the increase in basal cover of the stand. A positive correlation between basal cover and litter production has also been established by Gaur and Pandey (1978) and Corsby (1961). Similar relationship was not observed between stand density and litter production in the present study.

Phenological analysis of all the four stands reveals an overall similarity between moist deciduous and wet hill forests, apparently due to broad similarity in the climate of the two sites. Nevertheless, on account of more severe winter at Shillong, leaffall was almost complete in majority of broad leaved species during winter season but peak period of leaffall of pine was during March-April. Similarly, at Burnihat some species shed leaves upto May, therefore the period of leaffall extended from November to May. Trees in the old stand of wet hill forest showed flowering either during [illegible] (May-June, or during post-monsoon (October-December) period. At lower altitude there was only one flowering period during March-April.

Litter production attains higher value at favourable habitats than less favourable sites (Meentemayer 1984). It shows a greater variability in rhythm and may be continuous or seasonal (Bray and Gorham 1964). Since the present study was conducted in two forest types having distinct vegetation composition and slightly different climate, influence of both these factors could be seen on litter production. Besides, the effect of phenological behaviour of species was also evident on litter production pattern in the two forest types.

At Burnihat the young stand was dominated by herbaceous species and the old stand had abundance of deciduous trees. At Shillong the young stand was almost a pure stand of pine while the old stand had a mixed character due to presence of A. nepalensis along with P. kesiya. Thus, the species composition of the four stands was different markedly from one another. This variation in composition was responsible for strongly seasonal pattern of litter production in the herb dominated community to minimal seasonality in the pine dominated young stand at Shillong. In the old stand seasonal effect was minimised due to presence of pine which shed needles almost throughout the year. In both the forests the peak period of litterfall was more or less synchronised with the period of relative drought. The deciduous forest showed one peak during post rainy season (November-December) while the montane forest exhibited peaks during Dec & March. Several other investigators working in tropical forests at different places in India and elsewhere have reported maximum leaffall during the drier part of the year.

Leaf as well as total litter production increased from the young to old stand. The increase was about 68% in the deciduous forest and 50% in the montane forest. This was closely related to species richness and basal cover of the stand. The percentage contribution of different categories of litter to total production is, however, comparable to those reported for other forests of the tropics (Table 4.30). The percentage of woody litter is, however, low probably due to abundance of saplings and young trees in the stand (Christensen 1975).

The annual litter production in the two forest types is related to the rainfall and mean maximum temperature of the area. With the former, it showed direct relation while with the latter it depicted a reverse trend.

Since the climate of the study area is distinctly seasonal, litter production as well as its standing crop followed a seasonal pattern. Winter season being favourable for litterfall and unfavourable for decomposition activity due to low temperature and soil moisture, showed higher amount of litter on the forest floor. Reverse was true for the rainy season when the litterfall was low and decomposition was rapid due to the favourable moisture and temperature conditions (Sharma 1981). The annual mean standing crop although showed an increasing tendency from the young to old stand, it did not differ significantly, possibly due to overriding effect of climate over the age on litter dynamics. An increasing tendency in litter accumulation in secondary successional communities has also been observed by Pandey *et al.* (1980).

The values of decay constant of different fractions of litter are within the range reported by many workers for the tropical forests (Swift et al. 1979). The reasons for the rapid litter turnover may be the favourable microclimate on the forest floor such as temperature, aeration and diurnal wetting and drying cycles due to incomplete canopy development in the stands. The role of these factors on litter decomposition has been emphasized by Lindsay and Monk (1981). The difference in the decay constants in the two forest types may be ascribed to the variation in climatic conditions and quality of litter. Exceptionally high turnover of the litter in young stand at Burnihat was chiefly due to the high proportion of herbaceous litter which tends to decompose more rapidly than tree litter (Jensen 1974).

Decomposition of enclosed litter was faster in the moist deciduous forest at Burnihat than the montane forest at Shillong. Relatively high temperature and favourable soil moisture conditions through major part of the year were responsible for more rapid decay of enclosed litter in the moist deciduous forest than the wet hill forest, where low temperature for about six months provided unfavourable conditions for decomposition. Since the rainfall was not a limiting factor at both the sites, it appears that temperature, rather than the rainfall played a more important role in litter decay. Another factor that regulated temperature within the forest stand was the development of tree canopy. The young stand with an open canopy generally had higher soil surface temperature and might be experiencing wide fluctuations in diurnal temperature and drying and wetting cycles. These microclimatic differences between the young and old stands also contributed to the rapid decay of litter in the former at Burnihat where there was practically no fully grown tree in stand. Relatively rapid decomposition of angiospermous tree leaf litter as compared to pine needle is attributed to the difference in the chemical composition of the two types of litter. Staaf and Berg (1982) have also reported slow decomposition of coniferous litter.

Decomposition rate of litter can be explained in terms of C : element ratio. Plant materials with high C:N ratio tend to decompose more slowly than those having low ratio (Jensen 1929, Brady 1974; Wieder et al. 1983). C:N ratio in all the fractions was more in the wet hill forest than the deciduous forest. This was yet another reason for slow decomposition in the montane forest. In addition to the above factors, litter decomposition is also influenced by soil reaction. It has been shown that low pH retards decomposition of litter by influencing the activity of decomposer organisms (Sanchez 1976). Thus, acidic soil at Shillong might have been another important cause for slow decomposition.

The overall effects of physical conditions, litter quality and nature of soil substratum on decomposition have been evaluated through determination of Jenny's decay constant (k). In general, higher values at Burnihat further indicate more rapid litter decay in moist deciduous forest than wet hill forest. The k values obtained in the present study are comparable to those of tropical forests (Swift et al. 1979, Anderson et al. 1983, Singh 1980) and are higher than those reported from the temperate region (Olson 1963).

Nutrient (N, P, K) release pattern during the initial phases of decomposition of the confined leaf and woody litter was similar. The net release of any element during decomposition is directly related to the availability of that element to the decomposer organisms (Swift et al. 1979). Carbon is usually in plentiful supply during the early stages of decomposition while N and P are present in much lower amounts. As the decomposition proceeds mineral elements along with the C are released rapidly and become limiting to the decomposers during the later stages of decomposition (Jensen 1929). In the montane forest at Shillong high C:N ratio in the beginning followed by a rapid decline, indicates this possibility which, in turn, might have been responsible for slow nutrient release during later stages of decomposition. Upadhyay and Singh (1989) while working in the Central Himalayan forest have reported similar trend of nutrient release during litter decomposition. Negative values of net N and P release after 60 days at Burnihat and 120 days at Shillong indicate immobilization of these elements as suggested by Schlesinger (1985) and Upadhyay and Singh (1989). In the young stand total N and P immobilization in an annual cycle was about 6 and 0.30 Kg/ha, respectively in the wet hill forest and 1.6 Kg/ha N only in the deciduous forest. This amount in the old stand was 0.50 Kg N/ha at Burnihat and 0.20 Kg P/ha at Shillong. Although the amount of N that was immobilized in these forests was less compared to that reported by Upadhyay and Singh (1985), a relatively higher nutrient immobilization in the young stand of both the forest types might have served as a potential nutrient source for the subsequent seral communities.

Nutrient input through litterfall and its accumulation on the forest floor in litter mass are largely determined by climate and vegetation (Anderson *et al*. 1983). In general, winter season was the favourable period for nutrient input and accumulation while the rainy season was characterized by low litter accumulation and more rapid nutrient loss from litter. Leaf litter contributed a major portion to total nutrient input in both the forest types since woody litter production was less owing to the abundance of young trees in the stands. Besides, elemental concentration was also low in the woody litter. Conversely, higher nutrient concentration and larger production of leaf litter could be held responsible for higher nutrient return through leaf and miscellaneous fractions.

Annual return of N, P and K through litterfall and their mean standing state in litter mass increased with increasing age of the stand. At Burnihat, the percentage increase in N, P and K input through litter in the old stand, compared to that of the young stand, was N - 138%, P - 90% and K - 217%. The corresponding values for Shillong were 87, 42 and 59%. The increase of mineral elements in the litter mass was N - 20%, P - 14% and K - 300% at Burnihat and N - 6%, P - 2% and K - 8% at Shillong. The increase in nutrient input and accumulation in standing dead biomass on the forest floor during vegetation development has also been reported by Van Cleave and Viereck (1981) in boreal forest. The amount of N, P and K returned through litter in the two forests is low compared to other tropical and subtropical forests (Table 5.20). Again this may be due to lower stand age and poor stand density and basal cover.

In general, turnover values for N, P and K were higher indicating the rapid transfers from vegetation to soil compartment. The turnover was faster for leaf nutrients than for the total litter and generally it was more rapid in the old stand. A wide variation in the behaviour of N, P and K turnover was noticed in the two forest types. In the moist deciduous forest the trend was N > K > P while in the wet hill forest it was K > P > N. The trend observed in the wet hill forest is in conformity with temperate coniferous, temperate deciduous and mediterranean forests by Cole and Rapp (1981). They also noted that the coniferous forest floor had longer turnover period than the deciduous forest floor. Faster turnover of N in the moist deciduous forest and that of K in the wet hill forest indicates different nutrient requirement by the seral communities.

Cole and Rapp (1981) concluded that the requirement for different elements was significantly different in deciduous and coniferous forests and it was higher in the former.

The annual N, P, K balance-sheet showed that the input of nutrients and their turnover increased during vegetation regrowth at least upto 5-20 years of age. This kind of trend has been reported by Ovington (1959) in a series of plantation of varying ages from early stage of development to fully mature <u>Pinus sylvestris</u> stand.

A positive balance of N, P and K in soil at deciduous forest and negative values, except K, in the old stand of wet hill forest could be one of the major causes for relatively slow recovery of the forest at Shillong. Hilly topography, high rainfall and coarse soil contributed to the negative balance of mineral elements by accelerating losses from the soil substratum. In spite of above incongenial edaphic conditions wet hill forest has a marked advantage over the moist deciduous forest since Alnus nepalensis, a nitrogen fixer, became an important component of the community sometimes after about five years of stand growth and might have played a significant role in the annual nutrient-budget, particularly N-budget of the stand.

A summary of the annual litter production, N, P and K input through litter, their mean standing state in litter and soil and release during decomposition are given in Figures 6.1, 6.2. The two forests exhibited a broad similarity in the above parameters during secondary succession. However, input : output (release) ratio of the nutrients (N, P, K) decreased from 1.8 to 1.4 in the moist deciduous forest and 1.4 to 1.2 in the wet hill forest. In the wet hill forest the ratios for all the three elements decreased in similar manner from the young to old stand but in the moist deciduous forest the ratio for P decreased

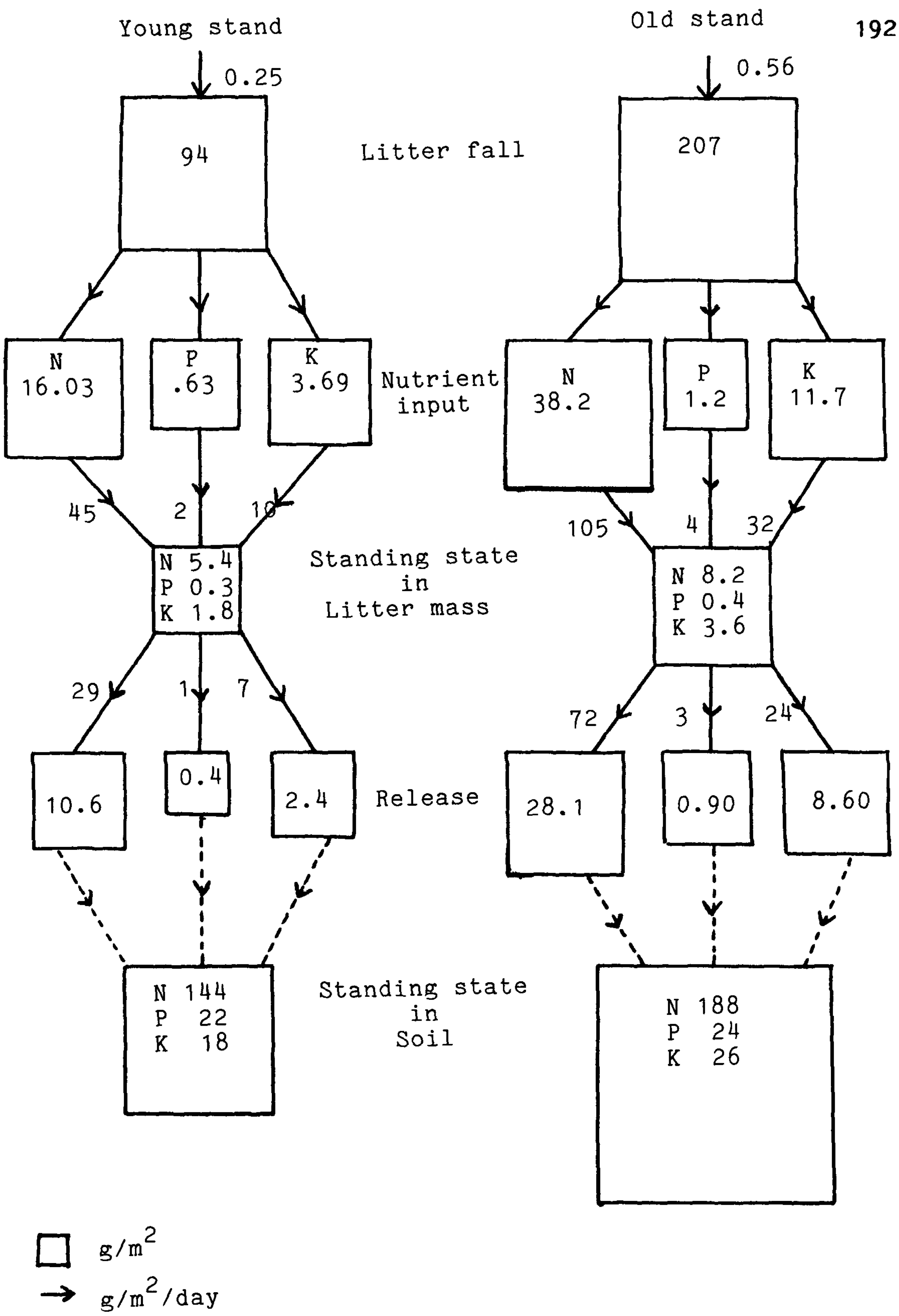

Figure 6.1. Schematic representation of annual litter production, nutrient input through litter, mean standing state in soil and litter and release during decomposition in the young and old stands in moist deciduous forest at Burnihat.

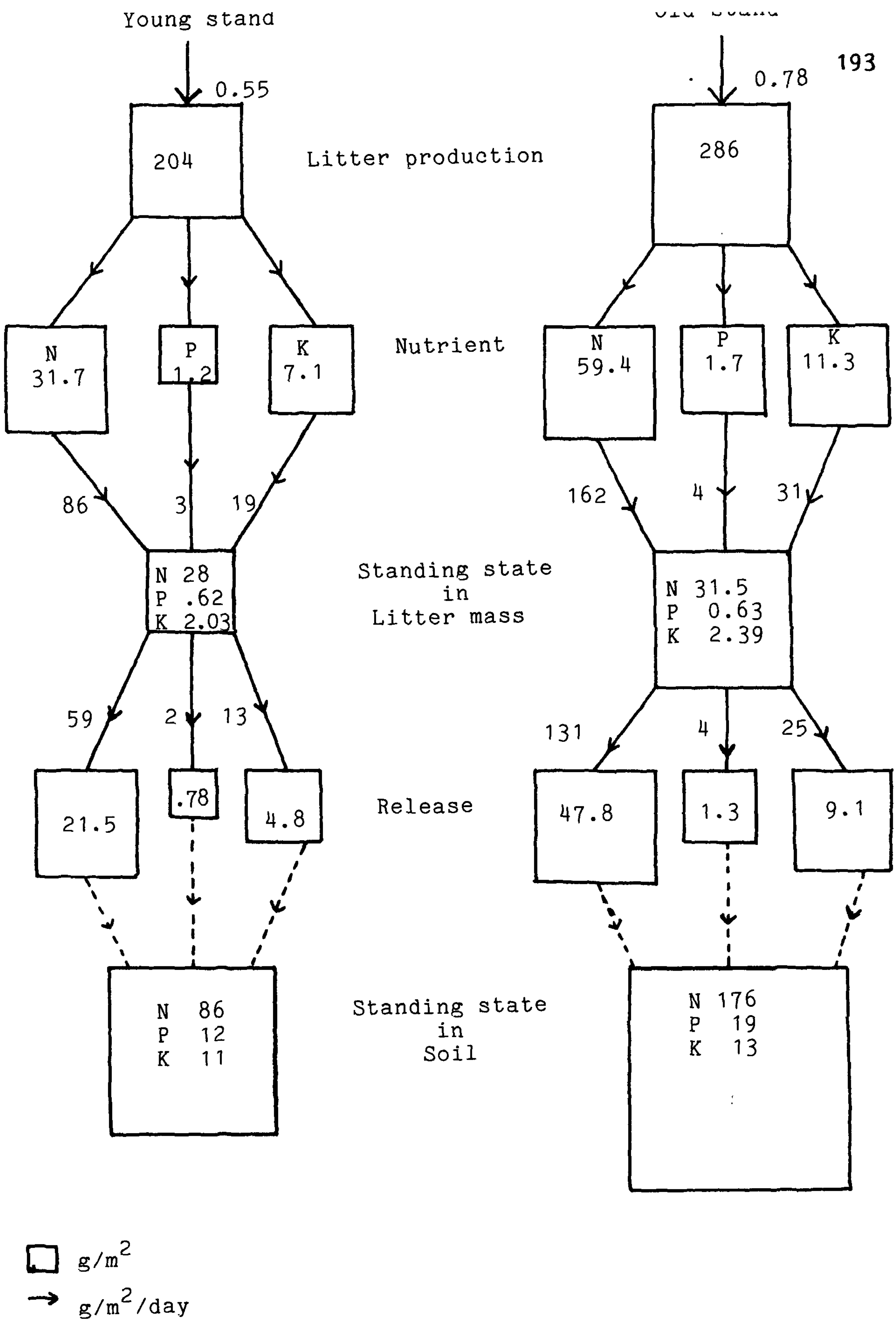

Figure 6.2. Schematic representation of annual litter production, nutrient input through litter, mean standing state in soil and litter and release during decomposition in the young and old stands in subtropical wet hill forest at Shillong.

more sharply than K and N. Greater reduction in the total elemental input : output ratio during secondary succession in moist deciduous forests was marked by better growth and development of the community. Among the three elements P seemed to have played more important role in vegetation growth, since it showed greater dynamism than the other two, especially in the moist deciduous forest.

SUMMARY

Community composition, litter production, decomposition, and N, P and K input through litter and their accumulation in litter mass and soil were studied in the regenerating young (⩽ 5 year old) and the old (15 - 20 year old) stands of moist deciduous forest at Burnihat (altitude 100 m) and wet hill forest at Shillong (altitude 1500 m) during 1987-88. The important findings of the study are summarised below:

1. The young stand at Burnihat was almost devoid of tree element and was dominated by herbaceous species like A. conyzoides and E. odoratum. In the old stand H. antidysentrica was the dominant tree species with abundant growth of A. conyzoides on the forest floor. At Shillong both young and the old stands were dominated by P. kesiya. The ground vegetation in both the stands showed dominance of Pteris longipes.

2. Number of tree species increased from 3 in the young stand to 10 in the old stand at Burnihat. The corresponding numbers were 5 and 7 at Shillong. Number of species in the ground flora decreased from the young to old stand at both the sites. The two stands of wet hill forest were more similar (ISJ - 72%) than those of moist deciduous forest (ISJ - 25%).

3. Density and frequency of trees of higher girth classes were more in the old stand at both the sites. Total basal cover increased from the young to old stand. The increase was more at Burnihat than at Shillong. The total stand density ranged from 10 to 530 plants/ha at Burnihat and 680 to 1350 plants/ha at Shillong.

4. Tree species diversity increased but dominance decreased from the young to old stand. The ground flora showed a reverse trend.

5. Phenology showed a distinct seasonality in both the forests. Most of the species showed leaffall during winter season (November-February). The period of leaf shedding in the wet hill forest extended until summer season (March-April) on account of P. kesiya.

6. Total annual litter production was 94 g/m^2 in the young stand and 207 g/m^2 in the old stand at Burnihat. The corresponding values for Shillong were 204 and 286 g/m^2. The peak period of litter production in both the forest types was between November to February. The percent contribution of leaf to total litter production declined from the young to old stand at Burnihat but increased at Shillong. The woody litter did not show marked difference either between the stands or between the forest types.

7. Litter production exhibited positive relationship with density and basal cover except in the old stand of wet hill forest where density declined but production increased.

8. Seasonality in litter mass was similar to that of litter production. The mean annual litter standing crop was 32 g/m^2 in the young and 51 g/m^2 in the old stand at Burnihat. The values for Shillong were 95 and 107 g/m^2, respectively. Thus, there was 63% increase in litter accumulation on forest floor in the moist deciduous forest and 54% in the wet hill forest in about 10 years of forest regrowth.

9. Turnover rate of total litter increased with the progression of succession and the values ranged from 3 to 4 and 2 to 3 at Burnihat and Shillong, respectively. Turnover of leaf litter was faster than total litter but it decreased with stand age.

10. About 64 and 72% of the total annual litter production disappeared in the young and old stands, respectively at Burnihat. The corresponding values for Shillong were 68 and 81%.

11. Decomposition of confined litter was faster in the moist deciduous forest than the wet hill forest. Decay

constant (k) revealed greater influence of litter quality than the stand microclimate on the decomposition process.

12. Net N, P and K release was more during early phase of decomposition, irrespective of litter quality, forest type and stand age. The phase of rapid nutrient release was until 60 days in the moist deciduous forest and 120 days in the montane forest. The net release of N and P was slowed down beyond this time but it remained unchanged in case of K.

13. C:N ratio in all the litter fractions was more in the wet hill forest than the deciduous forest.

14. Annual immobilization of N was 1.6 kg/ha in the young and 0.5 kg/ha in the old stand of the deciduous forest whereas 6 kg/ha N was immobilized only in the young stand of the wet hill forest. P was immobilized only in wet hill forest. The amount was slightly higher in the young stand (0.3 kg/ha) than in the old stand (0.2 kg/ha).

15. Annual nutrient return through litter and its mean standing state in litter mass increased with increase in age of the stands. In an annual cycle, winter season was the favourable period for nutrient input and accumulation while the rainy season was characterized by low accumulation and faster nutrient loss from the litter.

16. In the moist deciduous forest N, P and K return was 16.03, 0.63, 3.69 $g/m^2/yr$ in the young stand and 38.26, 1.26, 11.71 $g/m^2/yr$ in the old stand, respectively. The corresponding figures for the young and old of wet hill forest were 31.66, 1.15, 7.06 $g/m^2/yr$ and 57.45, 1.70, 11.33 $g/m^2/yr$, respectively.

17. In the young stand the mean standing state of N, P and K was 5.46, 0.33, 1.83 $g/m^2/yr$ in the moist deciduous forest and 27.99, 0.62, 2.03 $g/m^2/yr$ in the wet hill forest. The percent increase in the old stand over the young stand was N 60, P 56, K 66% in the former and N 52, P 50, K 54% in the latter forest.

18. The turnover rate of the elements was N > K > P in the moist deciduous and K > P > N in the wet hill forest.

19. Annual release of N, P and K through litter was 10.6, 0.4 and 2.4 g/m^2 in the young stand and 28.1, 0.90 and 8.6 g/m^2 in the old stand of the moist deciduous forest. The corresponding values for wet hill forest were 21.5, 0.78, 4.8 and 47.8, 1.3, 9.1 g/m^2, respectively.

20. Total nutrient (N, P, K) input and output (release) ratio decreased from 1.8 to 1.4 in the moist deciduous forest and 1.4 to 1.2 in the wet hill forest. The decline of input/ output ratio for P was more distinct than N and K in the

moist deciduous forest. The annual balance-sheet showed a net gain of N, P and K in soil at Burnihat and a net loss at Shillong.

21. Both the forests exhibited almost similar recovery pattern in community structure and processes, particularly nutrient (N, P, K) transfers and accumulation through litter within the ecosystem after cessation of human intervention. Nonetheless, the changes occurred at a faster pace in the deciduous forest probably due to net gain of essential macro-nutrients such as N, P and K in the forest floor during succession.

REFERENCES

Adaltonen V T 1948 Boden und Wald Paul Parey (Berlin and Hamburg)

Allen S E 1974 Chemical analysis of ecological materials (Oxford: Blackwell Scientific Publication)

Anderson J M and Swift M J 1983 Decomposition in tropical forests; in Tropical rain forest ecology and management (eds) S L Sutton T C Whitmore and A C Chadwick (Blackwell Scientific Publication) pp 287-219

Anderson J M Proctor J and Vallack H W 1983 Ecological studies in four contrasting areas of lowland rain forests in Gunung Mulu National Park III Decomposition process and nutrient losses from leaf litter; J. Ecol. 71 503-528

Bandhu D 1973 In Modeling Forest Ecosystem EDFB-IBP 73-80 (Oak Ridge USA)

Bazzaz F A 1979 The physiological ecology of plant succession; Annu. Rev. Ecol. Syst. 10 351-371

Beard J S 1946 The Mora forests of Trininad British West Indies; J. Ecol. 33 173-192

Berg B and Staaf H 1980 Decomposition rate and chemical changes of Scots pine needle litter II Influence of chemical composition; in Structure and function of northern coniferous forests. An ecosystem study; Ecol. Bull. 32 373-390

Berg B and Staaf H 1981 Leaching, accumulation and release of nitrogen litter; in Terrestrial nitrogen cycles processes ecosystem strategies and management impacts; Ecol. Bull. 33 163-178

Berhard Reversat F 1970 Etude de la littiere et de la contribution all cycle des elements mineraux en foret ompbrophile de cote-dilvoira; Oecologia 5 247-266

Bernhard Reversat F 1975 Nutrients in throughfall and their quantitative importance in rain forest mineral cycles; in Tropical Ecological Systems Ecological Studies II (eds) F B Golley and E Medina (New York: Springer-Verlag Berlin Heidelberg) pp 153-162

Birk E M and Simpson R W 1980 Steady state and the continuous input model of litter accumulation and decomposition in Australian Eucalypt forests; Ecology 61 481-485

Boojh R 1981 Observations on ecological adaptation of a forest ecosystem with emphasis on some tree species; Ph.D. Thesis NEHU Shillong

Boojh R Ramakrishnan P S 1981 Phenology of trees in a subtropical evergreen montane forest in north east India; Geo. Eco. Trop. 5 189-209

Brady N C 1974 The Nature and Properties of Soils (New York: Macmillan)

Brasel H M Unwin G L and Stocker G C 1980 The quality temporal distribution and mineral element content of litterfall in two forest types at two sites in tropical Australia; J. of Ecology 68 123-139

Bray J R and Gorhan E 1964 Litter production in forest of the world; in Advance in ecological research 2 (ed) J B Gragg (New York: Academic Press)

Champion H G 1936 A preliminary survey of the forest types India and Burma; Ind. For. Rec. (NS) Silvi **1** 1-126

Champion H G and Seth S K 1968 A revised survey of forest types of India (Delhi: Manager of Publications Government of India Press) p 404

Christensen D 1975 Wood litterfall in relation to abscission, environmental factors and the decomposition cycle in a Danish oak forest; Oikos **26** 187-195

Cole D W and Rapp M 1981 Elemental cycling in forests; in Dynamic Properties of Forest Ecosystems (ed) D E Reichle (London: Cambridge University Press) **23** 341-403

Cole D W Gessel S P and Turner J 1978 Comparative mineral cycling in reel alder and Douglas-fir; in Utilization and Management of Alder (eds) D G Briggs D S DeBell and W A Atkinson (Pac NW For and Rang Exp Stn Portland Oregon) pp 327-353

Connell J H 1979 Tropical rain forests and coral reefs as open non-equilibrium system; in Population dynamics (eds) R M Anderson B O Turner and L R Taylor (Blackwell Oxford) pp 141-163

Connell J H and Slatyer R O 1977 Mechanism of succession in natural communities and their role in community stability and organization; Amer. Nat. **111** 1119-1144

Cooper A W 1981 Above-ground Biomass Accumulation and net primary production during the first 70 years of succession in Populus grandidentata stands on poor sites in Northern Lower Michigan; in Forest succession concept and application (eds) D C West H H Shugrat and D B Botkin (Ney Yor Ki: Springer-Verlag) pp 339-360

Cooper A W F 1982 Litterfall and decomposition in tropical xeromorphic woodland and scrub; Trop. Ecol. **23** 193-207

Crosby J S 1961 Litter-and-duft fuel in short leaf pine stands in Southeast Missouri; Tech. Pap. Cent. St. For. Exp. Sta. **178** pp 10

Darlong V T 1984 Ecological studies of soil arthropods in forest and jhum system of Laitkor Meghalaya India; Ph.D. Thesis. NEHU Shillong

DeCatanzaro J B and Kimmins J P 1985 Changes in the weight and nutrient composition of litterfall in three forest ecosystem types on coastal British Columbia; Can. J. Bot. **63** 1041-1056

Dommergues Y and Mangenot F 1970 Ecologie Microbienne du sol Masson (Paris)

Duke A and Black G A 1953 Phytogeographical notes on the Brazilian Amazon; Anais. Acad. Bras. Cienc. **25** 1-46

Ebermayer E 1876 Die gesamte Lehre der Waldstreu mit Rucksicht auf die chemische statik des Waldbaues (Berlin Julius Springer) pp 116

Edmiston J 1970 Soil studies in El Verde rain forest; in A Tropical rain forest (eds) H T Odum and R F Pigeon (TID 24270 US Dept Commerce Springfield Virginia 22151) pp 479-87

Edward P J 1977 Studies of mineral cycling in a montane rain forest in New Guinea II production and disappearance of litter; J. Ecol. **65** 971-992

Edwards P J and Grubb P J 1977 Studies on mineral cycling in a montane rain forest in New Guinea I the distribution of organic matter in vegetation and soil; J. Ecol. **65** 945-969

Edwards C A and Heath G N 1963 The role of soil animal in breakdown of leaf material; in Soil Organisms (eds) J Docksen and J Van Der Drift (North Holland Amsterdam)

Egunjobi J K 1974 Litterfall and mineralization in a teak Tactona grandis stand; Oikos. **25** 222-226

Ellenbergh H 1956 Grundlagen der vegetations gliederung I Aufgaben und Methoden der vegetationskunde Eugen (Stuttgart: Ulmer Verlag) pp 136

Ewel J J 1976 Litterfall and leaf decomposition in a tropical forest succession in eastern Gutmala; J. Ecol. **64** 293-308

Fagerstrom T and Lohm U 1977 Growth in Scots pine (Pinus silvestris L) Mechanism of response to nitrogen; Oecologia Berl. **26** 305-320

Fittkau E J and Klinge H 1973 On biomass and trophic structure of the central Amazonian rain forest ecosystem; Biotropica **5** 2-14

Fogel R and Cromack Jr K 1977 Effect of habitat and substrate quality on Douglas-fir litter decomposition in western Oregon; Can. J. Bot. 55 1632-1640

Frankie G W Baker G H and Oplar A P 1974 Comparative phenological studies of trees in Tropical wet and dry forests in the Lowlands of Costa Rica; J. Ecol. 62 881-919

Gaur J P Pandey H N 1978 Litter production in two tropical deciduous forest communities at Varanasi India; Oikos. 30 570-575

Golley F B McGinnis J T Clements R G Child G F and Duever M J 1974 Mineral cyling in a tropical moist forest ecosystem (University of Georgia Press Athens)

Gimez Pompa 1974 Recovery of tropical ecosystems; in Fragile ecosystem evaluation of research and applications in the neotropics (eds) Farnworth E G and Golley F B (Springer-Verlag Berlin Heidelberg New York) pp 113-131

Gong W K 1972 Studies on the rates of fall, decomposition and nutrient element release of leaf litter of representative species in a low land dipterocarp forests; B Sc (Hons) thesis (University of Malaya)

Gong W K and Ong J E 1983 Litter production and decomposition in a coastal hill dipterocarp forest; in Tropical rain forest ecology and management (eds) S L Sutton T C Whitmore and A C Chadwick (Blackwell Scientific Publication) pp 275-285

Gonzalo de Las Salas 1973 Eigenschaften und Dynamik eines Waldstandortes im Grenzbereich des immergrunen tropischen Regenwaldes im mittleren Magdalenatal (Kolumbien) Gottinger Bodenk; Ber. **27** 1-106

Gorham E Vitousek P M Reiners W A 1979 The regulation of chemical budgets over the course of terrestrial ecosystem succession; Annu. Rev. Ecol. Syst. **10** 53-84

Gosz T R Liken G E and Bormann F H 1972 Nutrient content of litterfall on the Hubbard Brook Experimental forest. New Hampshire; Ecology **53** 769-784

Gosz J R Likens G E and Bormann F H 1973 Nutrient release from decomposing leaf litter and branch litter in the Hubbard Brook forest New Hampshire; Ecol. Monograph **143** 173-191

Gosz J R Likens G E and Bormann F H 1976 Organic matter and nutrient dynamics of the foest and forest floor in the Hubbard Brook; Oecologia **22** 305-320

Greenland D J and Kowal J M C 1960 Nutrient content of the moist tropical forest of Ghana; Pl. Soil. **12** 154-174

Greenland D J and Nye P H 1959 Increase in Carbon and Nitrogen contents of tropical soils under natural fallows; J. Soil. Sci. **9** 284-299

Hains B and Foster R B 1977 Energy flow through litter in a Panamanian forest; J. Ecol. **65** 147-155

Hall J R and Okali D U U 1979 A structural and floristic analysis of woody fallow vegetation near Ibadan Nigeria; J. Ecol. 67 321-346

Hanes T L 1977 Californian Chaparral; in Terrestrial vegetation of California (eds) M G Barbour and J Major Wiley (New York USA)

Harmon M E Bratton S P and White P S 1983 Disturbance and vegetation response in relation to environmental gradients in the Great Smoky mountains; Vegetatio 55 129-139

Harris W F Sollins P Edwards N T Dinger B E and Shugart H H 1975 Analysis of carbon flow and productivity in a temperate deciduous forest ecosystem, productivity of world ecosystem; Proc. Symp. V. General Assembly of the special committee for the IBP Seattle Wash Natl. Acd. Sci. (Washington DC) pp 116-138

Heilman P E and Gessel S P 1963 Nitrogen requirement and the biological cycling of nitrogen in Douglas-fir stands in relationship to the effects of nitrogen fertilization; Plant and Soil 18 386-402

Henderson G S and Harris W F 1974 An ecosystem approach to characterization of the nitrogen cycle in a deciduous forest watersheds; in Forest soil and forest lands management (eds) B Bernier and C H Winget Proc. IV Amer. Forest Soils Conf. (Larval University Quebec) pp 179-93

Hopkins B 1966 Vegetation of the Olokemeji Forest Reserve Nigeria IV, the litter and soil with special reference to their seasonal changes; J. Ecol. 54 687-703

Hutchinson H B and Richards E H 1981 Artificial farmyard manure; J. Min. Agr. **28** 398-411

Jaccard P 1912 The distribution of the flora in the alpine; New Phyto. **11** 37-87

Jenny H, Gessel S P and Bringham F T 1949 Comparative Study of decomposition rates of organic matter in temperate and tropical region; Soil Sci. **68** 419-432

Jensen H L 1929 On the influence of C:N ratios of organic material on the mineralization of nitrogen; J. Agr. Sci. **19** 71-82

Jensen H L 1931 The microbiology of farmyard manure decompostion in soil - I Changes in the microflora and their relation to nitrification; J. Agric. Sci. **21** 38-80

Jensen V 1974 Decomposition of angiosperms tree leaf litter; in Biology of Plant Litter Decomposition Vol I (eds) C H Dickinson and G S F Pugh (Academic Press, London and New York) pp 65-104

Jordan C F 1971 A world pattern of plant energetics; Amer. Scientist **59** 425-433

Jordan C and Murphy P G 1978 A latitudinal gradient of wood and litter production and its implication regarding competition and species diversity in trees; Amer. Midland Naturalist **99** 415-434

Jorgensen J R, Wells G G and Metz L J 1975 The nutrient cycle, key to continuous forest production; Journal of Forestry **73** 400-403

Kapur J N and Saxena H C 1967 Mathematical Statistics (S. Chand and Co.) Fourth edition

Kapur S K, Sarin Y K and Shahi A K 1986 Production decomposition and nutrient dynamics of tree species of Trikuta forest (India); J. Ecom. Taxon. Bot. **7** 49-54

Khan M L 1986 Ecological studies on regeneration of a few tree species in subtropical wet hill forests of Meghalaya; Ph.D. thesis, NEHU Shillong

Khan M L, Rai J P N and Tripathi R S 1987 Population structure of some tree species in disturbed and protected subtropical forests of north-east India; Acta. Oecologica (Oecol. Applic.) **8** 247-255

Klinge H and Rodrigues W A 1968 Litter production of tropical trees in an area of Amazonia terrifirma forest. Part II. Mineral nutrient content of the litter; Amazonia **1** 303-310

Kira T and Shidei T 1967 Primary productivity and turnover of organic matter in different forest ecosystems of the Western pacific; Jpn. J. Ecol. **17** 70-87

Kira T, Ogawa H, Yoda K and Ogfno K 1967 Comparative ecological studies on three main types of forests vegetation in Thailand IV. Nature Life S.E. Asia **5** 149-174

Kirpatrick J B 1984 Altitudinal and successional variation in the vegetation of the northern part of the West Coast Range Tasmania; Aus. J. Ecol. **9** 81-91

Kitazawa Y 1974 International wood lands workshop IBP-PT 1973 Gottinger Bodenkundliche Brichte **30**

Klinge H 1978 Litter production in tropical ecosystem; Malay Nat. J. 30 415-422

Knight D H 1975 A phytosociological analysis of species with tropical forests on Barro Colorado island Panama; Ecol. Monograph 451 259-284

Lam P K S and Dudgeon D 1988 Litter production in mixed forest Hong Kong Island; J. Trop. Ecol. 1 55-64

Lamb R J 1985 Litterfall and nutrient turnover in 2 eucalypt woodlands; Aust. J. Bot. 33 1-14

Lamotte M 1981 Research on the characteristics of Energy flows within Natural and man-altered Ecosystems; in Disturbance and Ecosystem (eds) H A Mooney and M Gordon Ecological Studies 44 48-70

Laudelot H and Meyer J 1954 Les cycles d'elements minerauz et de matrix organique end forest equctarials congolaise; Trans. Fith. Int. Cong. Soil. Sci. (Comm. II) pp 267-272

Lang G E and Forman R T T 1978 Detrital dynamics in a mature oak forest Hutchinson Memorial Forest New Jersey; Ecology 59 580-595

Levilt J 1972 Responses of plants to environmental stresses (Academic Press: London New York)

Likens G E and Bormann F H 1972 Nutrient cycling in ecosystems; in Ecosystem structure and function (ed) J A Wiens (Proceed 31st Annual Biology Colloquium Oregeon State University Press) pp 25-67

Likens G E, Bormann F H and Johnson N M 1969 Nitrification Importance of nutrient losses from a cut jover forested ecosystem; Science **163** 1205-1206

Likens G E, Bormann F H, Johnson N M, Fisher D W and Pierce R S 1970 Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed Ecosystem; Ecol. Monogr. **40** 23-47

Likens G E, Bormann F H, Pierce R S, and Reiners W A 1978 Recovery of a deforested ecosystem; Science **199** 492-496

Lim M S 1978 Litterfall and mineral nutrient content of litter in Pasoh Forest Reserve Malayan; Nature **30** 275-280

Lindsay E Rusted 1988 Element loss and retention during litter decay in a required space stand in Maine; C. J. For. Res. **18** 947-953

Lindsay R B and Monk C D 1981 Early regeneration of a clear cut southern Appalachian forest; Ecology **62** 1244-1253

Lousier J D and Parkinson D 1976 Litter decomposition in a cool temperate deciduous forest; Can. J. Bot. **54** 419-436

Lutz H J and Chandler R F Jr 1946 Forest Soils (John Wiley New York) p 514

MacLean D A and Wein R W 1976 Biomass of jack pine and mixed hardwood stands in northeastern New Brunswick; Can. J. For. Res. **6** 441-447

Madge D S 1965 Leaffall and litter disappearance in a tropical forest; Pedobiologia **5** 273-288

Madgwick H A I, White E H, Xydias G K and Leaf A L 1970 Biomass of Pinus resinosa in relation to potassium nutrition; For. Sci. **10** 154-163

Marks P L and Bormann F H 1972 Revegetation following forest cutting mechanisms for return to steady state nutrient cycling; Science **176** 914-915

Mehra M S, Pathak P C and Singh J S 1985 Nutrient movement in litterfall and precipitation components for Central Himalayan forests (India); Ann. Bot. **55** 153-170

Meentemeyer V 1984 The geography of organic decomposition rates; Annals of the Association of American Geographers **74** 551-560

Meentemeyer V 1978 Macroclimate and lignin control of litter decomposition rates; Ecology **59** 465-472

Mellinger M V and McNaughton S J 1975 Structure and function of successional vascular plant communities in Central New York; Ecol. Monogr. **45** 161-182

Mikola P 1955 Experiments on the rate of decomposition of forest litter; Comm. Inst. For. Fenn. **43** 1-50

Mishra B K and Ramakrishnan P S 1983 Secondary succession subsequent to slash and burn agriculture at higher elevations of north-east India II Nutrient cycling; Acta. Oecologia (Oecol. Applic.) **4** 237-245

Misra R 1968 Ecolog Workbook (Oxford & IBH Publishing Co.)

Mitchell M J 1974 Interactions of oribatid mites (Acari: Cryto stigmata) and fungi in an aspen woodland (Populus tremuloides Mich) soil; Bull. Ecol. Soc. Amer. p 51

Mooney H A 1977 The carbon cycle in mediterranean climate evergreen shrub communities; in Proc. Symp. the environmental consequences of fir and fuel management in mediterranean ecosytems (eds) H A Mooney and C E Conrad (Washington D C)

Moore P D and Chapman S B 1986 Methods in Plant Ecology, 2nd edition (Blackwell Scientific Publication, Oxford)

Muller P E 1887 Studien uber die naturlichen Humus formen und deren Einwirkung auf vegetation und Boden (Berlin Julius Springer) pp 324

Muller R N and Martin W H 1983 Autumn leaffall and nutrient return in an old growth and a second-growth forest in Eastern Kentucky; Bot. Gaz. **144** 552-558

Muller D and Nicesen J 1965 Production brute pertes par respiration et production nette dans la foret ombrophile tropicale Det Forstlige; Forsogsvaesen i Denmark **29** 69-160

Nicholson S A and Monk C D 1974 Plant species diversity in old field succession on the Georgia Piedmont; Ecology **55**(5) 1075-1085

Mihlgard B 1972 Plant biomass primary productivity and distribution of chemical elements in beech and planted spruce forest in South West Sweden; Oikos **23** 69-81

Nye P H 1961 Organic matter and nutrient cycle under moist tropical forest; Plant and Soil 13 333-346

Odum E P 1969 The strategy of Ecosystem development; Science 164 262-270

Ogawa H 1978 Litter production and carbon cycling in Pasoh forest Malayan; Nature Journal 30 367-373

Olson J S 1963 Energy storage and the balance of producers and decomposers in ecological system; Ecology 44 322-331

Ovington J D 1957 Dry matter production by Pinus sylvestris; Ann. Bot. 21 287-314

Ovington J D 1962 Quantitative ecology and the woodland ecosystem concept; in Advances in Ecological Research (Ed) J B Cragg (Academic Press, London and New York pp 103-192

Ovington J D 1965 Organic jproduction, turn over and mineral cycling in woodlands; Biol. Rev. 40 295-336

Pandey, Uma and J S Singh 1984 Nutrient changes and release during decomposition of leaf litter in a Himalayan (India) Oak conifer forest; Can. J. Bot. 62 1824-1831

Pandey H N, Gaur J P and Singh R N 1980 Litter input and decomposition in tropical dry deciduous forest, grassland and abandoned crop field communities at Varanasi, India; Acta. Ecologia (Ecol. Plant) 1 317-323

Park D 1976 Cellulose decomposition by a Pythiaceous fungus; Trans. Birt. Mycol. Soc. 66

Parkinson D 1967 Soil micro-organisms and Plant roots; in Soil Biology (eds) A Burges and F Raw (Academic Press, New York) pp 449-527

Parnas H 1975 Model for decomposition of organic material by micro-organisms; Soil. Biol. Biochem. **7** 161-169

Peet R K and Christensen N L 1980 *Succession of population* process; Vegetatio **43** 131-140

Prasad Ram and Mishra G P 1985 Litter productivity of dry deciduous forests stands of Sagar (M.P.) India; Indian For. **111** 359-367

Proctor J, Anderson J M, Fogden S C and Vallack H W 1983 Ecological studies in four contrasting rain forest in Gunung Mulu National park Sarawak II Litterfall, litter standing crop and preliminary observations on herbivory; J. Ecol. **71** 261-283

Puri G S 1953 Leaffall in Dehra Dun forests; Bull. Bot. Boi. Univ. Saugor. **9** 28-34

Rai R K 1986 Structural and geomorphic evolution of Meghalaya Plateau India on landsat imagery Proceeding of IGARSS Symposium; Zurich ESA SP-254

Rai B and Srivastava A K 1982 Decomposition of leaf litter in relation to microbial populations and their activity in a tropical dry mixed deciduous forest; Pedobiologia **24** 151-159

Ramakrishnan P S, Tokey O P and Mishra B K 1981 Jhum - An ecological assessment Souvenir Silver Jubilee Symposium of the Intrnational Society of Tropical Ecology (Bhopal India) pp 41-49

Rapp M 1971 Cycle de la matiere organique et des elements mineraux dans quelques ecosystemes mediterraneens Editions du Centre Nationale de la Recherche Scientifique Paris Recherche Cooperative sur programme du CNRS **40** pp 184

Reichle D E ed 1981 Dynamic properties of forest ecosystem (Cambridge University Press Cambridge)

Reiners W A 1980 Nitrogen cycling in relation to ecosystem succession; in Terrestrial nitrogen cycles processes, ecosystem strategies and management impacts (eds) Clark F E and Rosswall T Ecol. Bull. (Stockholm) **33** 507-528

Reiners W A and Reiners N M 1970 Energy and nutrient dymanics of forest floor in three Minnesota forests; J. Ecol. **58** 497-519

Richard P W 1952 The Tropical Rain Forest (Cambridge Universsity Press Cambridge)

Richerson P J and Lum K 1980 Patterns of jplant species diversity in California Relation to Weather and Topography; America Naturalist **116** 504-536

Risser P G and Rice E L 1971 Diversity in tree species in Oklahoma upland forests; Ecology **52** 876-880

Rochow J J 1975 Mineral nutrient pool and cycling in a Missouri forest; J. Ecol. **63** 985-994

Rodin L E and Bazilevich N I 1967 Production and mineral cycling in terrestrial vegetation (Oliver and Boyds Ltd London)

Rosen K 1984 Effect of clear-felling on runoff in two small watersheds in Central Sweden; For. Ecol. Management **9** 267-281

Ruinen J 1961 Pl. Soil **15** 81-109

Sanchez P A 1976 Properties and Management of soils in the Tropics (Wiley London)

Sapozhnikov A P 1987 Forest litter Nomenclature classification and notation; Pochvovedenie **0(5)** 96-105

Satchell J E 1974 Litter - Interface of animate/inanimate matter; in Biology of Plant litter decomposition (eds) Dickinson C H and Paugh G J F (Academic Press London and New York)

Schlesinger W H 1985 Decomposition of chapparral shrub foliage; Ecology **66** 1353-1359

Shanks R E and Olson J S 1961 First-year breakdown of leaf litter in southern Appalachian forests; Science **134** 194-195

Shannon C E and Wiener W 1963 The mathematical theory of communication; University of Illinois Press (Urbana) pp 117

Sharma G D 1981 Ecological studies on mycorrhizae of Pine (Pinus kesiya Royle ex 6 Gordon) Ph.D. Thesis, NEHU Shillong

Simpson E H 1949 Measurement of diversity; Nature **163** 688

Singh J 1980 Studies on structural and functional aspects of two subtropical humid forest types of Meghalaya Ph.D. thesis NEHU Shillong

Singh Jasbir 1984 Effect of temperature rainfall and soil moisture on soil respiration and litter decomposition in a subtropical humid forest ecosystem; Acta. Bot. Indica. **12** 167-73

Singh K P 1968 Litter production and nutrient turn over in deciduous forests of Varanasi; Proc. Symp. Recent Adv. Trop. Ecol. pp 655-665

Singh K P 1969 Studies in decomposition of leaf litter of important trees of tropical deciduous forests at Varanasi; Trop. Ecol. **10** 292-311

Singh J and Ramakrishnan P S 1982 Structure and function of a subtropical humid forest of Meghalaya II. Litter dynamics and nutrient cycling; Proc. Indian Acd. Sci. (Plant Sci.) **91** 255-268

Singh J S and Singh S P 1987 Structure and functioning of Central Himalayan Chirpine forest ecosystem; Curr. Sci. **56** 383-391

Singh R P Mathur H N and Gupta M K 1984 Litter production and release on nutrients in coniferous forest of Himachal Pradesh (India); Indian For. **110** 1014-1022

Staaf H 1988 Litter decomposition in beech forests effects of excluding tree roots; Biol. and Fertility of Soils **6** 302-305

Staaf H and Berg B 1981 Accumulation and release of plant nutrients in decomposing Scots pine needle litter, long-term decomposition in a scots pine forests II; Can. J. Bot. **60** 1561-1568

Staaf H and Berg B 1982 Release and accumulation of jplant nutrients in needle litter during decomposition of scots pine needle litter II; Can. J. Bot. **60** 1561-1568

Swift M J 1977 The roles of fungi and animals in the immobilization and release of nutrient elements from decomposing branch wood soil organisms as components of Ecosystem; (eds) U Lohm and T Persson Ecological Bulletins (Stockholm 25 Swedish National Science Research Council Stockholm) pp 193-202

Swift M J 1983 The importance of detrital resources in natural and managed terrestrial ecosystems, Proceedings of the Silver Jubilee Symposium, Intrnational Society for Tropical Ecology (ed) K C Mishra (Bhopal, India)

Swift M J, Heal O W and Andrson J M 1979 Decomposition in Terrestrial Ecosystems Studies in Ecology (Blackwell Scientific Publication Oxford)

Swift M J, Russel S A and Perfect T J 1981 Decomposition and mineral nutrients cynamics of plant litter in a regenerating bush-fallow in the sub-humid tropics; J. Ecol. **69** 981-995

Takashi A, Shidei T, Satoo K, Negishi K, Hozumi K, Chiba K, Nishimura T, and Tanimoto T 1970 Progress report of IBP-JIBP special committee in Japanese Science Congress

Tanner E V J 1980 Litterfall in montane rain forest of Jamaica and its relation to climate; J. Ecol. **68** 833-848

Tanner E V J 1981 The decomposition of leaf litter in Jamaican montane rain forest; J. Ecol. **69** 263-273

Tanney F G and Waksman S A 1929 Composition of natural organic materials and their decomposition in the soil IV The nature and rapidity of decomposition of the various organic complexes in different plant materials under aerobic conditions; Soil. Sci. **28** 55-84

Toky O P and Ramakrishnan P S 1983 Secondary succession following slash and burn agriculture in North Eastern India. II Nutrient cycling; J. Ecol. **71** 747-757

Tukey H B Jr 1970 The leaching of substances from plants; Ann. Rev. Plant Physiol. **21** 305-324

Turnbull C R A 1983 Relationship of litterfall to basal area and climatic variables in coll temperate forests of Southern Tasmania; Aus. J. Ecol. **8** 425-431

Upadhyay V P 1988 Pattern of immobilization and release of N in decomposing leaf litter in Himalayan forests; Proceeding of the Indian Academy of Science (Plant Science)

Upadhyay V P and Singh J S 1985 Nitrogen dynamics of decomposing hardwood leaf litter in a Central Himalayan forest; Soil Biology and Biochemistry **17** 827-830

Upadhyay V P and Singh J S 1986 Decomposition of woody branch litter on a altitudinal transect in the Himalaya; Vegetatio **64** 49-54

Upadhyay V P and Singh J S 1989 Pattern of nutrient immobilization and release in decomposing forest litter in Central Himalaya; India J. Ecol. **77** 127-146

Van Cleave K and Noonan L L 1975 Litterfall and nutrient cycling in the forest floor of birch and aspen stands in interior Alaska; Can. J. For. Res. **5** 626-639

Van Cleave K and Viereck L A 1981 Forest succession in relation to Nutrient cycling in the Boreal Forest of Alaska; in Forest Succesion Concepts and Application (eds) D C West, H H Shugart and D B Botkin

Van Hulst R 1978 On the dynamics of vegetation patterns of environmental and vegetational change; Vegetatio **38** 65-75

Vatsauliya P K 1981 Ecological studies on Jhum fallows of Burnihat (Meghalaya) with particular reference to soil fauna; Ph.D. thesis NEHU Shillong

Vitousek P M, Gosz J R, Grier C C, Melillo J M, Reiners W A and Todd R L 1979 Nitrate losses from disturbed ecosystems; Science **204** 469-474

Vogt D J 1985 Forest floor and soil nitrogen dynamics of Douglas-fir ecosystems related to productivity and stand age; Ph.D. dissertation University of Washington, Seattle

Vyas L N and Garg R K 1984 Stand structure and litter production in dry deciduous tropical forests around Udaipur; in Ecology and resource management in Tropics I (ed) K C Mishra pp 320-324

Waksman S A and Tenney F G 1928 Composition of natural organic materials and their decomposition in the soil III The influence of nature and Plant upon the rapidity of its decomposition; Soil. Sci. **26** 155-226

White P S 1979 Pattern process and natural distrubance in vegetation; Bot. Rev. **45** 229-299

Whittaker R H 1975 Communities and ecosystem; 2nd ed. (MacMillan Publishing Co Inc New York)

Wiegert R G and Evans F C 1964 Primary production and the disappearance of dead vegetation on an old field in southeastern Michgan; Ecology **45** 49-63

Wider R K, Carrel J E, Rapp J K and Kucera C L 1983 Decomposition of tall Fescue (Festuca elatior var Arundin acea) and cellulose litter on surface mines and a tallgrass prairie in Central Missuouri USA J. Apl. Ecol. **20** 303-321

William S T and Grey T R G 1974 Decomposition of litter on the soil surface; in Biology of Plant litter decomposition (2) (eds) C H Dickinson and G J F Pugh (Academic Press New York)

Witkamp M 1969 Environmental effects on microbial turnover of some mineral elements I Abiotic factors; Soil. Biol. Biochem. 1 167-176

Witkamp M 1970 Aspects of soil microflora n a gamm-irradiated rain forest; in Tropical rain forest (eds) H T Odum and R F Pigeon (U.S. Dept. Commerce Springfield Virginia 22151) pp 29-62

Witkamp M 1971 Soils as components of ecosystems Annual Review of Ecology and Systematics 2 85-110

Witkamp M and Ausmus B S 1976 Processes in decomposition and nutrient transfer in forest ecosystems; in The role of terrestrial and aquatic organisms in decomposition process (eds) J M Anderson and A Macfadyen (Blackwell Scientific Publication Oxford) pp 375-396

Witkamp M and Frank M 1970 Effects of temperature rainfall and fauna on transfer of 137 Cs K Mg and mass in consumer-decomposer microcosms; Ecology 51 465-539

Yoda K 1978 Organic carbon nitrogen and mineral nutrients stock in the soils of Pasoh forest Malayan; Natural Journal 30 229-251

ERRATA

Page	Line	Read as	Instead of
12	18	release and to	release to
33	3	old stand	old
42	10	in a protected	in protected
78	21	(Tables 4.18, 4.19)	(Tables 4.18, 4.24)
80	-	Table 4.19	Table 4.24
85	6	in the young	at the young
85	8	Mean standing crop of total and leaf litter	Mean standing crop of leaf litter
85	15	in all except the young stand at Shillong (Table 4.24)	in all the four stands (Table 4.15)
87		Table 4.24	Table 4.19
107	15	Likewise	conversely
108	9	more rapidly (Jensen 1974)	more rapid (Jensen 1973)
111	21	succession by Odum (1969)	succession (Odum 1969)
112	22	as the bags with larger	as bag with large
128	13	woody litter	wood
128	19	young to old stand	young stand
129	14	comparison	composition
130	1	has lower concentration	has minimum concentration
170	12	C:N and C:P ratio	C:N ratio
176	15	except K	extent K
184	10	of both the study	of the study
200	4	and the old stands.	young and old of