

DECOMPOSITION OF TERRESTRIAL PLANT LITTERS IN AQUATIC ECOSYSTEMS

R. R. MISHRA and B. K. TIWARI

*Department of Botany, School of Life Sciences,
North-Eastern Hill University, Shillong 793014, India.*

Decomposition is the act of separation of anything into its constituent elements. The term has been used to describe the processes by which the dead organic matter decays and resolves into simpler compounds resulting ultimately into simple inorganic compounds. During the process, chemical bond energy of the organic materials is utilized by various microorganisms and micro and macrofauna whose qualitative composition may vary as the materials decay. The process of decomposition is extremely complex & is controlled by multitude of organisms, chemical and physical properties of litter and by the abiotic factors. The quantity and quality of decomposers are determined largely by the chemistry of the material and the physico-chemical characters of the ecosystem.

The process is of fundamental importance for the proper functioning of any ecosystem. It helps in unlocking and regeneration of nutrients which are made available for the synthesis of fresh biomass by the green plants. Understanding of the process becomes of added importance in the aquatic ecosystems receiving allochthonous organic matter in the form of plant litters which serve as an additional source of energy for the system. Besides primary production, microbial production at the expense of the energy of the allochthonous organic matter also contribute significantly towards the total production of organic matter in such ecosystems. Streams, soil below litter layer, lake and marine benthos and estuaries which are primarily heterotrophic (respiration > production) depend considerably for their energy requirements on the allochthonous organic matter. Allochthonous plant litter input is the most dominant energy source of all woodland streams. The stream communities, generally do not depend on the primary producers and it has been experimentally proved by Hyatt (1961) that more than 2/3 of the species complete their life cycle in the winter when primary production would be minimum.

Thieneman (1912) was the first to point out the importance of organic matter in aquatic systems. Since then several investigators quantitatively assessed the plant litter input into aquatic systems. Eflord's (1969) study in Lake Marion Canada showed that 86% of the total energy in the lake was in the form of forest litter. Quantification of litter input has been done by several workers such as Levanidov (1959), Szczepanski (1965), Vannote (1969), Kowalczewski (1970), Fisher (1971), Fisher & Likens (1972), Liston (1972), Petersen & Cummins (1974), Jordan & Likens (1975), Gash & Haster (1976). The values ranged between 203-750 g m² year. These estimates have clearly demonstrated the degree and extent of contribution of the extraneous plant litters in the aquatic ecosystems.

Studies on decomposition of plant litters on the soil were started in late thirties (Waksman & Tenny, 1927; Waksman *et al.* 1928; Melin, 1930) and since then the subject has reached at an advanced stage of perfection (Dickinson & Pugh 1974; Hayes, 1979). Studies on litter decomposition in aquatic systems started quite late and the pace of progress was also extremely slow, so much so that most of the studies available so far from temperate waters. A couple of detailed study from tropics is of Padgett (1976) and Herbst (1980). The works of Minshall (1967), Kaushik & Hynes (1968, 1971) Mathews & Kowalczewski (1969), Hynes (1963), Iversen (1973), Peterson & Cummins (1974), Willoughby (1974) and Willoughby & Archer (1973) gave sufficient impetus to the subject and presently almost all aspects of terrestrial plant litter decomposition in aquatic systems viz., rate, chemistry change, microbiology, invertebrate interactions as well as system modellings have been studied by various schools of Europe and North America. Since the publication of Willoughby's (1974) review on the subject there has been considerable advancement in this area of study. Therefore, it was thought necessary to review and examine, the recent advances in the subject.

Weight loss : Weight loss is most reliable criterion for estimating plant litter decomposition in aquatic ecosystems. Generally, a modified version of soil litter bag method or sometimes leaf pack is used for this purpose. For the weight loss measurement and quantification of rate of weight loss as well as to get a value which can be compared with other similar studies, an exponential decay model has been used by many terrestrial (Olson, 1963; Ando, 1970; Fogel & Coomark, 1977) and aquatic (Fisher, 1971; Peterson & Cummins, 1974, Hodgkinson, 1974; Gasith & Lawacz, 1976; Benfield *et al.*, 1977; Barnes *et al.* 1978; Herbst, 1980) ecologists. The model assumes that for any amount of material at any time there is a constant fractional loss :

$$W_t = W_0 e^{-kt} \quad \dots \dots 1$$

Where W_0 is the initial weight, W_t is the weight at time t and k is the rate constant or rate coefficient (per day). Recent studies on decomposition of plant litters in aquatic systems (Peterson & Cummins, 1974; Herbst, 1980) have shown that this model is quite useful for comparison of rate of decomposition of plant litters in aquatic systems. Values of k are calculated by equation :

$$\text{Log}_e (\% R/100)/t = -k \quad \dots \dots 2$$

$$\text{or } k = (\text{Log}_e 100 - \text{Log}_e \% R)/t \quad \dots \dots 3$$

where R is weight remaining after time t . Using above equations we can calculate the time required for 50% loss or biological half life ($0.693/k$) and the time required for loss of 95% of the initial weight or 95% life ($3/k$).

TABLE 1

Decay coefficients for various plant litters in aquatic ecosystems

Species	Locality	Type of Habitat	Duration of experiment (days)	Decay Co-efficient, k-1 (days)	92% life (days)	Author
<i>Fagus sylvestris</i> L	Denmark	stream	365	0.0057	525.6	Hodkinson, 1975
<i>F. grandifolia</i>	Canada	river	10210	0.0006	4584.4	Hodkinson, 1975
<i>Quercus alba</i> L	USA	stream	365	0.0175	167.9	Thomas, 1970
<i>Q. alba</i> L	USA	stream	—	0.0052	376.9	Petersen & Cummins 1974
<i>Q. alba</i>	USA	stream	90	0.0038	789.4	Marzolf (in Petersen & Cummins 1974)
<i>Q. alba</i> L	Canada	river	210	0.0012	2439.0	Kaushik & Hyne 1971
<i>Q. rubur</i>	England	stream (3mm)	273	0.0038	789.4	Mathew & Kowleswski, 1969
<i>Q. rubur</i>	England	stream (0.27mm)	273	0.00186	1612.9	—do—
<i>Ulmus americana</i>	Canada	river	210	0.0055	547.5	Kaushik & Hynes (1971)
<i>Acer saccharum</i>	USA	stream	145	0.0107	280.4	Petersen & Cummins 1974
<i>A. pseudoplanatus</i>	England	river	273	0.0108	178.3	Mathews & Kowazewski, 1968
<i>A. pseudoplanatus</i>	Englnd	river	273	0.0025	1200.0	—do—

<i>Acer rubrum</i>	USA	stream	146	0.0062	483.8	Petersen & Cummins, 1974
<i>A. platanoides</i>	USA	stream	146	0.0076	394.7	—do—
<i>A. rubrum</i> L	USA	stream (3mm)*	356	0.0273	109.5	Thomas, 1970
<i>A. macrophyllum</i>	USA	stream	203	0.0049	593.6	Sedell <i>et al.</i> 1980
<i>A. circinatum</i> Pursh	USA	stream	203	0.0122	244.5	—do—
<i>A. saccharinum</i> L	Israel	stream (surface)	365	0.0173	173.4	Herbst, 1980
<i>A. saccharinum</i> L	Israel	stream (buried)	365	0.0034	882.3	—do—
<i>Populus deltoides</i> Marsh	Israel	stream (surface)	365	0.0060	500.0	—do—
<i>P. deltoides</i> Marsh	Israel	stream	365	0.0020	1500.0	—do—
<i>Tilia americana</i>	USA	stream	146	0.0175	171.4	Petersen & Cummins 1974
<i>Cornus amomum</i>	USA	stream	Fall spring	0.0115	260.8	—do—
<i>Decodon verticillatus</i>	USA	stream	—do—	0.0101	280.3	—do—
<i>Fraxinus americana</i>	USA	stream	—do—	0.1200	250.0	—do—
<i>F. nigra</i>	USA	stream	126	0.0084	357.1	—do—
<i>F. nigra</i>	USA	stream	Oct—Feb.			—do—
<i>Salix</i> sp.	Canada	pond(3.9mm)*	126 Nov—March	0.0107	280.3	—do—
<i>Salix</i> sp.	England	river (3mm)*	525	0.0026	1119.4	Hodkinson, 1975
<i>Salix</i> sp.	England	river (3mm)*	273	0.0168	178.3	Mathews & Kowalzewski 1969
<i>Salix</i> sp.	England	river (0.27)	273	0.0058	509.3	—do—
<i>Alnus rugosa</i> (Du Roi) Speng.	Canada	river	210	0.0011	2608.6	Kaushik & Hynes, 1971

Species	Country	Stream	233	0.0049	568.6	Sedell et al, 1974
<i>Alnus rubra</i> Bongard	USA	stream	233	0.0049	568.6	Sedell et al, 1974
<i>Deschampsia cespitosa</i> L. Beauv.	Canada	Pond(3.5mm)*	525	0.0018	1639.3	Hodkinson, 1975
<i>Juncus tracyi</i> Rydberg.	Canada	Pond(3.5mm)*	525	0.0011	2678.5	—do—
<i>Pinus contorta</i> Louden.	Canada	Pond(3.5mm)*	525	0.0005	5217.3	—do—
<i>Liriodendron tulipifera</i> L.	USA	stream	525	0.0147	171.4	Thomas, 1970
<i>Pseudotsuga menziesii</i> (Mirt) Franco.	USA	stream	203	0.0049	203.5	Sedell et al. 1974
<i>Tsuga heterophylla</i> (Raf) Sarg.	USA	stream	203	0.0049	667.7	—do—
<i>Carya glabra</i>	USA	lake(2.m deep)	85	0.0512	58.5	Barnes, et al 1978
<i>C. glabra</i>	USA	lake(6m deep)	85	0.0195	153.8	—do—
<i>C. g'abra</i>	USA	lake(12m deep)	72	0.0027	1111.1	—do—
<i>Quercus alba</i>	USA	lake(2.5m deep)	85	0.0080	375.0	—do—
<i>Q. alba</i>	USA	lake(6m deep)	85	0.0041	731.7	—do—
<i>Q. alba</i>	USA	lake(12m deep)	72	0.0318	1666.6	—do—
<i>Acer saccharum</i>	USA	stream	600	0.0019	1578.9	Meyers, 1980
<i>Betula alleghaniensis</i>	India	lake (1m deep)	600	0.0041	731.7	Tiwari & Mishra 1983
<i>Fagus grandifolia</i> mixed in equal quantity		lake (3m deep)	600	0.0074	405.4	—do—
		lake (6m deep)	600	0.0029	1034.4	—do—
<i>Tectona grandis</i> L.	India	lake (1m deep)	600	0.0037	810.8	—do—
<i>T. g'andis</i> L.	India	lake (3m deep)	600	0.0074	405.4	—do—
<i>T. grandis</i> L	India	lake (6m deep)	600	0.0029	1034.4	—do—
<i>Pinus kesiya</i> Royle	India	lake (1m deep)	600	0.0037	810.8	—do—

<i>Pinus kesiya</i> Royle	India	lake (3m deep)	600	0-0032	937.5	—do—
<i>P. kesiya</i> Royle	India	lake (6m deep)	600	0-0009	3333.3	—do—
<i>Alnus rubra</i>	USA	stream 1	300	0-0120	250.0	Sedell et al 1975
<i>A. rubra</i>	USA	stream 2	300	0-1680	17.8	—do—
<i>Acer circinatum</i>	USA	stream 1	300	0-0068	441.1	—do—
<i>A. circinatum</i>	USA	stream 2	330	0-0201	149.25	—do—
<i>A. macrophyllum</i>	USA	stream 1	300	0-0024	1250.0	—do—
<i>A. macrophyllum</i>	USA	stream 2	300	0-0108	277.7	—do—
<i>Pseudotsuga menziesii</i> and <i>Tsuga heterophylla</i>	} USA	stream 1	300	0-0025	1200.0	—do—
<i>Pseudotsuga menziesii</i> and <i>Tsuga heterophylla</i>	} USA	stream 2	300	0-0131	229.0	—do—
<i>Platanus occidentalis</i>	USA	river	161	0-0057	526.3	Benfield et al. 1077
<i>Populus deltoides</i>	Poland	lake	285	0-0504	59.5	Gasith & Lawacz, 1976
<i>Salix nigra</i>	Poland	lake	285	0-387	77.5	—do—
<i>Acer saccharum</i>	Poland	lake	285	0-0218	137.6	—do—
<i>Ulmus americana</i>	Poland	lake	285	0-0134	223.8	—do—
<i>Quercus alba</i>	Poland	lake	285	0-0097	309.3	—do—

*Size of the pores of litter bag nets.

Table 1 summarizes the data on rate constant from some of the important publications on decomposition of terrestrial plant litter in aquatic systems. A perusal of the table depicts that most of the studies have been conducted in woodland streams and information on ponds and lakes are very meagre (Hodkinson, 1975; Barnes, 1978).

Leaching : The weight loss data of several studies in aquatic systems suggest that the litters undergo an initial leaching phase (Meyer, 1980; Tiwari & Mishra, 1982) which prolongs upto 30 days and may account for as much as 1/3 of the initial weight of litter in the case of angiosperm leaves and upto 10 percent in the pine needle litter (Fig. 1). This loss of weight is mainly due to dissolution of soluble matter, viz., soluble carbohydrates, proteins, pigments and minerals. Our study in an aquatic system in Ward's lake, Shillong has clearly shown that leaching of sugars and amino acids is responsible for the initial loss of the litter (Fig. 2)

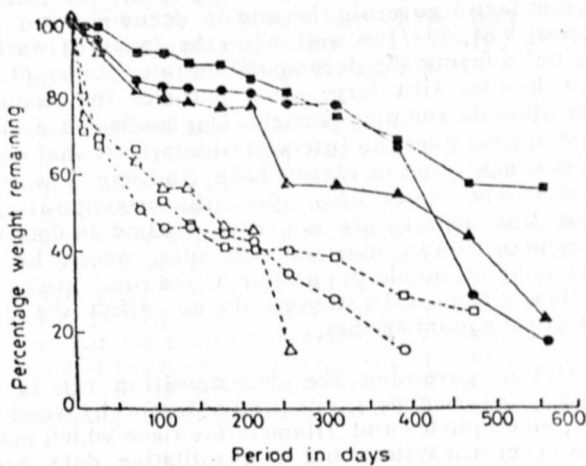


Fig. 1 Percentage weight remaining of *Pinus kesiya* Royle needle (solid lines) and *Tectona grandis* L. leaf litters during processing in Wards, Lake, Shillong at three stations. Station 1 (1m deep) shown by circles, stations 2 (3m deep) shown by triangles and station 3 (6m deep) shown by rectangles.

Environmental factors : In terrestrial ecosystems, the rate of decomposition is largely governed by the time, temperature and moisture and in most of these habitats moisture is a limiting factor playing a decisive role. In aquatic ecosystems, the additional factors such as depth of water, current velocity and oxygen deficiency also become important. While current velocity is important for streams, the oxygen deficiency is generally noticed in the deeper lakes. Unlike terrestrial ecosystem, where moisture plays decisive role, in aquatic systems it loses its significance.

Among various physico-chemical factors regulating the rate of decomposition, depth, temperature, sediment and nutrient richness have received attention. Very few studies are available on the effect of water depth on the decomposition of terrestrial plant litter in aquatic systems. Litters in the lakes slowly move towards the deeper regions where the processing proceeds at a very slow rate. Barnes *et al.* (1978) and Tiwari & Mishra (1983) have clearly demonstrated slower weight loss at deeper stations. This has been mainly attributed to the less microbial and microfaunal populations, anacrobiosis and slower water movement, at deeper stations. The low temperature at the deeper depth due to the stratification also retards the rate of decomposition. In general, also the rate of decomposition is governed by the temperature. The optimum activity of bacteria and fungi is expected between 15-30°C and therefore, the decomposition rate of same litter in various system differing in temperature varies (Table I). Sediment morphology has been found to be other very important factor governing the rate of decomposition of plant litters. In streams (Reice 1974, 1977) as well as in the lakes (Tiwari, 1980), the larger sediment particles favour the decomposition rate. Reice (1977) has clearly demonstrated at the sites with large sized particles the decomposition was faster than the site with silt and clay particles. Our studies have also shown that the deposition of sediments over the litters, particularly at shallow stations slows down the rate of decomposition in Ward's Lake, Shillong (Tiwari, 1980). The dissolved nutrients in the water also affect the decomposition rate in aquatic ecosystems but this aspect has not been studied in detail. Tiwari (1980) found faster decomposition in nutrient rich sites, which he ascribed to the higher microbial and chironomid population at the site. Triska & Sidell (1976) found that nitrate addition to the streams did not affect the decomposition rate of leaf litter of four plant species.

Other abiotic factors governing the decomposition rate in aquatic systems are crevice spaces, bed roughness, retention of litters by woody debris and boulders in streams; macrophytes and filamentous algae which may be of considerable importance in certain systems but no quantitative data are available on the effect of these factors on litter decomposition,

Microbial populations: Recent works (Willoughby & Sutcliffe, 1976; Marcus & Willoughby, 1978; Rossi & Fan, 1979) on the microbiology of plant litter decomposition have shown that essentially only bacteria and fungi act as primary decomposers and that organisms higher in food chain (micro and macrofauna) utilize mainly the microbial biomass. The microbial population therefore, acts directly on the rate of decomposition. The studies of Triska (1970), Kaushik & Hynes (1971) and Suberkropp & Klug (1976) have shown that fungi dominate the microbial biomass during initial phases and bacterial biomass increases during decline of fungal biomass and dominates the microflora in the terminal stages of processing. Fungi are capable of producing an array of extracellular enzymes & therefore, are more invasive than bacteria. In addition to this, fungi are capable of penetrating the plant tissue through the mycelium. The dominance of bacterial activity during the later periods has been attributed to the release of soluble compounds by fungi or by other physico-chemical means, for which bacterial community can more successfully compete than the fungi. The microbial populations have been found to increase exponentially with time (Suberkropp & Klug 1976). However, this

may not be generalized in view of the finding of Mishra & Tiwari (1983) who reported an initial increase followed by subsequent decrease during winter months and a very high population at the end of the processing. Our observations hint that the findings of Suberkropp & Klug (1976) might have also been temperature or season dependent because the study was started in November and a temperature dependent fall was noted in December and again the increase in microbial population was parallel with the temperature. It could be concluded from various recent studies that microbes play a fundamental role in the litter processing.

Like terrestrial decomposition studies, in aquatic systems also much attention has been on the fungal decomposers. Fungi belonging to almost every major group are found associated with the decomposing plant litters in aquatic systems. For a long time aquatic mycologists believed that only a small group of "so called aquatic hyphomycetes" (Ingold, 1979) colonize and actively participate in the decay of plant litters in aquatic systems (Willoughby & Archer, 1973; Suberkropp & Klug, 1976). Other groups of fungi were considered "aliens" (Park, 1972) although they have been isolated by several workers (Cooke, 1961; Kaushik & Hynes, 1971; Park, 1972; Barlocher & Kendrick, 1974; Padgett, 1975; Mishra & Tiwari 1983).

Among aquatic hyphomycetes most common forms are *Helescus*, *Lemoniera*, *Tricladium*, *Alatospora*, *Anguilospora*, *Articulospora*, *Clavariopsis*, *Clavatospora*, *Dendrospora*, *Margarispora*, *Helecomyces*, *Flagellaspota*, *Tetracladium* & *Dictyosporium*, *Alternaria*, *Cladosporium*, *Penicillium*, *Aspergillus*, *Geotrichum*, *Fusarium*, *Gliocladium*, *Aureobasidium*, *Heterocephalum*, *Cylindrocarpon*, *Epicoccum*, *Trichoderma*, *Pythium*, *Phialophora*, *Mucor*, *Rhizopus*, *Zygorhynchus*, and *Cephalosporium* are most common terrestrial genera found associated with the decomposing plant litters in aquatic ecosystems. A complete list and their relative importance has been reviewed by Willoughby & Archer (1973). By and large the role of fungi other than aquatic hyphomycetes is considered to be 'inactive aliens'. In our studies (Table 2) in the lake all the fungal flora associated with decaying litters (pine needles and teak leaves) belonged to the

TABLE 2

List of fungi isolated from pine needle and teak leaf litter during processing in Wards lake, Shilong (After Mishra & Tiwari, 1983).

Pythium monoceros Pringsheim, *Absidia cylindrospora* Hageni *Mucor circinnelloides* van Tiegham *M. hiemalis* *M. plumbeus* Bonorden, *M. racemosus* Preseuius, *Rhizopus nigricans* Ehrenberg, *Phoma humicola* Gilman & Abott *Phoma* sp., *Aureobasidium pullulans* (de Bary) Arnaud, *Agerita candida* Pers ex Fries, *Alternaria alternata* (Fries) Keissler, *Aspergillus candidus* Link ex Thom et Church *A. nidulans* (Eidam) Winter, *A. niger* van Tiegham, *A. sydowii* Thom et Church, *A. versicolor* Triebosch, *Bispora monoceros* Corda, *Cladosporium cladosporioides* Eresenius de Vries, *C. herbarum* (Persoon) Link, *Curvularia lunata* (Wakker) Boedijin, *Fusarium oxysporum* Schiechtensahl, *F. roseum* Link ex Fries, *Geotrichum candidum* Link ex Persoon, *Gliocladium*

Penicillium brefeldium Dodge. *P. chrysogenum* Thom *P. javanicum* Beyma
P. nigricans (Bainier) Thom, *Pseudotorula heterospora* Subram. *Trichoderma*
konningii Oudemans, *T. viride* Pers ex Gray. *Trichothelcium roseum* (Pers) Link
 ex Fries., *Vitricillium tenerum* (Nees ex Pers) Link.

so called "geofungi" (Cooke 1976). Their definite succession and their presence in the tissue showed active involvement of these forms. We could say conclusively that at least in the lakes and ponds (where aquatic hyphomycetes are generally absent, Ingold, 1976), the terrestrial fungi play a dominant role in the breakdown of plant litters. Also the role of aquatic hyphomycetes in the decomposition of gymnosperm needles is very little and only rarely (Ingold, 1976) they colonize the naturally decaying gymnospermous needles (Barlocher 1978).

Most common bacterial genera found associated with decomposing plant litters in aquatic systems are : *Pseudomonas*, *Flavobacterium*, *Archaeobacter*, *Chromobacterium*, *Flexibacter*, *Actinobacter*, *Bacillus*, *Cytophaga* and *Sporocytophaga*. These genera are common in most of the natural water bodies. These forms are generally active on the nitrogenous substances and they have little role to play in the breakdown of major chemical components of plant tissue such as cellulose and lignin. Bacterial populations are generally active on the simple carbohydrates (monosaccharides and oligosaccharides), proteins, gelatin, casein and other similar compounds. They are actively involved in the decay of dead fungal mycelium and micro and macrofauna associated with the litters during later periods of decay.

Invertebrates : The studies on decomposition and role of plants litters in aquatic system have been mainly conducted by Zoologists for their interest in the food value of these materials for the aquatic invertebrates. Hynes (1963) in the 16th International Congress of Zoology held at Washington put forth that "a large part of the productivity of all running waters is based on photosynthesis which takes place elsewhere", and its absence "would cause it to be a desert habitat". Researches of Darnell (1964), Nelson & Scott (1962), Minshall (1967) and Kaushik & Hynes (1968) established the food value of the plant litters for the invertebrates in the streams. Petersen and Cummins (1974), after a series of experiments, concluded that differential invertebrate colonization of leaf packs in streams is a function of microbial colonization and conditioning. They developed a general scheme of detritus processing in streams: leaching phase, microbial processing and animal microbial processing. Depending on the plant species and habitat type the contribution of invertebrates in weight loss of plant leaf litter may range from 13 to 24% of the original weight. (Petersen & Cummins, 1974; Cummins *et al.* 1973; Mathews, 1967) Sedell *et al.* 1975).

Fenchel & Harrison (1976) found considerable effect of protozoan grazers on the rate of decomposition of barley hay. The system with a natural assemblage of protozoa showed a rapid rate of decomposition; the pure bacterial system had a lower and declining rate, and the system inoculated with only one species of protozoa took an intermediate position. Similar results were reported by Harrison & Mann (1975). The conditioning of plant litters by microbial activity makes it more palatable for the invertebrates (Triska, 1970; Iverson, 1973; Boling *et al* 1975; Sedell *et al.* 1975). Kaushik & Hynes (1971) concluded that fungi are major source of protein for invertebrates feeding on leaves. Contrary to this, Iverson (1973) found that for animals feeding on beach leaves; bacteria are more important protein source than fungi. The relative food value of the microorganisms vs detrital particle substrate is still conflicting (Cummins & Klug 1979). Researches of Barlocher & Kendrick (1973) Ward & Cummins (1979) Willoughby & Sutcliffe (1976) Marcus & Willoughby (1978), and Ross & Fan (1979) have very clearly demonstrated that microbial biomass constitute the most important component of invertebrate diet. Baker & Bradnam (1976) opined that at normal field densities the bacterial component was insufficient to support blackfly growth. The differences in the chemical composition of plant litters, probably, play a decisive role in the relative importance of microbes and detritus proper towards the food of aquatic invertebrates. In less refractile plant materials eg. macrophyte litters the dead organic part of the detritus may have major contribution towards invertebrate food, but in the case of more refractile plant litters eg. pine needles the substrate has little role and almost whole food ingested by the invertebrates comes from the microbial component.

Chemical composition of plant litters : The plant litters differ in their chemical composition depending upon the species. Minor differences may occur within the species depending on the age of plant, soil type and position of plant part on the individual trees etc. In general, angiosperm litters decompose faster than the gymnosperm litters which has been attributed to the simpler chemistry of the former and their fast colonization by the microbes and microfauna. Woody and more lignified tissues decompose slower than nonwoody & less lignified tissues. It has been found that litters with higher level of nitrogen, generally, decompose faster. Young and senescent leaves and soft tissues also decompose faster. The extraneous plant litters decompose slower when compared with the autochthonous macrophyte or other herbaceous litters. Our studies (Tiwari, 1980; Tiwari & Mishra, 1983) on this aspect has shown that under similar conditions 95% life for pine needles was 3333 days while for teak it was only 1034 days. The chemical composition of plant litters changes as the process of decomposition proceed. The soluble organic and inorganic components leach out of the material within a very short span of time which may range from a week to few months depending upon the physical structure of the material. These compounds have been extensively studied for the loss (Petersen & Cummins, 1974) and qualitative changes (McConnell 1968; Krumholz 1972; Lush and Hynes, 1973; Suberkropp *et al* 1976) Macromolecules such as lignin, cellulose, hemicellulose, lipids, sugars and aminoacids and total nitrogen concentration have been generally considered as a measure of degree of decomposition. Sugars and amino acid concentration declines very fast during initial periods of processing and afterwards it, gene-

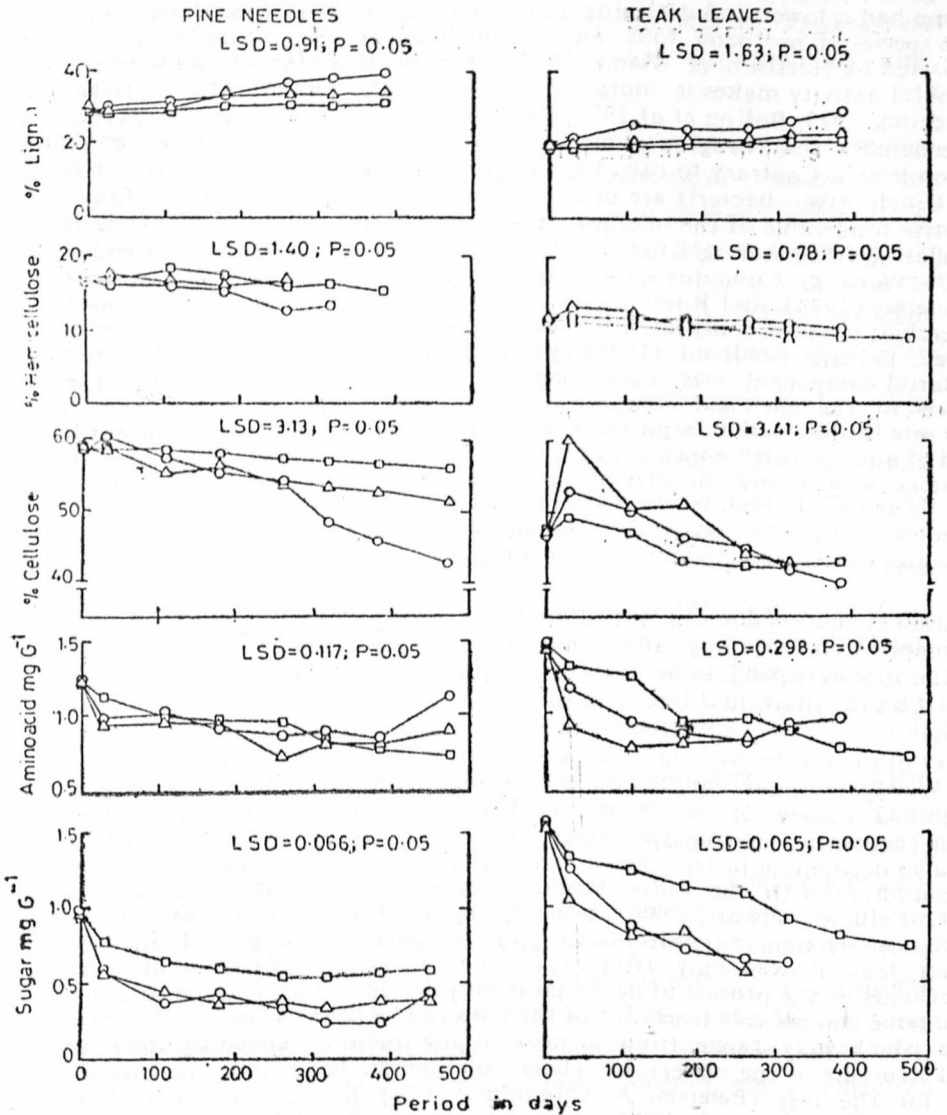


Fig. 2. Changes in the lignin, hemicellulose, cellulose amino acid and sugar content of *Pinus kesiya* Royle needle and *Tectona grandis* L. leaf litters during processing in Wards Lake, Shillong at three stations. Station 1 (1m deep) shown by circles, stations 2 (3m deep) shown by triangles and station 3 (6m deep) shown by rectangles.

ally, stabilizes (Fig. 2). The increments in the percentage nitrogen and lignin with decomposition have been found by several workers (Suberkropp *et al*, 1976; Hodgkinson, 1973; Tiwari, 1980), the change in the percentage hemicellulose

Hulose and cellulose concentration is quite slow and, generally, it remains near original value (Suberkropp *et al.* 1976 & Fig. 2)

A detailed study was conducted by Tiwari (1980) on the weight loss, microbiology and chemistry change of pine needles and teak leaves in the Wards Lake, Shillong and the process of decomposition could be divided into three distinct phases :

Leaching phase : This is characterised by fast microbial colonization attaining peak values within a short span of time; rapid loss of soluble components, rapid weight loss and little change in the composition of macromolecules. This period is of 2-4 months depending upon the site characters and type of litter.

Processing phase : This is characterized by low microbial activity, low concentration of soluble components, slow weight loss and slow change in composition of macromolecules. This phase continues for a long period of time until the material is quite softened, heavily colonized by microbes and becomes palatable for invertebrates.

Dispersal phase : This is characterized by high microbial activity, rapid loss in weight, colonization by detritivorous invertebrates and high lignin content. During this phase the invertebrate population plays the most important role by cutting the litter into small pieces and passing it through their intestine. This phase continues until the litter is changed into an unrecognizable detritus heavily loaded with various invertebrates.

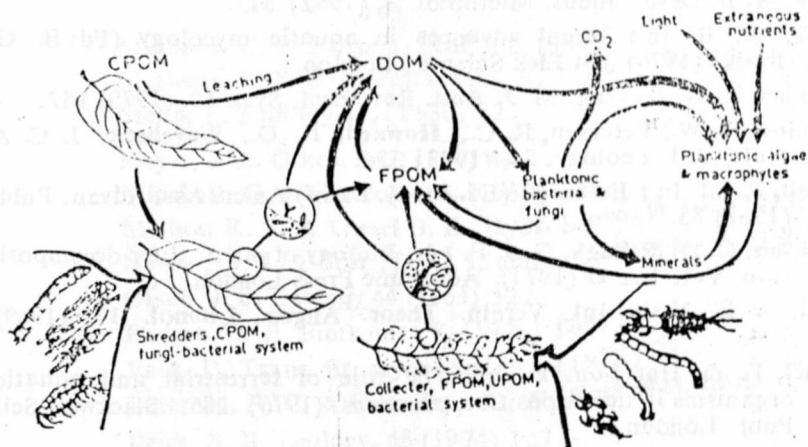


Fig. 3. Schematic representation of the processing of extraneous litters in aquatic ecosystems, showing various inter-relationships, and linkage of the extraneous litters with the ecosystem function. CPCM, coarse particulate organic matter; DOM, dissolved organic matter; FPOM, fine particulate organic matter; UPOM, ultra-fine particulate organic matter.

The process of decomposition of plant litters in aquatic environments is summarised in Fig. 3 which shows the links between various ecosystem processes, community metabolism and the association of microbial and animal communities with the allochthonous plant litters. The relation of the decomposing terrestrial plant litters with the phytoplanktons, invertebrates, and heterotrophic microbes is so vital that their absence from many woodland streams, and lakes would turn these systems into a barren habitat with poor or negligible biomass production per unit area.

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