Tropical Ecology **44**(2): 171-176, 2003 ISSN 0564-3295

Leaf litter retention, transport and decomposition in a tropical forest stream of Sirumalai hill (eastern ghats), South India

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Abstract: Leaf litter dynamic processes (retention, transportation and decomposition) were quantified in three different hydraulic habitats (riffle, run and pool) in a tropical deciduous forest stream of Sirumalai Hill (10º 27′ N & 77º 29′ E), South India. Total number of leaves per unit area, number of leaves retained by each habitat and litter retention coefficients were highest in pools, lowest in runs and intermediate in riffles. Leaf litter and total detrital dry weights were highest in pools and riffles respectively. One way ANOVA revealed significant effect of habitat types on all selected parameters except leaf litter dry weight. All selected hydraulic parameters vary significantly between habitat types particularly depth and water current. Quantitative data suggested that selected hydraulic factors (depth, water current and substrate heterogeneity) associated with habitat type strongly influence litter dynamic processes in the selected tropical forest stream.

Resumen: Los procesos dinámicos del mantillo foliar (retención, transporte y descomposición) fueron cuantificados en tres hábitats hidráulicos diferentes (rápido, corriente y poza) en un arroyo ubicado en un bosque tropical deciduo de Sirumalai Hill (10º 27′ N y 77º 29′ E), sur de la India. El número total de hojas por unidad de área, el número de hojas retenidas por cada hábitat y los coeficientes de retención de mantillo alcanzaron sus máximos en las pozas, sus mínimos en las corrientes, y fueron intermedios en los rápidos. Los pesos secos del mantillo foliar y del total de detritus tuvieron sus valores más altos en las pozas y en los rápidos, respectivamente. Un análisis de varianza de una vía mostró un efecto significativo del tipo de hábitat sobre todos los parámetros seleccionados exceptuando el peso seco del mantillo foliar. Todos los parámetros hidráulicos seleccionados varían significativamente entre tipos de hábitat, particularmente la profundidad y la corriente de agua. Los datos cuantitativos sugirieron que los factores hidráulicos seleccionados (profundidad, corriente de agua y heterogeneidad del sustrato) asociados con el tipo de hábitat tienen una fuerte influencia sobre los procesos dinámicos del mantillo en el arroyo de bosque tropical seleccionado.

Resumo: A dinâmica do processo de evolução da folhada (retenção, transporte e decomposição) foi quantificada em três habitats hidráulicos diferentes (zonas de caudal lento, zonas de curso rápido e zonas de empoçamento) num curso de água numa floresta decídua nas colinas do Sirumalai (10º 27' N & 77º 29' E), Sul da Índia. O mínimo total de folhas por unidade de área, número de folhas retidas em cada habitat e coeficientes de retenção de folhada eram mais elevados nas zonas empoçadas e mais baixos nas zonas de curso de água rápido e intermédios nas zonas de velocidade lenta, respectivamente. Uma ANOVA revelou o efeito significativo dos tipos de habitat em todos os parâmetros seleccionados excepto para o peso seco da folhada. Todos os parâmetros hidráulicos seleccionados variam significativamente entre os tipos de habitat particularmente a profundidade e a corrente da água. Os dados quantitativos sugerem que os factores hidráulicos seleccionados (profundidade, corrente de água, e heterogeneidade do sub-

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strato), associados com o tipo de habitat influenciam fortemente a dinâmica do processo de folhada no curso de água seleccionado na floresta tropical.

Key words: Deciduous forest stream, hydraulic habitats, hydraulic factors, litter dynamics, leaf litter, Sirumalai hill.

Introduction

Indian subcontinent is blessed with diverse freshwater habitats. Three comprehensive and systematic reviews (Gulati & Schulz 1980; Gopal & Zutshi 1998; Michael 1980) have clearly ascertained that hydrobiological studies in past were highly restricted to lentic ecosystems. Studies on lotic ecosystems especially streams have lagged behind those on the lentic ecosystems not only in India but throughout Asia (Dudgeon 1995). Streams are physically heterogenous ecosystems consisting of a diverse assemblage of hydraulic habitats, associated environmental variables and biotic communities (Winterbourn 1986). Leaf litter from riparian and corridor vegetation forms the vital energy input into the streams as coarse particulate organic matter (CPOM). The ecological role of allochthonous leaf litter as principal source of energy in forested streams of temperate areas has been well documented (Anderson & Sedell 1979; Cummins 1974, 1979). Despite the importance of leaf litter in stream ecosystems, to our surprise, studies on tropical Indian streams have been restricted to estimation of conventional physico-chemical factors (Joshi & Tyagi 1997; Roy 2000). Information on leaf litter dynamics in streams would be of practical importance towards our comprehension of energetics of the tropical streams. Thus the objective of this study was to assess the influence of different hydraulic habitats (riffle, run and pool) and their associated factors (depth, water current and substrate heterogenity) on retention, transportation and decomposition of leaf litter in a tropical deciduous forest stream of Sirumalai hill (eastern ghats), South India.

Materials and methods

Sirumalai hill forms a minor range in the Deccan plain (10° 27′ N and 77° 29′ E; altitude; 350–800 m above man sea level) and exists as an isolated hill at southern most tip of the eastern ghats (Mathur 1994). The mixed moist dry deciduous forest of the hill is composed of mainly protected vegetation. The selected segment is situated about 32 km away from Madurai city. The selected perennial stream of this segment cascades as Thadaka Nachi Amman Falls near a village, Kuttladampatti, which recently developed as a picnic spot. It is second order rocky stream and shaded by thick riparian and corridor vegetation. The study segment consists of approximately 4-12 km upstream stretch from Thadaka Nachi Amman Falls which included numerous heterogenous habitats (riffles, runs and pools). Their arrangement and relative proportion were governed by geomorphic and hydrologic processes operating in an integrated fashion.

To quantify the leaf litter retention or accumulation, at selected three habitats viz., riffle, pool and run, a wooden square frame of 30 cm^2 size was immersed slowly into the water at random sites and the leaf litter enclosed within it were transferred gently into a tray without loss to downstream and counted. Then the whole detritus adhered to these leaves was completely washed into a tray, filtered through a preweighed filter paper, labeled for habitats and preserved. It is only an indirect estimate of detritus. As maximum as possible, the macro-invertebrates (mayflies, caddisfly larvae, crustaceans and others) from these samples were removed visually.

To study the leaf litter decomposition, an indirect approach is used. A random subsample of the leaf litter consisting of ten completely washed leaves were counted for their number of well exposed veins on their leaf blade due to decomposition by microbes and subsequent feeding by benthos. The leaves were placed behind a window of 2 cm^2 size and the major veins visible through this window only were counted. The washed leaf litter

Table 1. Litter dynamic and hydraulic factors of Sirumalai hill stream (n = 9) in relation to habitat types. Values are mean ± SD.

Parameters	Habitat types		
	Riffle	Run	Pool
No. leaves/ 30 cm^2	49.50 ± 9.32	19.38 ± 5.07	77.63 ± 10.95
No. leaves retained	27.10 ± 3.54	11.20 ± 3.24	36.13 ± 6.73
No. leaves transported	23.30 ± 3.24	39.10 ± 3.39	13.88 ± 6.79
Litter dry weight / 30 cm^2/g	1.07 ± 0.348	1.85 ± 0.49	2.11 ± 0.61
Detrital dry weight / 30 cm^2/g	1.10 ± 0.660	1.05 ± 0.40	1.07 ± 0.81
No. veins exposed / 2 cm^2	23.25 ± 5.77	11.25 ± 2.69	19.26 ± 4.58
Retention coefficient (%)	54.10 ± 7.07	26.12 ± 12.69	12.25 ± 13.47
Transport coefficient (%)	47.75 ± 8.94	79.63 ± 7.19	27.75 ± 13.49
Water current (cm/second)	14.25 ± 1.54	20.63 ± 2.72	8.25 ± 1.37
Depth (cm)	12.63 ± 2.52	28.88 ± 6.88	97.75 ± 10.54
No. boulders/cobbles/m^2	24.13 ± 3.29	10.75 ± 4.06	20.51 ± 5.22

as well as filtered detrital matter were transported to laboratory, dried in an oven at 60°C and re-weighed. No species-specific discrimination of leaf litter was made in these samples.

To study the leaf litter transportation, at each type of habitat, 20 m stretches were selected randomly with well marked starting and ending points. Fifty completely dried leaves of unknown species were collected from the adjacent banks, labeled with red flourescent sticker and released at starting point. The number of leaves retained within 20 m stretch as well as transported beyond the ending point was counted after 20 minutes. The number of leaves transported beyond the ending point is calculated by subtracting the number of leaves retained from the total number of leaves released. The litter retention as well as transport co-efficients in percentage were calculated as ratios of total number of leaves released to the number of leaves retained and number of leaves transported respectively. These two indices are slight modifications of the litter decomposition coefficient of Olson (1963).

Totally 9 samples were collected for each parameter during post-monsoon seasons of (October-November) of 1999 (n = 4), 2000 (n = 4) and 2001 (n = 1), when the stream was accessible for sampling (each sample is the mean of three replicates). Estimations were made in habitat types of different segments to ensure true replication and statistical precision. The last sampling was made during an exiguous flow of the stream in February 2001. Comparisons of the mean values of each parameter between habitats were done by using t-test while one way ANOVA was employed to test the effect significance of habitat type on both litter dynamic parameters as well hydraulic factors (Zar 1984).

Results and discussion

Table 1 contains data on litter dynamic and hydraulic parameters in chosen stream. Table 2 presents the matrix of t values for comparison of the mean values between habitat types. The result

Table 2. Matrix 't' values for comparison between the selected habitas.

Parameters	Riffle vs Run	Riffle vs Pool	Run vs Pool
	t	t	t
No. leaves/ 30 cm^2	5.74*	17.88*	49.61*
No. leaves retained	12.40*	8.88*	24.95*
No. leaves transported	25.21*	9.44*	24.87*
Litter dry weight	9.64*	10.92*	2.45*
Detrital dry weight	24.00*	16.96*	13.07*
No. veins exposed	14.12*	4.05*	10.95*
Retention coefficient	14.41*	8.92*	18.64*
Transport coefficient	20.86*	9.28*	24.49*
Water current	15.29*	12.00*	24.76*
Depth	23.23*	58.76*	40.94*
No. boulders/cobbles	19.57*	4.09*	11.83*

*Significant P<0.001, NS, not significant

Table 3. ANOVA matrix for comparison between the selected habitat types code: SV, sources of variation; BS, between samples; WS, within samples; SS, sum of squares; df, degree of freedom; MS, mean squares.

Parameters	SV	SS	df	MS	F(P)*
No. leaves/ 30 cm^2	BS	4823	8	689.01	36.11 (P<0.001)
	WS	439	24	19.08	
No. leaves retained	BS	2588	8	369.71	15.59 (P<0.001)
	WS	546	24	23.77	
No. leaves transported	BS	2589	8	369.81	16.04 (P<0.001)
	WS	542	24	22.73	
Litter dry weight	BS	4617	8	659.5	3.35 (NS)**
	WS	4523	24	196.6	
Detrital dry weight	BS	11488	8	1641.14	12.97 (P<0.001)
	WS	2911	24	126.5	
No. veins exposed	BS	696	8	99.42	5.83 (P<0.01)
	WS	392	24	17.04	
Retention coefficient	BS	8832	8	1261.71	8.66 (P<0.01)
	WS	3348	24	145.56	
Transport coefficient	BS	2512	8	1564.42	18.88 (P<0.001)
	WS	1905	24	82.82	
Water current	BS	612	8	87.42	31.07 (P<0.001)
	WS	69	24	2.87	
Depth	BS	32677	8	4668.14	74.84 (P<0.001)
	WS	1434	24	62.38	
Boulders/Cobbles	BS	765	8	109.25	5.83 (P<0.05)
	WS	431	24	18.73	

*Probability level, ** Not significant

of ANOVA is given in Table 3. Significant differences were estimated in total numbers of leaves/30 cm^2 area among habitats. Overall, it was highest in pools, lowest in runs and intermediate in riffles. Similar quantitative trend was noticed in number of leaves retained by each habitat and percentage retention co-efficients. There were statistically significant differences among habitats in number of transported leaves. Overall, it was highest in runs, lowest in pools and intermediate in riffles. This trend was confirmed by the estimates of percentage transport co-efficients. Leaf litter dry weights were not significantly different among habitats. Significant inter-habitat differences were noticed in number of exposed veins as an index of decomposition and detrital dry weights. The latter parameter was highest in riffles, lowest in runs and intermediate in pools. All selected hydraulic factors vary significantly between habitats particularly depth and water current. Depth was highest in pools, lowest in riffles and intermediate in runs. Conversely, velocity of water current was highest in runs, lowest in pools and intermediated in riffles. ANOVA predicts significant effect of habitat types on both leaf litter dynamic as well as hydraulic factors except leaf litter dry weight.

Leaf litter forms the dominant fraction of CPOM in selected stream. In general there were more litter in streams that drain through forest compared to those draining open grass land or landscapes (reviews: Anderson & Sedell 1979; Winterbourn 1986). Pools exhibit maximum litter retention capacity than other habitats, probably due to high depth and slow water current. Generally, increase in depth enhances the leaf litter burial in forested streams (Rounick & Winterbourn 1983). The magnitude of retention is dependent on the occurrence, strength and density of litter retention structures (Bilby & Likens 1980). The moderate quantity of litter retained by riffles is possibly due to retention structures such as substratum heterogenity, organic debris dams, bark and branch litter, rock outcrops, large wood logs, roots of riparian vegetation and others. Rock outcrops and debris dams are two major descriptors of the streambed heterogenity and responsible for litter retention in Kenyan (Mathooko *et al.* 2001) as well as temperate streams (Ehrman & Lamberti 1992; Smock *et al.* 1989). Runs with faster water current allow the downstream transport of maximum quantity of litter. According to Winterbourn (1986), the poor retention capacity of New Zealand streams is due to steep and youthful topography, unpredictable rainfall and discharge. In Kenyan streams, it is due to low density of major retention structures (Mathooko *et al.* 2001). Litter retention has been observed to decline with increased discharge (Jones & Smock 1991; Speaker *et al.* 1988). However, there are no major variations in discharge during the study period. In general, the litter retention by small forested streams is determined by flood events, rainfall, stream size, configuration, watershed topography, composition and seasonality of riparian vegetation and seasons (Cummins 1979).

In fact only a very small fraction of the total leaf litter entering streams is processed and the major proportion is transported to downstream (Winterbourn 1986). Runs transport maximum quantity of litter when compared to other habitats. This is due to absence of effective retention structures and fast water current. The high flow rate of surface water increases the litter transports while decreases the macroinvertebrates especially shredders in runs could result in low detrital weight. Conversely, several earlier mentioned retention structures in riffles retard the transport and made litter available to decomposition by both microbes and shredders. Earlier report has shown that the macroinvertebrates of riffles in this stream include ten genera of nine families, belonging to six orders of aquatic insects (Dinakaran & Nagendran 1997). Pools transport minimum quantity of litter due to slow water current and high depth, the latter is responsible for litter burial in pools. In general, transport and retention mechanisms in the streams may operate either independently or in an alternating fashion (Mathooko *et al.* 2001).

Decomposition is highest in riffles as evidenced by maximum detrital weight. Similarly Cummins *et al.* (1980) reported that decomposition rate was faster in riffles than pools. Conversely Mutch & Davies (1983) estimated that litter breakdown in a mountain stream was faster in both rifles and pools. According to Reice (1977) such variations could be due to different substrate composition of the habitat types. Such variations in composition of the substratum among habitats are statistically significant in the present study. In deciduous forest stream, species of shredders appear to coincide their period of life cycle with input of leaf litter (reviews: Andersen & Sedell 1979; Cummins & Klug 1979). Tiwari & Misra (1993) concluded that depth influences the decomposition of litter in lentic ecosystems. Significant variations in depth among habitats in the present study could be the reason for observed variation in decomposition. The low decomposition at runs could be due to minimum retained leaf litter and absence of heterogenous substratum for colonization of both microbes and litter shredders. Similarly in pools, this could be due to high sediment deposition and leaf burial as reasoned by Rounick & Winterbourn (1983). Reice (1974) has also demonstrated that large quantity of trapped sediments in pools reduces the growth of microbial decomposers and slows down the decomposition. In general, factors governing litter decomposition in streams include water temperature, physical and chemical nature of leaves, position of litter in relation to water current, diversity and density of fungal-bacterial decomposers as well as litter-shredding macrobenthos and local weather (Anderson & Sedell 1979; Winterboum 1986). In conclusion, the variations in the selected hydraulic factors among selected habitat types account for corresponding variations in litter dynamic processes viz., retention, transport and decomposition.

Acknowledgements

We are grateful to an anonymous reviewer and Dr. Uppeandra Dhar (Associate Editor), G.B. Pant Institute of Himalayan Environment and Development, Almora, for valuable comments on our MS. We acknowledge the immense help and constant support by Dr. P. Murugavel, MKU, Madurai. Thanks to Board of Madura College, Principal, HOD and all faculty members.

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