LEAF PROCESSING RATES IN THREE TROPICAL STREAMS OF SOUTHERN THAILAND: THE INFLUENCE OF LAND-USE*

By

Supatra Parnrong, Kittiyaporn Buapetch &
Muratha Buathong

Department of Aquatic Science,
Faculty of Natural Resources,
Prince of Songkla University, Hat Yai

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Department of Aquatic Science, Faculty of Natural Resources, Prince of Songkla University, Thailand

ABSTRACT

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Comparisons of the leaf processing rates of six plant species were carried out between the forested and agricultural sections of three streams. The species were the native trees *Radermachera glandulosa* and *Pometia pinnata*, two economic crops *Hevea brasilliensis* and *Nephelium lappaceum* and the introduced species *Eucalyptus camaldulensis* and *Acacia mangium*. The results show no significant difference between the forested and agricultural sites. However, *H. brasilliensis* and *N. lappaceum* leaves are processed faster than *R. glandulosa* and *P. pinnata*. Also, overall leaf processing rates are faster than the results of similar studies elsewhere, which suggests higher turn-over rates for nutrients and food availability.

บทคัดย่อ

การศึกษาอัตราการสลายของใบไม้ 6 ชนิด ซึ่งจัดอยู่ใน 3 กลุ่ม คือกลุ่มไม้พื้นเมืองที่พบมากในบริเวณที่ทำการศึกษาคือ สาย (*Pometia pinnata*) และแคก้านดำ (*Radermachera glandulosa*), ไม้เศรษฐกิจ คือ ยางพารา (*Hevea brasilliensis*) และเงาะ (*Nephelium lappaceum*), และกลุ่มที่นำเข้ามาจากต่างประเทศ คือ ยูคาลิปตัส (*Eucalyptus camaldulensis*) และกระถินเทพา (*Acacia mangium*) โดยเปรียบเทียบระหว่างจุดป่าและจุดเกษตรในลำธารสามสาย พบว่า ไม่มีความแตกต่างระหว่างอัตราการย่อยสลายของใบไม้ที่วางไว้ในจุดป่ากับจุดเกษตร อย่างไรก็ตามใบยางพาราและใบเงาะจะย่อยสลายได้เร็วกว่าใบไม้สายและใบแคก้านดำ นอกจากนี้ยังพบว่าอัตราการย่อยสลายของใบไม้จากการศึกษานี้จะสูงกว่าการศึกษาที่ส่วนอื่นของโลก ซึ่งแสดงให้เห็นถึงการหมุนเวียนที่เร็วกว่าของแร่ธาตุและอาหารของสิ่งมีชีวิต

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Keywords: leaf processing, Tropical stream, Thailand

Introduction

The significance of litter in stream ecosystems is well established (HYNES 1975; CUMMINS 1986; BENFIELD 1996). Litter is the main energy source for forest streams, providing a varied food source, and a habitat for stream invertebrates (LOPEZ et al. 1997; DUDGEON & WU 1999). Leaf processing rates vary from species to species (PETERSEN & CUMMINS 1974; CAMPBELL et al. 1992; LOPEZ et al. 1997), with the rates determining how quickly the leaves become available to stream organisms. Most data on these topics comes from studies outside of Asia (e.g. PETERSEN & CUMMINS 1974; PEARSON et al. 1989; CAMPBELL et al. 1992; LOPEZ et al. 1997), but very little is known about leaf processing in tropical Asian streams (two relevant pieces of studies are LAM & DUDGEON 1985; DUDGEON & WU 1999).

Much of the forest in Thailand has been cleared to make way for economic crops. Although there are many national parks and reserved areas, farmers encroach upon them by planting economic crops among the natural vegetation, often right down to the stream banks. Subsequently, the farmers claim ownership and modify the land for agricultural use, by planting economic crops. In the southern part of Thailand, rubber plantations and fruit orchards are most common, occupying more than 70% of the agricultural land (CENTER FOR AGRICULTURAL INFORMATION 1997). Most of the native vegetation are evergreens, and replacing them with economic plant species, such as the deciduous *H. brasiliensis*, may drastically affect stream ecosystems, including changes to the amount and timing of leaf litter accession, and the leaf processing rates. Few studies consider the effect of land use on leaf processing rates (CAMPBELL et al. 1992).

Our study provides data on leaf processing rates in three tropical streams in Thailand. The rates are given in terms of total weight loss over time (in terms of exponential decay coefficients) for various plant species. Our experiments were designed to test whether processing rates differ between (i) common riparian, economic, and introduced species; (ii) forested and agricultural sites; (iii) dry and wet seasons.

Material and Methods

Study sites

Our experiments were carried out upon three second-order streams of southern Thailand, called the Wang Pha, Tone Nga Chang, and Tone Plew. The streams originate in nearby mountain tops, and flow past narrow low land to drain into Songkhla lake. The streams are quite short in length, and similar in width, water depth (25-40 cm), substrate type, and riparian vegetation composition and density. The substrate is heterogeneous, being mostly cobbles and sand. Two sites were selected from each stream: a 50 m riffle stretch in a reserved area with native vegetation (the 'forested site') and a stretch in an area of economic species (the 'agricultural site') often containing fruit orchards or rubber plantations.

Leaf processing

Six species of leaves from three groups were used in the experiment: common riparian vegetation *Radermachera glandulosa* and *Pometia pinnata*, common economic species *Hevea brasilliensis* and *Nephelium lappaceum*, and introduced species *Eucalyptus camaldulensis* and *Acacia mangium*. Since most of the trees are evergreens, except for *H. brasilliensis*, leaves were freshly picked to obtain sufficient quantities and increase homogeneity. Leaves were air dried and stored in unsealed cardboard boxes. The experimental leaf packs consisted of 5 ± 0.2 g of leaves, fastened with plastic tags and labels. Each pack was placed in a bag with a mesh size of 2 cm, and attached by ropes to metal poles on the stream beds. Leaf packs were recovered after 48 hours, and at intervals for 35 days afterwards. Reclaimed leaf packs were gently washed in the field to remove silt and invertebrates. Leaves were dried and reweighed. The experiments were carried out once in the wet season (July-December) and once in the dry season (January-June). Exponential decay coefficients '-k' were calculated by fitting a line to the logarithm of weight remains against time, for each species and group, using all the data points (PETERSEN & CUMMINS 1974). A factorial analysis was carried out on the entire data set using the SPSS statistical package (KINNEAR & GRAY 1999) to investigate the effects of plant species, plant groups (introduced/economic/native), streams, seasons (wet/dry), and types of land use or sites(forested/agricultural). Our methods are based on the study by CAMPBELL et al. (1992).

On each sampling date, pH, conductivity, water temperature, water velocity, and nitrogen and phosphorus concentrations were measured for each experiment.

Results

Stream characteristics

The streams are approximately neutral (an average pH value of 6.4 ± 0.3) at all the sites and seasons. Conductivity is similar in all the streams (Wang Pha = 43.43, Tone Nga Chang = 41.91, Tone Plew = 38.21 µS cm^{-1} at 25 °C, n = 6) and seasons (wet = 39.13, dry = 42.72 µS cm^{-1} at 25 °C). However, agriculture sites have slightly higher conductivity than the forested sites (44 5.2 and 37.8 ± 5.1 µS cm^{-1} at 25 °C, p = 0.001). The stream temperatures fluctuate within a narrow range in all the streams (23.0 °C - 27.0 °C). The dry season has a slightly higher average temperature than the wet season (25.3 ± 0.5 °C, 24.3 ± 0.4 °C). The agriculture sites consistently have a slightly higher temperature than the forested sites at all the streams in the experiments. The average temperature at the forested sites is 24.3 ± 0.9 °C and 24.9 ± 0.9 °C for the agricultural sites ($p<0.001$). Nitrogen and phosphorus concentrations are not consistently different between the sites, streams, and seasons. They were analysed in the form of nitrite (from 1.49 μg l^{-1} to 2.18 μg l^{-1}), nitrate (from 1.15 μg l^{-1} to 10.11 μg l^{-1}), total nitrogen (from 111.38 μg l^{-1} to 212.24 μg l^{-1}), phosphorus (from 1.63 μg l^{-1} to 13.88 μg l^{-1}), and total phosphorus (from 19.85 μg l^{-1} to 235.77 μg l^{-1}). Water velocity is similar, except at the pasture sites of Tone Nga Chang and Tone Plew which have higher water velocities (0.73 m sec^{-1}, 0.85 m sec^{-1}) when compared to the other sites (0.45 - 0.61 m sec^{-1}). The wet season displays a slightly higher water velocity than the dry season (0.43 m sec^{-1} for the dry season, 0.85 m sec^{-1} for the wet season).

Leaf processing rates

Weight loss was very high during the first 48 hours of incubation, and gradually decreased in all the leaf species. *Eucalyptus camaldulensis* processed the fastest with a decay coefficient of 0.0747 day^{-1}. The value was similar to *A. mangium* which belongs to the same introduced species group (Table 1). The introduced species group also has the highest decay coefficient of 0.0694 day^{-1}. Although the economic species have the medium processing rate of 0.0504 day^{-1}, *N. lappaceum* processed slightly slower than *R. glandulosa*. The native group processed the slowest; *P. pinnata* has the lowest decay coefficient (0.0236 day^{-1}) and belongs to this group.

Factorial ANOVA analyses on the species and group data sets show non-significant effects for the streams, sites and seasons on the decay coefficients. Only the species/group of leaves has an effect on the processing rates (see Table 2). The interaction is significant between the sites and seasons for both data sets ($p = 0.029$ for the species, $p = 0.028$ for the group). However, the results from a two-way ANOVA test on the effects of the sites and seasons on the decay coefficients confirms that each site in a different season does not have any effect on the decay coefficients ($p = 0.709$ for the species, $p = 0.752$ for the groups).

Multiple comparisons of the mean decay coefficients for the group data sets were made between the groups, forested and agricultural sites, wet and dry seasons, and the Wang Pha, Tone Nga

Chang and Tone Plew streams. There were non-significant differences in the decay coefficients between the streams, seasons, and sites. The only significant result was between the groups of leaves. The introduced species had a higher decay coefficient than the economic species, and the native species processed the slowest (Table 3).

Discussion

Leaf processing rates

Our study shows very high processing rates for all the leaf species, and that processing rates (in terms of decay coefficients) are strongly influenced only by the leaf species, not by the streams, seasons, or sites (forested/agricultural).

PETERSEN & CUMMINS (1974) categorise leaf processing rates based on decay coefficients (-k) as 'fast' (0.010-0.015 day^{-1}), 'medium' (0.005-0.010 day^{-1}) and 'slow' (<0,005 day^{-1}). All the species in our study process extremely quickly (very 'fast') compared to previous studies (CAMPBELL et al. 1992; LOPEZ et al. 1997). The introduced species *E. camaldulensis* and *A. mangium* from Australia were found to have the highest decay coefficients (0.0747 day^{-1}, 0.0682 day^{-1}), and are much higher than the results of CAMPBELL et al. (1992) for *E.viminalis* (0.0313 day^{-1}) and *A. melanoxylon* (0.0119 day^{-1}). Also the *E. camaldulensis* leaves are processed faster than might be supposed from the results of LOPEZ et al. (1997) for the processing rates of *E. globulus* (0.0449 day^{-1}) in a forested headwater stream in north west Spain. However, processing rates in our study are similar to those for *Ficus fistulosa* leaves in a tropical stream in Hong Kong (DUDGEON & WU 1999).

The chemical composition of leaves appears to be one of the main factors affecting leaf processing rates. For example, Oak (*Quercus* spp.) with high lignin, tannin, and a C : N ratio is processed slower than tupelo gum (*Nyssa aquatica*) (DAY 1982). However, when CAMPBELL et al. (1992) studied the litter processing rates of five species of common riparian vegetation in south eastern

Australia, they found that chemical composition was not an accurate index of how fast leaves were processed. Biological factors appear to be better indicators of leaf processing rates; for example, shredders density has been associated with faster processing rates (BENFIELD 1996; LOPEZ et al. 1997; CAMPBELL et al. 1992). This measure is not applicable in tropical streams, which have low number of shredders (DUDGEON & WU 1999; WATANASIT 1996). However, tropical streams have higher water temperatures than temperate streams, which may be a compensating factor for the low number of shredders. This was suggested by CAMPBELL et al. (1992) as an explanation for the higher processing rates at their pasture site compared to their forested site. The processing rates in tropical streams may be the work of micro organisms which prefer higher temperatures. Physical breakdown rates have been suggested as another possible cause of the differing processing rates at the two streams (CAMPBELL et al. 1992). Our study did not find a streams effect, but physical breakdown may be contributing to the overall high processing rates because of unpredictable rains and floods, which caused severe damage to one of our experiments.

The influence of land-use

Our results show non significant differences in the leaf processing rates at the forested and agriculture sites. It is well established that the effects of land-use on stream ecosystems are triggering by activities such as logging (WALLACE & GURTZ 1986; CAMPBELL & DOEG 1989) and grazing (CAMPBELL et al. 1992; REED et al. 1994; PARNRONG 1998). The similarity between these examples in the need to clear vegetation, including the tree canopy, which eliminates most of the direct leaf input. However, this is not the case for the economic crops in our study, which do provide shading and litter input, but the plant species composition has been altered nonetheless. Although our study did not show any effects on leaf processing rates by the agricultural sites, the economic species are processed faster than the native vegetation.

Streams invertebrates utilise leaf litter as a food source and as habitat (DUDGEON & WU 1999), DUDGEON & WU (1999) also found that palatable leaves (*Fiscus fistulosa*) attract more invertebrates, and are processed faster, than *Castopsis fissa* leaves. Invertebrates benefit in terms of food sources from the availability of rapidly processed leaves, but this may also be a disadvantage in terms of habitats since the leaves quickly disintegrate. A decrease in the variety of plant species may affect stream invertebrates which feed on specific plant species.

The other possible effect of an agricultural site is the amount and timing of litter input access to streams. *H. brasiliensis* is a deciduous species with an abscission period in the dry season (February). During this time, the high litter access to the streams, together with high processing rates, can cause an over abundance of food, followed by scarcity later. This is in contrast to native vegetation which being mostly evergreens, provides continuous litter input.

Conclusion

All the leaf species have very high processing rates, which may be caused by high stream temperatures and physical breakdown. The streams, seasons, and sites (forested/ agricultural) do not influence the leaf processing rates. Comparisons of the rates do not detect any effects caused by agriculture. This suggests that the biological component of the stream may be a better index for evaluating the effects agricultural activity.

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Author address:

Supatra Parnrong, Kittiyaporn Buapetch and Muratha Buathong, Department of Aquatic Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai 90112, Thailand.

E-mail: psupatra@ratree.psu.ac.th

Table 1 Maximum, minimum, mean and the standard error of the mean (SE), for the decay coefficients (day^{-1}), for each leaf species and plant group. Data was pooled from all the streams, sites, and seasons, n = 12.

	Max.	Min.	Mean	SE
Native specie	0.0405	0.0198	0.0292	0.0018
R. glandulosa	0.0545	0.0254	0.0413	0.0024
P. pinnata	0.0333	0.0114	0.0236	0.0016
Economic species	0.0693	0.0294	0.0504	0.0031
H. brasilliensis	0.1060	0.0303	0.0636	0.0058
N.lappaceum	0.0517	0.0284	0.0380	0.0024
Introduced species	0.1080	0.0479	0.0694	0.0053
E. camaldulensis	0.1330	0.0349	0.0747	0.0079
A. mangium	0.1330	0.0169	0.0682	0.0087

Table 2 Factorial ANOVA tests on the species and group data sets, considering the effects of the species, groups, streams, sites and seasons on the decay coefficients. n = 72 for the leaf species data set , and n = 36 for the leaf groups data set. Only significant interactions are shown.

Variable	df	F-ratio	p
Species data set			
Species	5	15.209	<0.005
Stream	1	1.958	0.168
Site	1	0.648	0.425
Season	1	0.834	0.366
Site/season interaction	1	5.047	0.029
Group data set			
Group	2	33.661	<0.005
Stream	1	1.235	0.278
Site	1	0.054	0.817
Season	1	1.706	0.204
Site/season interaction	1	5.475	0.028

Table 3 Comparisons of the mean decay coefficients (± standard error of mean) from the pooled data made between the plant groups, streams, seasons, and sites. An underlined heading indicates a non-significant difference, p = 0.05.

Group:	Introduced species	>	economic species	>	native species
	(0.0694 ± 0.0053)	p=.003	(0.0504 ± 0.0031)	p=.001	(0.0292± 0.0018)
Stream:	Wang Pha	Tone Nga Chang	Tone Plew		
	(0.0436 ± 0.005)	(0.0562 ± 0.0073)	(0.0491 ± 0.0055)		
Season:	Wet	Dry			
	(0.0470 ± 0.0048)	(0.0522 ± 0.0050)			
Site:	Forest	Pasture			
	(0.0501 ± 0.0047)	(0.0492 ± 0.0052)			