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Leaf Litter Processing and Patterns of Shredder Distribution in Headwater Streams in Southeastern Korea

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한국 남동지역 상류 하천에서의 낙엽 분해기작과 shredder 분포 유형

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ABSTRACT

During the period of December 1992 (winter-spring) and from February 1995 (winter-spring), the leaf processing rates of oak (*Quercus serrata*) and tulip (*Liriodendron tulipifera*) tree was investigated in the headwater streams in southeastern part of Korea in conjunction with the distribution pattern of macroinvertebrate fauna. Using two types of bags (10×30 cm with 5 g of dry leaves; open bag with holes, closed bag without holes), decomposition rates of oak and tulip tree by shredder and/or microbiota at a relatively undisturbed 2nd-order stream were compared. Regardless of leaf type, leaves in the open bags decomposed slightly faster than those in the closed bags. In the 1992 experiment, oak leaves decomposed much slower than tulip leaves (after 138 degree days, oak: closed, 0.006% loss/day; open, 0.008; tulip: closed, 0.021; open, 0.023; n=2). The results of the identical decomposition experiment using oak leaves in 1995 were similar to those of the first experiment (after 151 degree days, oak: closed, 0.005% loss/day; open, 0.006; n=6). Over 50% of invertebrates from 122 leaf pack samples collected from 12 streams during the winter period of 1994 were identified as shredders (shredder, 56.2; collector, 32.7; scraper, 8.65; predator, 2.45%). Among shredders, *Gammarus* sp. and *Tipula* sp. were dominant species in terms of number and biomass (8.2 ind./g, 1.0 ind./g AFDW of leaves). Among many physico-chemical parameters, the width of stream channel was found to be the most influential factor in the distribution of *Gammarus* and *Tipula* (*Gammarus*: $r=-0.34$, $P<0.001$; *Tipula*: $r=0.40$, $P<0.001$). Considering the fact that oak is one of the dominant riparian vegetation in the southeastern part of Korea, the patterns of oak processing and shredder distribution shown in this study may well represent some of the important characteristics of headwater streams in southeastern Korea.

Key words: *Gammarus*, Litter processing, Shredder, Stream, *Tipula*

INTRODUCTION

Allochthonous organic materials is a major energy source in the headwater streams. The processing of these materials is a functional characteristic of small forested streams (Cummins 1974, Fisher and Likens 1972, 1973). Leaf processing is an integrative function of headwater systems and involves microbial, animal, and physico-chemical interactions (Benfield and Webster 1985, Iversen 1975, Petersen 1984, Wallace *et al.* 1982).

For many years, the mechanism of leaf processing has been the subject of numerous investigations in a variety of aquatic ecosystems (such as leaf type, water temperature, water chemistry, micro- and macrohabitat factors, biotic activity, and resource quality) (Cuffney *et al.* 1990, Kaushik and Hynes 1971, McArthur *et al.* 1994, Webster and Benfield 1986). In south Korea, studies on the distribution of macroinvertebrate and the factors affecting their distribution have been increased during the last decade (Bae and Yoo 1993, Bae 1993, Oh and Chon 1993, Park and Cho 1995). However, few studies have concerned with quantification or characterization of macroinvertebrate fauna in small forested streams. In addition, distribution of macroinvertebrates associated with natural leaf packs has remained to be studied. For these reasons, we intended to produce basic data on the leaf litter processing and macroinvertebrate distribution in leaf packs. Specific objectives of this study were to 1) compare the rate of litter decomposition of oak and that of tulip leaves, 2) quantify the macroinvertebrate fauna in naturally conditioned leaf packs, and 3) determine factors affecting the distribution of shredder in headwater streams.

DESCRIPTION OF THE STUDY SITES

All study sites (12 headwater streams) are located in the forested mountains of Pusan and Kyoungsangnamdo Province (Fig. 1). The sites lie within 200~400 m in elevation and are 1-3rd order streams. Studies on the rate of leaf decomposition were conducted in a relatively undisturbed 2nd-order stream in Pusan (Jangjuncheon, KumjeoungGu). This stream supplies residents in Jangjundong area with drinking water.

The details of physico-chemical properties for 12 streams were described in Table 1. Stream gradients at all reaches of study sites were relatively high (>1.2%) with a substrate predominantly of granite bedrock and boulder. All sites were soft water (pH, 6.0~7.7; alkalinity, 5.5~12.7 mg as $CaCO_3$/l). Dissolved nutrient levels were generally low (total N, 1138±448 μg/l; total P, 236±105 μg/l; n=6). During the low discharge periods, the mean range of water depth at 12 streams was 9.3~22.2 cm (n=40). Most streams were shaded by dense riparian vegetation [range of light penetration 17.5~71% (n=40), except for Sangii2: 100%]. The woody riparian vegetation is dominated by oak and pine trees, making up more than 85% of the canopy in the study sites.

Table 1. Summary of selected physico-chemical parameters of 12 study sites. All samples were collected bimonthly from Feb. 1994 to Feb. 1995. (NA3, Naewonsa 3; TO1, Tongdosa 1; CH, Chulma; SA1, Sangii 1; NA2, Naewonsa 2; BU2, Bumosa 2; BU1, Bumosa 1; SA2, Sangii 2; JA, Jangjuncheon; BU3, Bumosa 3; TO2, Tongdosa 2; NA1, Naewonsa 1)

SITE	Active channel (cm)	Bank full width (cm)	Channel slope (%)	Light input (%)	Channel depth (cm)	Temp. (℃)	pH	Alkalinity (mg $CaCO_3$/l)	D.O. (mg/l)	D.O. (% Sat.)	TP (μg/l)	TN (μg/l)
	**	**	**	**	**	**	*	*	*	*	*	*
NA3	69	224	2.2	28	10	12.9	6.1	8.7	8.9	89	476	1500
TO1	79	390	11.3	19	15	12.5	6.5	7.2	10.7	107	174	1348
CH	80	301	5.6	71	11	15.3	7.3	10.7	10.2	112	369	1126
SA1	112	347	7.2	23	11	13.2	6.7	8.7	10.5	108	247	1316
NA2	104	380	13.8	36	13	13.9	6.1	5.7	10.3	104	197	1049
BU2	110	338	7.9	28	11	11.9	6.1	5.5	8.8	86	2.8	661
BU1	203	308	10.7	28	13	11.8	6.1	5.7	10.3	102	196	746
SA2	111	320	1.2	100	9	14.1	6.4	12.7	9.5	97	264	1060
JA	201	450	7.0	31	10	11.0	7.0	16.0	11.2	110	64	2060
BU3	259	748	10.8	17	22	13.2	6.9	12.3	10.1	113	263	1112
TO2	631	1261	7.8	54	22	15.4	7.6	11.2	9.8	118	231	1604
NA1	863	1499	1.5	34	22	13.9	6.4	6.3	9.1	94	253	1004

* : N=6
** : N=40

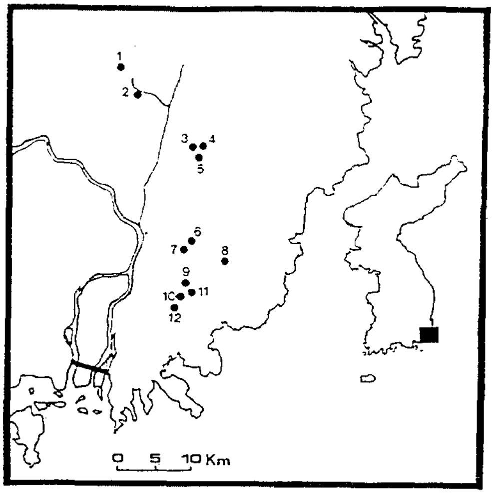

Fig. 1. Map of the Pusan and Kyoungsangnam-do Province, with the location of study sites: 1, Tongdosa 1; 2, Tongdosa 2; 3, Naewonsa 2; 4, Naewonsa 3; 5, Naewonsa 1; 6, Sangii 1; 7, Sangii 2; 8, Chulma; 9, Bumosa 1; 10, Bumosa 2; 11, Bumosa 3; 12, Jangjuncheon. Sampling sites-●.

MATERIALS AND METHODS

Litter processing

Leaves of oak (*Quercus serrata*) and tulip tree (*Liriodendron tulipifera*) around the Mt. Kumjung were collected at the end of October 1992. These leaves were dried (24h at 50℃) and weighed so that the ratio of dry-mass to fresh-mass could be obtained. From December 1992 through April 1993, and from February to July 1995, two different species of leaves (oak and tulip tree) were studied in a series of experiment by using two types of nylon-mesh bags (bag dimension: mesh size 2 mm, 10×30 cm; closed bag: without holes; open bag: 20 holes of 1 cm in diameter). Each type of bag was designed to compare the rate of decomposition by shredder plus microbial community, and that by microbial community alone. Oak leaves were chosen for its dominance in riparian community in the region. Tulip leaves were used to mimic soft texture leaves.

For the first experiment of leaf litter processing, a total of 80 packs of oak and tulip leaves (5 g dry leaves in each bag) anchored with bricks were placed on the stream bed of Jangjuncheon on the 3rd of December, 1992. Collections of litter bags from stream were made after 0, 8, 15, 22, 31, 47, 62, 76, 114, and 138 days. In the second experiment of that, a total of 128 packs of oak leaves anchored with bricks were set in stream on the 14th of February 1995. Collections of litter bags from the stream were made after 0, 19, 34, 50, 68, 90, 111, 131, and 151 days.

The remaining leaf material for each species was dried (24h at 80℃), weighed, and then ashed (10h at 500℃). Loss rates were obtained by fitting % weight loss data to negative exponential model ($\log_e X = -kY$, where X is the proportion of initial weight remaining, and Y is a function of time elapsed either in days or degree days). This was calculated to allow comparison of breakdown rates with literature values (Petersen and Cummins 1974, Webster and Benfield 1986).

Macroinvertebrate community associated with natural leaf pack

During the winter and spring of 1994, invertebrate fauna associated with 122 natural leaf packs sampled from 12 headwater streams were analyzed. All packs were cleaned of debris and macroinvertebrates were removed and preserved in 10% formalin. The macroinvertebrates retained by a 200 μm screen sieve were sorted under a dissecting microscope, identified to the lowest possible taxon. The taxa were assigned to functional feeding groups according to various literature sources (e.g., Iversen 1988, Merritt and Cummins 1978). In order to determine the factors that affect the distribution of macroinvertebrate community, basic physico-chemical parameters of 12 headwater streams were measured bimonthly from Feb. 1994 to Feb. 1995. Physical (light penetration, temperature, depth, channel width, and gradient), and chemical features (alkalinity, dissolved oxygen, pH, and nutrients) were measured. Light intensity was measured using a Li-Cor Quantum meter (model 183). The Winkler method was used for the measurements of dissolved oxygen. Alkalinity was measured using the titration method (0.02 N H_2SO_4 to an end point of pH 4.5). pH was measured using an Orion Model 407A pH meter. Nutrient concentrations (TP, TN) were analyzed by Standard Methods (APHA, AWWA, WEF 1995) and methods described in Wetzel and Likens (1991).

RESULTS AND DISCUSSION

1. Litter processing

A. Decomposition of leaves

Tulip and oak leaf breakdown in this stream followed a typical negative exponential pattern (Fig. 2A, B, C). The breakdown rate shows that tulip leaves (k=0.022~0.023) were decomposed faster than oak leaves (k=0.004~0.008). Slower processing of oak leaves was possibly due to the texture and chemical composition of leaves. When $\log_e$-transformed values were linearly regressed, decay coefficients were higher in the open bags and tulip leaves (tulip open bag, 0.023 > tulip closed bag, 0.021 > oak open bag, 0.004~0.008 > oak closed bag, 0.004~0.006% loss/day, respectively; n=2~12). After two months of submersion in the stream, 50% of the leaf materials of tulip was processed. In contrast, oak leaves were slowly processed (after 4 months, 50% loss) (Fig. 2A′, B′, C′). It is assumed that faster processing of tulip leaves is possibly related to its leaf structure. There were differences in lignin content between oak (36.6% of AFDW) and tulip leaves (11.1% of AFDW) (Ward and Woods 1986). Tulip leaves are more permeable and soft because of lower concentration of phenolics and tannins than oak leaves. Inhibitory compounds such as phenolics and tannins can retard the decomposition of some leaf types (Harrison 1971). Cummins *et al.* (1989) determined the time required to reach the point at which approximately 50% of the input of a given litter class is processed. For the fast species, 50% litter processing would occur after approximately 300 degree days. From this study, we expected that 50% litter processing of oak would occur after approximately 150 degree days in the southeastern part of Korea.

Regardless of leaf type, we found that leaf breakdown rates did differ between open

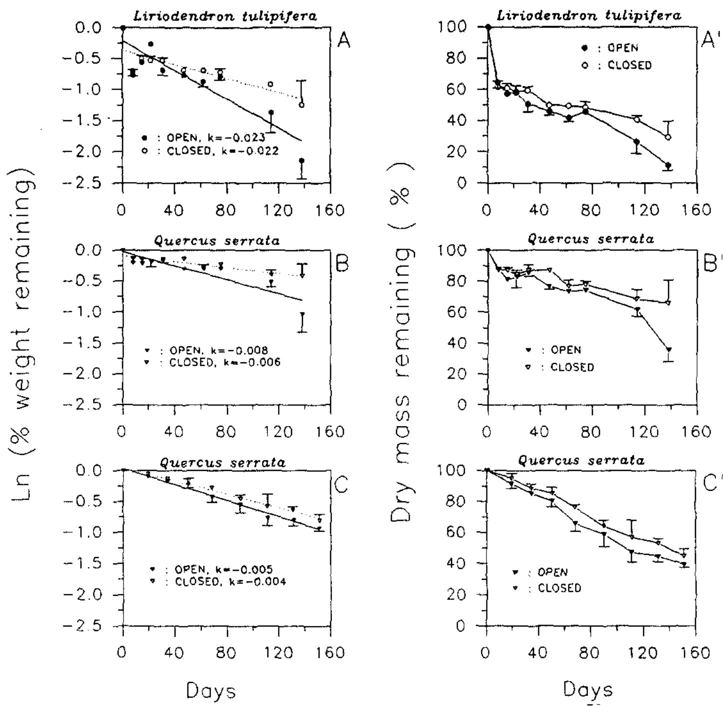

Fig. 2. Decay rate for tulip (*Liriodendron tulipifera*) and oak (*Quercus serrata*) in open and closed bag (A, B, C) and dry mass remaining (%) of tulip and oak (A′, B′, C′) in Jangjuncheon from December 1992 through April 1993 (A, A′, B, B′) and from February to July 1995 (C, C′). Error bars denote 95% confidence limits (A, B, n=2; C, n=6).

bags and closed bags. Decay rates for closed bags were lower than those observed in open bags. In the open bags, higher numbers of macroinvertebrates were attained in the bags. It is likely that macroinvertebrates facilitated physical breakage and processing of leaves in the open bags. Regardless of leaf bag position and collection date, however, no shredders were found in more than 40% of the bags. Dry weight of shredder was generally low. In most of leaf bags, dry weight of shredder was less than 1 g /g leaf remaining. Considering the results, it is believed that water circulation through holes, snail movement, and microbial dynamics were primary factors causing the differences in decomposition between leaf bag types in the study site.

Compared to other studies, oak leaf in this study broke down slowly. Decay rate of tulip leaves is similar to that of soft texture leaf such as elm and willow (Table 2). Compared to oak decomposition in this study, decay rates of water oak in 3-4th order stream of coastal plain region, South Carolina, U.S.A. were much slower (McArthur *et al.* 1994). Even though the leaf used in these experiments were in the same genus, k-value can vary significantly depending on the climate of the region and stream characteristics. Mild winter and high microbial activity might possibly have contributed to the faster processing of oak

Table 2. Comparison of decay rates (-k values) of selected species

Leaf		-k values	Stream order	Sample (g)	Replicates n	Mesh size and type (mm)	Study site	Reference
water oak								
Quercus nigra	mixed	0.0004~0.002	3,4	10	5	0.25	U.S.A	McArthur *et al.* 1994
	alone	0.0009~0.002						
sweetgum								
Liquidambar styraciflua	mixed	0.0004~0.005	3,4	10	5	0.25	"	"
	alone	0.001~0.0124						
box elder								
Acer negundo		0.01~0.04	3	3	2,4	1	U.S.A	Oberndorfer *et al.* 1984
alder								
Alnus glutinosa		0.0229	3	17~24	5	9	Germany	Gessner *et al.* 1991
willow								
Salix fragilis		0.0236	3	17~24	5	9	"	"
elm								
Ulmus minor		0.0361	2	5	12	onion bag	Italian	Gazzera *et al.* 1991
Ulmus americana		0.0263	2	5	12	"	"	"
maple								
Acer pseudopl		0.0542	2	5	12	"	"	"
Acer rubrum		0.0285	2	5	12	"	"	"
elm								
Ulmus minor		0.03	2	5	12	"	U.S.A	"
Ulmus americana		0.0129	2	5	12	"	"	"
maple								
Acer pseudopl		0.0152	2	5	12	"	"	"
Acer rubrum		0.0146	2	5	12	"	"	"
oak								
Quercus serrata	closed	0.004~0.006	2	5	2,6	2	S.Korea	this study
	open	0.005~0.008						
tulip								
Liriodendron tulipifera	closed	0.022	2	5	2	2	"	"
	open	0.023						

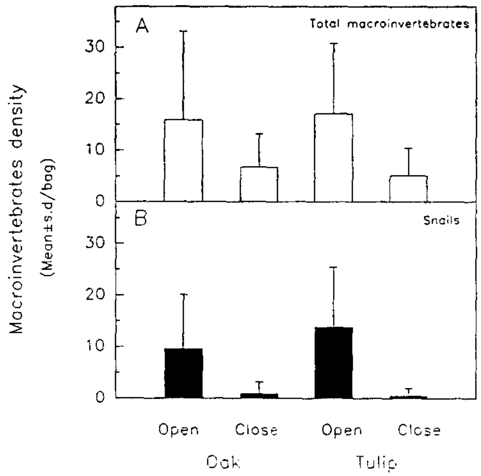

Fig. 3. Total density of macroinvertebrates and snails in different leaf bags (n=20 for each bag type). Values are means of 10 samples during the decomposition experiment in 1993.

and tulip in this study.

B. Macroinvertebrate community within leaf bags

Trichoptera, Ephemeroptera, Diptera, Plecoptera, and Gastropoda were present in the bags. In the present study, aquatic insects contribution on the decomposition of leaves was small as is apparent from the low total numbers per bag (Fig. 3). As parameters indicates (mean number of tulip leaves: open bag, 17.1±13.7; closed bag, 5.1±5.3; oak leaves: open bag, 15.9±17.2; closed bag, 6.7±6.4; n=7), it is very unlikely that macroinvertebrate caused the difference in decomposition rate. In contrast to low number of aquatic insects, snail density within the bags was high (over 49% of total macroinvertebrate numbers in leaf bags). In Jangjuncheon, snail density in the stream channel was also very high (*Semisulcospira* sp., 379±205 ind./m^2, n=7) during the study period. Thus, we thought that activities of snail were the major contributor in the processing of leaves. Recently, many workers have documented functional role of snail as a grazer in lentic ecosystem (Feminella *et al.* 1989, Lamberti and Resh 1983, Power *et al.* 1988). However, we suggest that snails can be a very important functional feeding groups both as grazer and shredder in certain streams where they maintain a high density.

2. Macroinvertebrate community associated with natural leaf packs

The classified taxa of aquatic insects were 37 species of 32 genera, 23 families, and 9 orders. Shredders were numerically the most abundant functional feeding group associated with natural leaf packs; collectors were the next most abundant group (shredder, 56.2%; collector, 32.7%; scraper, 8.65%; predator, 2.45%). Composition of the functional groups in natural leaf packs per unit AFDW was similar to the numeric abundance at all sampling sites (shredders (1.6±1.4), collectors (1.0±1.0), scrapers (0.3±0.5), predators (0.1±0.1 ind./g, n=121, respectively). However, overall more than 90% of macroinvertebrates found in this study can be classified as detritivores because shredders and collectors depend on coarse and fine detritus for their food source.

Distribution of shredder and collector in the naturally occurring leaf pack showed contrasting pattern with respect to the channel size (Fig. 4). Shredder abundance was higher toward a smaller stream while collector tended to occur in lower order stream. Dis-

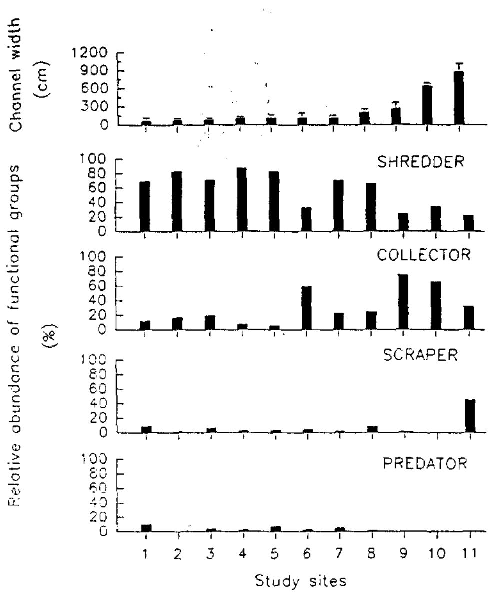

Fig. 4. Relative abundance of 4 major functional groups in the naturally occurring leaf packs along the channel size (channel width): 1, Naewonsa 3; 2, Tongdosa 1; 3, Chulma; 4, Sangii 1; 5, Naewonsa 2; 6, Bumosa 2; 7, Bumosa 1; 8, Sangii 2; 9, Bumosa 3; 10, Tongdosa 2; 11, Naewonsa 1. Bar in channel width is standard deviation.

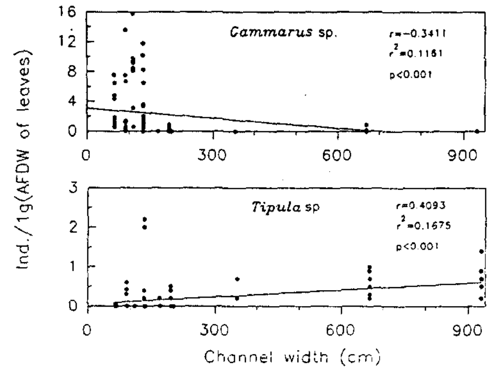

Fig. 5. Distribution patterns of *Gammarus* sp. and *Tipula* sp. (ind./g AFDW of leaves) *versus* channel width (cm).

tribution of scraper and predator in natural leaf packs did not show any clear pattern with respect to the channel size of stream. The abundance of shredders in the first order stream, and increased scraper populations in stream order greater than one, were also predicted by the River Continuum Concept (RRC) (Vannote *et al.* 1980). According to the prediction of RRC, the distribution of shredders was high toward headwater stream where the interaction between water and land is high. Contribution of riparian vegetation in headwater stream is reciprocally proportional to the channel size. We were unable to obtain data on macroinvertebrate distribution of stream channel. However, shredder and collector in this study clearly show that these two functional groups utilize leaf packs as a habitat. The mechanism of resource utilization or habitat use by these functional groups deserves a further study.

Among many physico-chemical variables that were measured at the site of natural leaf pack sampled, the width of stream channel was the most noticeable factor affecting the distribution of shredder. Among shredders, *Gammarus* and *Tipula* sp. were the most common in the natural leaf packs (*Gammarus* sp.: 2.0±3.0/g AFDW, n=111 and *Tipula* sp.: 0.2±0.3/g AFDW, n=111). A quantitative analysis (width *vs* ind./g AFDW) was performed using simple linear correlation. Negative correlation was found in *Gammarus* sp. ($r=-0.3411$, $P<0.001$; $n=111$). In contrast, *Tipula* sp. ($r=0.4093$, $P<0.001$; $n=111$) was positive (Fig. 5). *Gammarus* tends to occur in higher order streams (e.g., 1~2nd order stream) while *Tipula* prefers lower order stream (2~3rd order stream). However, habitat partitioning between *Gammarus* and *Tipula* is not clearly understood. It is very difficult to perform the quantification research related to leaf types in natural stream.

We believe that a reasonably clear understanding of the main mechanism involved in litter processing is available, but the detailed mechanism of microbial, macroinvertebrate contribution in the process in streams has just begun in this country. Further study shall show litter processing in different geographical regions while introducing biogeography of aquatic macroinvertebrate abiding in south Korean headwater stream.

CONCLUSIONS

Tulip and oak leaf breakdown in this study followed a typical negative exponential pattern. The breakdown rate shows that tulip leaves (k=0.022~0.023, 50% processing of dry weight about 2 months) decomposed faster than oak leaves (k=0.004~0.008, 50% processing of dry weight about 4 months). Regardless of leaf type, we found that leaf breakdown rates in open bag were slightly faster than rates observed in closed bags.

Shredder contribution to the decomposition of leaves in open bags was small as is apparent from the low total numbers. Snails possibly made a difference in the processing rates between open and closed bags.

Shredders and collectors were numerically the most abundant functional feeding group associated with natural leaf packs. Among shredders, *Gammarus* sp. and *Tipula* sp. were the most common in the natural leaf packs. *Gammarus* tends to occur in higher order streams (e.g., 1~2nd order stream) while *Tipula* prefer lower order stream (2~3rd order stream).

For better understanding of litter processing in headwater streams, a more sophisticated experimental design would be required to distinguish the effects of purely physical, microbial and animal.

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적 요

한국 남동지역의 상류 수계의 낙엽 더미 내의 수서 무척추동물 분포 유형과 상수리 잎과 튜울립나무 잎의 분해기작을 관찰하였다. 1992년 겨울부터 1993년 봄과 1995년 2월부터 7월까지 상

수리나무 (*Quercus serrata*) 잎과 튜울립나무 (*Liriodendron tulipifera*) 잎의 분해율을 파악하였다. 2가지의 분해망에 (10 × 30 cm 내의 건조 중량 5g 잎; 폐쇄망과 1cm 직경의 구멍을 가진 개방망), 미생물 또는 shredder에 의해 일어나는 분해 정도를 인위적 교란이 적은 2차 하천에서 (장전천) 비교 분석하였다. 잎종류와는 상관없이 개방망 내의 잎이 폐쇄망 내의 잎보다 빨리 분해가 되었다. 1992년에는 상수리 잎의 분해 속도가 튜울립 잎보다 매우 느렸다 (실험 138일 후, 상수리 잎: 폐쇄망, 0.006% loss/day; 개방망, 0.008; 튜울립 잎: 폐쇄망, 0.021%; 개방망, 0.023; n=2). 1995년에는 상수리 잎을 이용하여 실험한 결과 1992년과 유사하였다 (실험 151일 후, 상수리 잎: 폐쇄망, 0.005% loss/day; 개방망, 0.006; n=6). 1994년 겨울 동안 12개 상류 하천 내의 122개 낙엽 꾸러미들에서 무척추동물을 기능군별로 정량한 결과 50% 이상이 shredder였다 (shredder, 56.2; collector, 32.7; scraper, 8.65; predator, 2.45%). Shredder들 중 옆새우와 각다귀는 총개체수나 생체량에서 우점하는 종이었다 (8.2 ind./g, 1.0 ind/g AFDW of leaves). 많은 이화학적인 요인 중 하천의 폭이 옆새우와 각다귀 분포에 영향을 미치는 가장 중요한 요인으로 사료된다 (옆새우: r=−0.34, P<0.001; 각다귀: r=0.40, P<0.001). 한국 남동부지역의 하천 주변에서 우점하는 식생중의 하나가 상수리 군락인 점을 감안하면, 상수리의 분해기작과 shredder의 분포 양상은 한국 남동부지역의 상류 하천에서 일어나는 낙엽 분해의 특성을 잘 대표하리라 생각된다.

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