Zoological Studies **43**(4): 795-802 (2004)

Zoological Studies

Density and Diversity of Litter Amphibians in a Monsoon Forest of Southern Taiwan

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(Accepted July 29, 2004)

Ching-Yu Huang and Ping-Chun Lucy Hou (2004) Density and diversity of litter amphibians in a monsoon forest of southern Taiwan. *Zoological Studies* **43**(4): 795-802. In this study, we examined the density and diversity of litter amphibians in a monsoon forest of southern Taiwan. We conducted bimonthly surveys in 2001 in a wind-exposed and in a creek (wind-shielded) site in Nanjenshan Nature Reserve using the quadrat (5 x 5 m in size) method. Our results showed that the mean density of litter amphibians for the entire year at the creek site (10.24 individuals (ind.)/100 m^2) was higher than that in the wind-exposed site (3.5 ind./100 m^2), and the compositions of litter amphibians at the 2 sites also significantly differed. The creek site was dominated by *Rana latouchii* and *Microhyla heymonsi*, while the population of the wind-exposed site was mainly composed of *Bufo bankorensis*, *R. latouchii*, and *Chirixalus eiffingeri*. Juvenile frogs constituted 52% and 46% of the litter amphibians in the creek and wind-exposed sites, respectively. In conclusion, the distribution of litter amphibians is highly heterogeneous in the monsoon forest. http://www.sinica.edu.tw/zool/zoolstud/43.4/795.pdf

Key words: Frog community, Nanjenshan, Subtropical rainforest.

Amphibians are important tertiary or quaternary consumers in forest ecosystems (Steward and Woolbright 1996). Recent studies have shown that floor-dwelling (litter) amphibians in the forests exert a substantial top-down control over their prey densities and thus play an important role in regulating forest nutrient dynamics (Wyman 1998, Beard et al. 2002). While the relationships between amphibians and forest ecosystem functions have received increasing attention, precise estimates of litter amphibian densities have not been reported in Taiwan despite the general distribution patterns and relative abundances of amphibians having been known for years (Lue et al. 1990). It is only in recent years that amphibian diversities have been reported in a few forests of Taiwan (Hou 1998, Kam 1999, Chou et al. 2002). Those studies using visual-encounter, audio, or drift fence-and-pitfall trap methods, however, did not quantify density.

Numerous methods have been employed to study amphibian ecology and biodiversity, but only a few are able to obtain credible densities of amphibians (Heyer et al. 1993). Quadrat, transect, and patch sampling have all been used to measure the density of adult and juvenile amphibians. Among them, quadrat sampling has been widely used in estimating densities of ground-dwelling amphibians in tropical as well as temperate forests (Lloyd et al. 1968, Scott 1976, Inger 1980, Toft 1980, Fauth et al. 1989, Allmon 1991, Vonesh 2001). For example, Inger (1980) used quadrat sampling to investigate the densities of floor-dwelling amphibians in Borneo and Thailand. The same method was used by Scott (1976) to measure densities of the litter herpetofauna in lowland forests of Costa Rica and Panama.

In this study, we investigated the density and diversity of the litter amphibian community using the quadrat method in the Nanjenshan forest, a lowland monsoon forest and a long-term ecological research site in southern Taiwan, to serve as the basis for amphibian monitoring and further ecological studies.

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MATERIALS AND METHODS

Study area

The experiment was carried out in Nanjenshan Nature Reserve (22°03'N, 120°51'E) of Kenting National Park in southern Taiwan. It is one of Taiwan's Long Term Ecological Research sites and is at elevations ranging from 10 to 460 m.

The annual mean temperature is 22.3°C, and annual precipitation is ~3500 mm. There are about 230 rainy days annually which are evenly distributed throughout the year. However, high rainfall resulting from tropical cyclones (typhoons) occurs in summer and fall (July to Sept.). From Oct. to late Feb. of the following year, northeasterly monsoon winds prevail. During this time, winds continuously blow, and wind speeds can increase 3- to 4-fold in exposed sites; thus, monsoon winds do not cause direct damage, but chronic stress, to the forest and potentially have larger cumulative effects on the forest structure and species composition (Sun et al. 1998).

Vegetation in this area is strongly influenced by topography and the monsoon winds. Vegetation on the exposed slope is dominated by *Eurya hayata* and is highly disturbed by strong wind. However, vegetation by the streamside is dominated by *Schefflera octophylla* (Hsieh 1990). Annual litterfall was 11.77 and 9.43 tons/ha in 1995-1996 and 1996-1997, respectively. Two peaks of litter fall occur in Mar.-May (the growing season) and July-Sept. (the typhoon season) (Chang 1998).

Soils are typically Ultisols and are extremely acidic (pH < 4.5). Soil depths range from 60 to 130 cm with a clay texture on top and clay loam beneath. The soils are low in organic matter content and are nutrient deficient (Lee and Liao 1996). The litter layer on the forest floor is usually less than 5 cm.

Experimental design

Two study sites representing wind-exposed (windward) and wind-shielded (creek) vegetation types were chosen within the 2-ha Guhu permanent plot near Nanjen Lake in the reserve (Fig. 1). Ten plots were set up in the creek site, while only 8 plots were available on the smooth area in the exposed site. The 18 plots, each 5 x 5 m in area, were marked with yellow plastic strings. Each plot was surveyed 6 times at 2-mo intervals from Jan. to Nov. in 2001. Each survey was performed between 0830 and 1700 h for 2 d with 6 persons. Air temperature, relative humidity, and soil pH of each plot were recorded during each survey.

Quadrat sampling

At the beginning of each survey, the 6 people were separated into 2 groups who stood on the opposite sides of a plot. The 2 groups then moved toward the opposite sides of the plot searching for

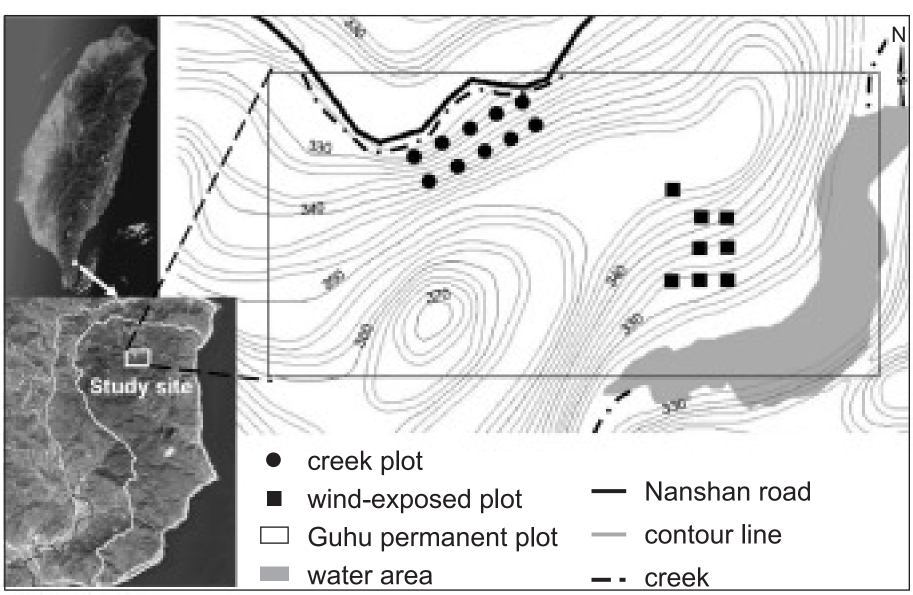

Fig. 1. Map of the Guhu permanent plot and study site showing the creek and wind-exposed plots.

amphibians. We overturned all leaves, logs, pieces of wood, fallen branches, and exposed stones inside the plot and checked the spaces between stems for amphibians. We captured and identified each individual to species and recorded the number of individuals for each species. All captured amphibians were immediately released after the investigation which generally took 15 min per plot.

Statistical analysis

Because density data did not fit the normality hypothesis, the effect of site and sampling month on the densities of amphibians were analyzed using the Mann-Whitney *U*-test and Friedman repeated-measure analysis of variance on ranks, respectively, with the SigmaStat statistical software program (Jandel Corp., Fox et al. 1995). The similarity of litter amphibian compositions between the creek and wind-exposed sites was calculated using the Bray-Curtis measure of similarity (Bray and Curtis, 1957). Differences in amphibian communities from different sampling months and sites were analyzed by a multivariate ordination method (multidimensional scaling, MDS) and were subsequently tested by the analysis of similarity (ANOSIM) procedure of PRIMER (Plymouth routines in multivariate ecological research) statistical software (Primer-E, Clarke and Warwick 1994, Clarke and Gorley 2001). Species diversity, richness and evenness were calculated with the Diverse procedure of PRIMER.

RESULTS

Environmental variables

During the survey periods, air temperature (24.33~25.0°C) and humidity (72.3%~79.0%) did not significantly differ between the creek and the wind-exposed sites (independent *t*-test, $p > 0.05$). The mean soil pH at the creek site was 6.05 and was higher than that in the wind-exposed site (pH 5.38), however, the values did not significantly differ between the 2 sites (*t*-test, $p > 0.05$).

Density and composition of litter amphibians

We captured a total of 154 amphibians at the creek site, whereas only 39 were found in the wind-exposed site in 2001. The mean densities of litter amphibians for the entire year in the creek plots were significantly higher than those in the wind-exposed plots (Mann-Whitney *U*-test, $p = 0.019$). The mean densities in both the wind-exposed and creek plots did not differ between months (Friedman repeated measure analysis of variance on ranks, $p = 0.52$). The mean density of litter amphibians for the entire year at the creek site was 10.2 individuals (ind.)/100 m^2, which was 3-fold higher than that at the wind-exposed site (3.5 ind./100 m^2) (Table 1). The mean bimonthly amphibian densities were highest in May at both sites and were lowest in Nov. and Mar. at the creek and wind-exposed site, respectively. There was no significant correlation between the soil pH and

Table 1. Species richness, total densities, and diversities of litter amphibians at 2 sites in the Nanjenshan forest, Taiwan, in 2001

		Month						
		Jan.	Mar.	May	July	Sept.	Nov.	Mean
Density [a]	C [b]	12.4 ± 5.3 (0-56)[c]	12.8 ± 5.4 (0-48)	18.0 ± 9.9 (0-100)	8.0 ± 2.6 (0-24)	6.4 ± 3.1 (0-32)	3.6 ± 1.4 (0-12)	10.2 ± 1.8
	W [b]	2.5 ± 1.3 (0-8)	2.0 ± 0.7 (0-4)	5.0 ± 1.8 (0-16)	3.5 ± 1.9 (0-12)	3.5 ± 1.2 (0-8)	3.0 ± 1.3 (0-8)	3.5 ± 0.4
Shannon-Wiener index (H’)	C	1.07	1.21	0.95	1.11	1.23	1.15	1.30
	W	0.67	1.04	1.19	1.27	1.74	0.45	1.65
Evenness (J’)	C	0.77	0.89	0.59	0.80	0.76	0.83	0.67
	W	0.97	0.95	0.86	0.92	0.98	0.65	0.85
Richness (no. of spp.ecies)	C	4 (0-3)	4 (0-3)	5 (0-4)	4 (0-2)	5 (0-3)	4 (0-2)	
	W	2 (0-2)	3 (0-1)	4 (0-3)	4 (0-3)	6 (0-2)	2 (0-1)	

[a] Densities are the number of individuals per 100 m^2 and are shown as the mean ± 1 S.E.
[b] C: creek site, W: wind-exposed site.
[c] Ranges of data are given in parentheses.

amphibian density (Pearson Correlation, $p = 0.94$).

Seven anuran species were recorded at each site (Table 2). *Bufo bankorensis*, *B. melanostictus*, *Rana latouchii*, *Microhyla heymonsi*, *M. ornata*, and *Chirixalus eiffingeri* were observed at both sites, whereas *R. swinhoana* was found only at the creek site, and *Polypedates megacephalus* was seen only at the wind-exposed site (Table 2). *Rana latouchii* and *M. heymonsi* were the most abundant species at the creek site, while *B. bankorensis*, *R. latouchii*, and *C. eiffingeri* were dominant in the wind-exposed site (Table 2). The amphibian compositions between the 2 sites significantly differed by MDS (ANOSIM, $p = 0.002$) (Fig. 2), although neither the Shannon-Wiener diversity index (H') nor species evenness index (J') significantly differed between the 2 sites (Table 1). The similarity of litter amphibian compositions between the wind-exposed and creek sites for the entire year was 32.12%. Furthermore, species compositions between months did not statistically differ at the creek site (ANOSIM, $p = 0.464$) or wind-exposed site (ANOSIM, $p = 0.105$), respectively.

Abundance of juveniles

Juveniles constituted 52% and 46% of total litter amphibians at the creek and wind-exposed site, respectively. Juveniles of *B. bankorensis*, *R. latouchii*, and *C. eiffingeri* were abundant on the forest floor of both sites, while juveniles of *M. heymonsi* were only dominant at the creek site (Fig. 3). Most juveniles of *B. bankorensis* were found in Jan. and Nov. (Fig. 4a), while those of *R. latouchii* were observed from Jan. through May (Fig. 4b). Juveniles of *C. eiffingeri* were most abundant in Mar. (Fig. 4c).

DISCUSSION

Density of litter amphibians

The mean densities of litter amphibians for the entire year in the Nanjenshan forest ranged from 3.5 to 10.2 ind./100 m^2, which were lower than those in Central American forests studied by Scott (1976) and Inger (1980). Nevertheless, these values are within the range of those of South

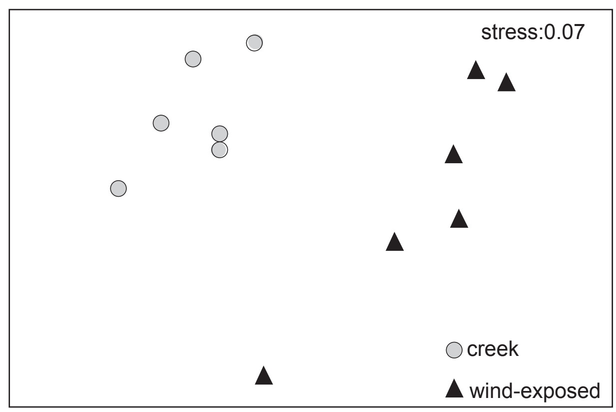

Fig. 2. Multi-dimensional scaling (MDS) plot of the bimonthly litter amphibian compositions from the creek (circles) and wind-exposed (triangles) sites of Nanjenshan forest, Taiwan.

Table 2. Density of litter amphibians at 2 sites in the Nanjenshan forest, Taiwan, in 2001

	Creek		Wind-exposed	
	Density [a]	Percentage (%)	Density	Percentage (%)
Bufonidae				
Bufo bankorensis	0.53 ± 0.25 (0-36) [b]	5.20	1.17 ± 0.36 (0-8)	35.90
Bufo melanostictus	0.07 ± 0.07	0.65	0.10 ± 0.10	2.56
Ranidae				
Rana latouchii	5.07 ± 1.64 (0-72)	49.35	0.67 ± 0.11 (0-8)	20.51
Rana swinhoana	0.40 ± 0.18 (0-8)	3.89	0	0
Microhylidae				
Microhyla heymonsi	3.27 ± 0.66 (0-28)	31.82	0.17 ± 0.11 (0-4)	5.13
Microhyla ornata	0.27 ± 0.27 (0-12)	2.60	0.33 ± 0.33 (0-4)	10.26
Rhacophoridae				
Chirixalus eiffingeri	0.67 ± 0.43 (0-12)	6.49	0.67 ± 0.31 (0-8)	20.51
Polypedates megacephalus	0	0	0.17 ± 0.11 (0-4)	5.13

[a] Densities are the number of individuals per 100 m^2 and are shown as the mean ± 1 S.E..

[b] Ranges of data are given in parentheses.

American forests (Allmon 1991). In Central American forests, densities of litter amphibians in Costa Rica and Panama varied between 7.5 and 36.1 ind./100 m^2 (Heatwole and Sexton 1966, Scott 1976, Inger 1980), while those in the South American forests were 2.3~15.5 ind./100 m^2 (Allmon 1991). There is a general pattern of densities of litter herpetofauna (amphibians and lizards) in Asian forests being significantly lower than those in Neotropical forests (Scott 1976, Inger 1980, May 1980). Scott (1976) attributed this discrepancy between Asian tropical forests and Neotropical forests to the higher litterfall, and thus higher insect abundance, in Neotropical forests. However, Inger (1980) reviewed the litterfall data and found that litter production was 2-fold higher in the Malayan and southern Thai rain forests than in Neotropical and African forests. We calculated the litterfall (731~1973 g/m^2/yr) on Barro Colorado Is., Panama, (from Levings and Windsor 1982) and found that it was similar to that (943~1177 g/m^2/yr) in the Nanjenshan forest (Chang 1998). Therefore, high litterfall does not account for the higher amphibian density in Neotropical forests. Inger (1980) proposed that synchronized mast fruiting in Asian tropical forests causes fluctuations in arthropod abundances, thus indirectly affecting the abundance of amphibians. The low amphibian density in Asian tropical forests might be the results of non-mast years. Nevertheless, Allmon (1991) pointed out that Inger's suggestion could not explain differences in amphibian densities between Central and South American forests and

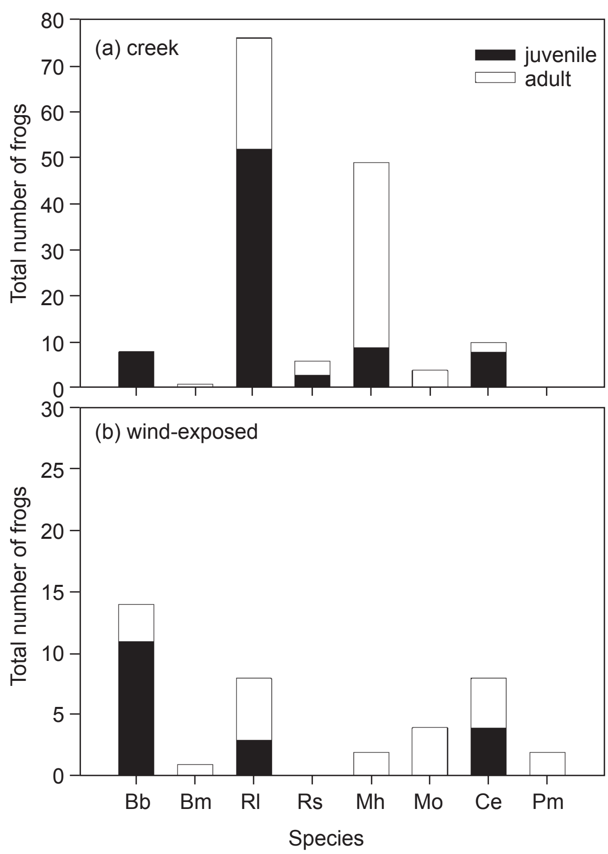

Fig. 3. Compositions of litter amphibians in the creek (a) and wind-exposed (b) sites of Nanjenshan forest, Taiwan, during the 2001 survey. Bb, *Bufo bankorensis*; Bm, *B. melanostictus*; Rl, *Rana latouchii*; Rs, *R. swinhoana*; Mh, *Microhyla heymonsi*; Mo, *M. ornata*; Ce, *Chirixalus eiffingeri*; and Pm, *Polypedates megacephalus*.

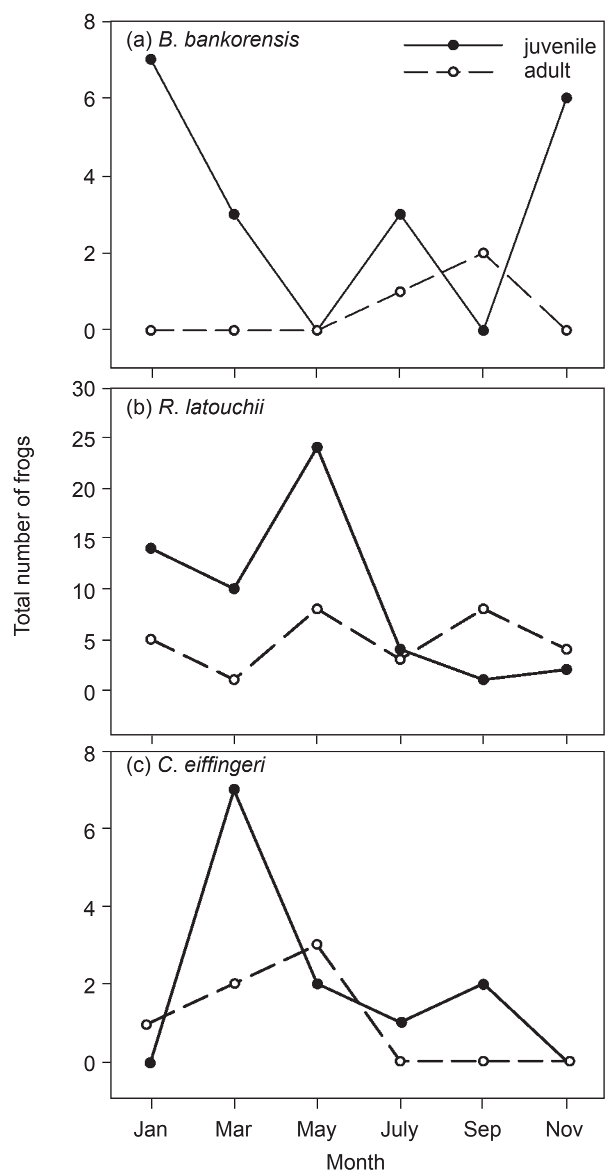

Fig. 4. Abundance of juvenile and adult anurans on the forest floor of Nanjenshan during the 2001 survey. (a) *Bufo bankorensis*, (b) *Rana latouchii*, and (c) *Chirixalus eiffingeri*.

proposed that the geological history of lowland tropical forests (as reflected, for instance, in soil nutrients) might influence the abundance of the litter herpetofauna. However, there is no evidence in support of his hypothesis.

Densities of litter amphibians in the Nanjenshan forest were higher than those in other Asian forests (Inger 1980). Mean densities of floor-dwelling amphibians in the tropical forests of Borneo and Thailand were 0.12~1.31 ind./100 m^2 (Inger 1980). This difference may have resulted from variations in vegetation density. Vegetation density of the Nanjenshan forest at the study sites was 110.25 stems/100 m^2 (Hsieh 2000). This value is much higher than the vegetation density (7.23~19.06 stems/100 m^2) for evergreen and deciduous forests in Thailand (values calculated from Inger and Colwell 1977). Higher vegetation density may increase heterogeneity on the forest floor, hence providing more microhabitats for amphibians. We suggest that available microhabitats might influence densities of floor-dwelling amphibians. Nevertheless, the relationship between densities of amphibians and the abundance of microhabitats remains to be examined.

Although density estimates can vary with different methods, density differences between this and previous studies suggest that this is less likely to be the cause. Rocha et al. (2001) evaluated densities of litter amphibians using large (8 x 8 m) and small (1 x 1 m) plot methods in an undisturbed Atlantic rainforest of Ilha Grande, Brazil. They found that the large plot method tended to miss frogs of very small size, such as *Psillophryne didactyla*, and to underestimate the abundance of litter frogs of a given area. They suggested that the small sampling plot method is better. Although we used a larger quadrat size in this study, our density estimates are perhaps quite accurate because the study site did not contain very small frog species and thorough, labor-intensive searches were conducted. Nevertheless, the quadrat size (5 x 5 m) and sampling time (daytime) adopted in this study were similar to those of previous studies (Scott 1976, Inger 1980, Fauth et al. 1989, Allmon 1991), therefore, our results should be comparable with those from previous studies. Furthermore, repeated surveys on the same plot in this study did not apparently influence densities of litter amphibians since our data did not show a decreasing trend with repeated sampling after Jan. 2001 (Table 1).

Effect of sites

At the creek site, the mean density of litter frogs was 3-fold higher than that at the wind-exposed site, and amphibian compositions significantly differed between the 2 sites. Higher densities of litter frogs at the creek site might have been due to the fact that the creek site is closer to water sources. In addition, differences in amphibian compositions between the creek and wind-exposed sites may have been related to the types of nearby aquatic habitats. The closest water source to the creek site is an intermittent small brook, where *R. latouchii*, *M. heymonsi*, and *R. swinhoana* were frequently observed. On the other hand, the nearest water source for the wind-exposed site is a permanent pond, where *B. bankorensis* and *P. megacephalus* breed.

Soil pH and moisture may also influence the density of amphibians. Vernberg (1955) indicated that salamanders (*Plethodon cinereus*) preferred neutral soils with a pH range of 6.2~7.2. Wyman and Hawksley (1987) showed that the acute lethal soil pH for *P. cinereus* was between 2.5 and 3.0 and the 8-month chronic lethal pH was between 3 and 4. They suggested that low soil pH enhances release of aluminum and heavy metals into soil solutions that would harm young and adult amphibians. Furthermore, low soil pH might increase sodium loss in amphibian larvae and reduce food resources (e.g., isopods and millipedes) of the amphibians. Although soil pH (6.05) at the creek site was slightly higher than that (5.38) at the wind-exposed site, there was no significant correlation between soil pH and amphibian density. In addition, some papers documented that the movement of amphibians was significantly affected by soil or substrate moisture (Keen 1984, Seebacher and Alford 1999). Keen (1984) found that salamanders (*Desmognathus fuscus*) took refuge more frequently in high-moisture substrates. However, the relationship between amphibian distribution and soil or substrate moisture remains to be studied.

Densities of litter amphibians may also be related to the abundance of arthropods. Toft (1980) compared 2 forest sites in Panama and found amphibian density to be positively correlated with the abundance of litter arthropods. In a study on invertebrates in litterbags on the forest floor (Huang and Hou, manuscript in preparation), a higher density of invertebrates was obtained from the creek site. Hence, the higher density of litter amphibians at the creek site might result from higher food density at the site.

Juvenile anurans

Newly metamorphosed amphibians comprising a high proportion of the litter amphibians (Fig. 3) was similar to the result found in another study (Moreira and Lima 1991). The pattern of juveniles occurring at specific times of a year is in general agreement with the reproductive patterns of the adults. Some studies have shown that post-metamorphic froglets predominantly eat mites and collembolans in the litter layer (Simon and Toft 1991, Lima 1998). Collembolans and mites are dominant constituents of detrital food webs and can influence decomposition processes and nutrient mineralization through regulating microbial activity (Hanlon and Anderson 1979, Vossbrinck et al. 1979). Nevertheless, it is worthy investigating the possible impacts of juvenile anurans on litter micro-arthropod abundance and indirect effects on decomposition in terrestrial ecosystems.

In conclusion, this study provides the 1st quantitative data on litter amphibians in Taiwan. Our results suggest that distributions of litter amphibians in a little-disturbed lowland monsoon forest are highly heterogeneous.

Acknowledgments: We thank students from the Tadpole Laboratory, Biology Department, National Cheng Kung University, Tainan, Taiwan, for field sampling assistance. We also thank Dr. Andrew Moldenke for reviewing an earlier draft of this manuscript. This study was supported by grants (NSC-89-2621-B-006-005-A10 and NSC-90-2621-B-006-005-A10) from the National Science Council of Taiwan to P.-C. L. Hou.

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