

Original article

Inverse Relationship of Hemiptera Richness with Temperature in South Korea

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Abstract The distribution pattern of species richness was determined by temperature. To examine the relationship between hemipteran richness and temperature, hemipteran species were collected using pitfall traps at six different oak forest sites with different annual mean temperatures in South Korea. Multiple linear regression analyses were conducted with mean annual temperature (MAT) and plant richness to evaluate differences in hemipteran richness. The influences of MAT and plant richness of study sites on hemipteran richness were examined by comparing three models (plant richness + MAT + MAT², plant richness + MAT, and MAT) or two models (plant richness + MAT and MAT). Hemipteran richness showed an inverse diversity pattern as a function of temperature, with higher species richness at lower temperature sites. Meanwhile, Aphididae showed a bell-shaped diversity pattern with the highest value at low medium temperatures. The regression analysis showed that hemipteran richness was affected by temperature and plant richness in their habitats.

Key words: Hemiptera, Aphididae, inverse diversity pattern, temperature, distribution, forest

INTRODUCTION

The species richness of many taxa such as insects, mammals, reptiles, and plants in the Northern Hemisphere is usually high in the tropics and decreases towards the northern pole (Stevens, 1989). In contrast, the species richness of some taxa such as aphids and linyphiid spiders is high in the temperate zone and low in the tropics (Cushman *et al.*, 1993). The distribution pattern of species richness was determined

based on climates, and the topographical characteristics of the regions (Lee *et al.*, 2020, Kwon *et al.*, 2021a, b). For example, in Korea, the diversity of butterflies increases in colder regions with higher latitudes - observable from the fact that there are many northern species and fewer southern species due to the peninsula effect (Choi, 2004). Many arthropods in Korea follow this inverse diversity pattern, showing an increase in species richness at higher latitudes (Lee *et al.*, 2016). Although many studies on insect diversity in Korea have been conducted for a long period, few studies (Choi, 2004; Kwon, 2014) have been conducted on species diversity patterns at the national scale.

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Species richness also has a strong relationship with the elevation. Based on data collected from 12 high mountains in South Korea, Kwon *et al.* (2014) reported that the species richness of ants decreases as the elevation increase. They also showed that the species richness of ants decreased as the temperature decreased. However, a bell-shaped pattern with the highest ant species diversity in the middle temperature range was found in ant data collected from 365 forest sites at a nationwide scale in South Korea (Lee *et al.*, 2016). This indicates that the pattern of biodiversity is closely related to sampling scales or areas. Kwon (2014) documented that evolution events such as origin regions (tropical or temperate) of clines are key factors that determine the pattern of species diversity. He predicted that taxa evolved in the tropics would have higher species diversity as the temperature increased, whereas richness of the taxa evolved in the temperate zone would show an inverse diversity pattern, being higher in the temperate zone and lower in the tropics. This idea is closely related to niche conservatism - a hot, current ecological theory that provides a theoretical basis for various ecological themes such as global diversity patterns, species evolution theory, species conservation, and niche modeling (Wiens and Graham, 2005). Kwon *et al.* (2014) expected that the aphids that evolved in the temperate zone would show a bell-shaped pattern of richness across the temperature gradient in temperate regions such as Korea.

The present study was conducted to test the hypothesis that taxa evolved in the temperate zone would show a bell-shaped pattern of species richness across the temperature gradient, as predicted by Kwon *et al.* (2014).

MATERIALS AND METHODS

1. Study sites

The study was conducted in six different forests (Unduryong, Gaebangsan, Gwangneung, Sobaeksan, Gayasan, and Geumsan) at different temperatures ranging from the northernmost part (Mountain Gaebangsan) to the southernmost part (Mountain Geumsan) in South Korea (Table 1). The study sites were located in oak forests (crown coverage 60~95%), where understory vegetation was sparse to moderate (coverage approximately 5~50%) and litter covered the ground. More information on the study sites is provided in Kwon (2017). The temperature was measured using temperature data loggers (Hobo VTBI/Hobo Tidbit v2, USA) placed at a depth of 10 cm in the soil at each study site. The data loggers were set to measure the temperature every 30 min from mid-November 2013 to mid-November 2014. The mean annual temperature (MAT) at the six study sites ranged from 7.4°C to 12°C (Table 1).

2. Field sampling

Samples were collected using pitfall traps at a plot measuring 15 m × 20 m, of 5 × 4 grid cells placed at 5 m intervals at each study site. Samples were collected twice - once from late May to early June and once in August 2014. Twenty traps were installed with plastic cups (diameter, 9.5 cm; depth, 6.5 cm) as pitfall traps for 10 days. Propylene glycol was used as a conservative agent to fill approximately 30% of each trap. Two period samples were pooled because this study was not aimed at studying seasonal differences in diversity. Hemipter-

Table 1. Number of plant species and mean annual temperature measured at six study sites.

Variable	Study site						Mean (standard deviation)
	Unduryong (UD)	Gaebangsan (GB)	Gwangneung (GN)	Sobaeksan (SB)	Gayasan (GA)	Geumsan (GS)	
Location (latitude (N), longitude (E))	37.707024, 128.444379	37.747514, 128.441602	37.745846, 127.152624	36.904588, 128.458703	35.790053, 128.100551	34.763516, 127.988308	—
Elevation (m)	1089	813	460	490	498	355	617.5 (277.4)
Mean annual temperature (MAT) (°C)	7.4	8.6	10.3	10.7	11.1	12.0	10.0 (1.7)
Number of species of plant	13	18	14	16	11	14	14.3 (2.4)

Table 2. Number of individuals of Hemiptera (except Aphididae) at six different study sites. Acronyms of study sites are given in Table 1.

Family	Species	Study site						Total
		UD	GB	GN	SB	GA	GS	
Lygaeidae	<i>Eremocoris plebejus</i>		1					1
	<i>Neolethaeus dallasi</i>	1	1		5	1		8
	<i>Paradieuches dissimilis</i>				2			2
	<i>Trichodrymus pameroides</i>	1						1
Anthocoridae	<i>Amphiareus</i> sp.					1		1
Cydnidae	<i>Macroscytus japonensis</i>	1	1	119	34	2	1	158
Miridae	<i>Castanopsides kerzhneri</i>						1	1
	<i>Castanopsides potanini</i>			1				1
	<i>Dryophilocoris</i> sp.	1						1
	<i>Hallodapus</i> sp.	1						1
	<i>Josifovolygus niger</i>		1					1
	<i>Mermitelocerus annulipes</i>	5						5
	<i>Orthonotus</i> sp.	2						2
	<i>Phytocoris</i> sp.			1				1
	<i>Psallus castaneae</i>	1						1
Nabidae	<i>Gorpis brevilineatus</i>		1					1
Reduviidae	<i>Epidaus tuberosus</i>	1						1
Urostylidae	<i>Urochela quadrinotata</i>	1			1			2
	<i>Urostylis</i> sp.			1				1
Cicadellidae	<i>Athysanopsis salicis</i>		1					1
	<i>Bathysmatophorus japonensis</i>	50	28					78
	<i>Evacanthus ogumae</i>	1						1
	<i>Futasujinoidella nobilis</i>		1					1
	<i>Japananus hyalinus</i>			1				1
	<i>Kolla atramentaria</i>		1					1
	<i>Ledra auditura</i>				1			1
	<i>Pagaronia continentalis</i>	1						1
Aphrophoridae	<i>Aphrophora intermedia</i>	1						1
	<i>Cremidanomia lugubris</i>		1					1
Number of species of Hemiptera except Aphididae		14	10	7	5	3	3	29
Number of species of Aphididae		10	16	7	6	4	1	—
Number of species of Hemiptera		24	26	14	11	7	4	—

an samples were identified to the species level, whereas aphids were identified as morpho species at the family level because of the difficulty involved with their identification. The pooled richness of Aphididae was not estimated because morpho species were identified at each site. Vegetation of each study site within the plot was identified using plant samples, including branches containing leaves, fruits, or flowers.

3. Data analysis

Differences in hemipteran richness were evaluated using

multiple linear regression analysis with MAT and plant richness (number of species per plot). Aphididae richness showed a humped pattern as a function of temperature. Therefore, quadratic polynomial regression analysis was used for taxa showing a humped pattern. The influences of MAT and plant richness on hemipteran richness were examined by comparing three models (plant richness + MAT + MAT², plant richness + MAT, and MAT) or two models (plant richness + MAT and MAT). The minimal adequate model (MAM) was determined according to Crawley (2007). The optimal model (OM) was defined as the model with the lowest Akaike informa-

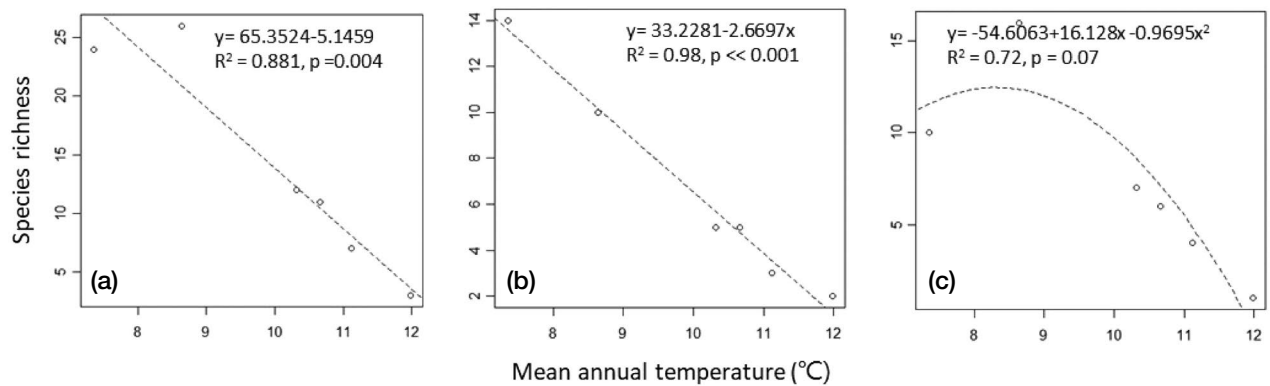


Fig. 1. Richness (number of species) of Hemiptera and mean annual temperature at six study sites. (a) Richness of Hemiptera, (b) richness of Hemiptera except Aphididae, and (c) richness of Aphididae. Richness data are given in Table 2. The trend lines were fitted with simple (linear) or humped (quadratic polynomial) regression models.

tion criterion (AIC). AIC is the statistical trade between the log-likelihood value and the number of parameters (Crawley, 2007). Statistical analyses were conducted using a stat package in R (R Core Team, 2017).

RESULTS AND DISCUSSION

Among the 29 species in Hemiptera, except Aphididae collected from the field survey, the richness ranged from 2 species to 14 species per sampling site (6.5 ± 4.6 , mean \pm SD). Aphididae richness displayed high variation among the study sites, ranging from 1 species to 16 species per study site (7.3 ± 5.2) (Table 2). The high richness of Aphididae might be caused by the frequent flying of aphids to find their hosts (Paek, 1972). The pitfall trap had the same collection mechanism as the yellow water-filled dish traps, which is a standardized aphid collection method (Kwon *et al.*, 2002). However, the yellow dish traps have an attractive effect and can collect many aphids, whereas the pitfall traps do not have an attractive effect. Therefore, aphids are randomly collected in pitfall traps, as are other insects.

Among the 29 species of Hemiptera, excluding Aphididae, 25 species were collected at only one site with few individuals. The excessively high proportion of singleton species indicates that hemipteran insects were not collected in large numbers by pitfall traps. Although the pitfall traps cannot catch many hemipteran insects, they can be used to compare species diversity because few insects were randomly sampled from populations. In Hungary, pitfall traps were used to determine the micro-scale effect of forest edges on the diversity

of Heteroptera (Torma and Galle, 2011).

Among the collected species, *Macrosctus japonensis* in Cydnidae was the dominant species with the highest abundance collected at all six study sites. Unlike other species living in vegetation, this species inhabits the ground or the soil. It is observed on a nationwide scale in South Korea and is also distributed in Japan and Russia (Kwon *et al.*, 2001). In this study, several individuals were collected at medium temperatures around 10.3°C (Tables 1 and 2), while few individuals were collected at sites with low or high MATs - showing a bell-shaped distribution pattern against temperature gradients. *Bathysmatophorus japonensis* in Cicadellidae was the second most abundant species, although it was collected only at two sites with the lowest MAT (Tables 1 and 2). However, *Neolethaeus dalasi* in Lygaeidae was commonly collected at 4 locations (Tables 1, 2). Similar to *M. japonensis*, *N. dalasi* had the highest abundance at medium temperature around 10.7°C , although its abundance was not high, indicating the possibility of a bell-shaped abundance distribution with regards to the temperature gradient in South Korea.

Hemiptera richness was closely related to temperature (Fig. 1, Table 3). Thus, Hemiptera, excluding Aphididae, decreased linearly with increasing temperature, showing an inverse diversity pattern, whereas Aphididae richness displayed a bell-shaped pattern with a peak at low medium temperature around 8.6°C (bell-shaped diversity pattern) (Fig. 1, Table 3). The total abundance of Hemiptera appeared somewhat bell-shaped because of the influence of Aphididae. However, the regression analysis showed that it was linear rather than bell-shaped (inverse diversity pattern) (Table 3) because the optimum model and minimum adequate models do not contain

Table 3. Regression analysis to evaluate the influence of mean annual temperature (MAT) and plant richness (plant) on Hemiptera richness. Underlined variables in the models are significant ($p < 0.05$).

Taxa	Model	<i>F</i>	DF	<i>P</i>	Adj. R^2	AIC	Evaluation
Hemiptera	<u>Plant</u> + <u>MAT</u> + MAT ²	32.21	3, 2	0.030	0.94	29.23	MAM, OM
	<u>Plant</u> + <u>MAT</u>	53.56	2, 3	0.004	0.95	29.0	
	<u>MAT</u>	38.01	1, 4	0.004	0.88	34.5	
Hemiptera except Aphididae	<u>Plant</u> + <u>MAT</u>	102.9	2, 3	0.002	0.98	16.8	MAM
	<u>MAT</u>	267.3	1, 4	<0.001	0.98	14.9	OM
Aphididae	Plant + MAT + MAT ²	7.77	3, 2	0.110	0.8	30.5	OM
	Plant + MAT	9.12	2, 3	0.052	0.77	31.9	MAM
	<u>MAT</u>	7.79	1, 4	0.049	0.58	35.2	

MAM: minimal adequate model, and OM: optimal model.

the quadratic term of MAT. Regression analysis showed that the number of plant species had a significant effect on the total richness of Hemiptera, but no significant effect was found on the richness of Hemiptera, excluding Aphididae, or on the richness of Aphididae (Table 3). The different patterns between aphids and other hemipterans are probably related with their global distributional patterns which may be determined by evolutionary processes (Kwon, 2014).

A negative correlation between species richness and temperature is often observed in arthropods in Korea, although this is not common (Kwon *et al.*, 2014). For example, the abundance of various taxa in arthropods such as Arthropoda, Auchenorrhyncha, and Lepidoptera collected with pitfall traps at 365 sites on the Korean nationwide scale showed a negative correlation with temperature (Lee *et al.*, 2016). In general, since abundance is positively correlated with richness, the richness of these taxa is likely to have a negative correlation with temperature. In the case of butterflies in Korea, butterfly richness is positively correlated with latitude (Choi, 2004). The percentage of the northern species of butterflies is 50.2% in Korea, whereas the southern species occupies as little as 18.5% (Kwon *et al.*, 2021c). On account of the peninsula effect, there are many northern insects from the northern inland, whereas the southern part is blocked by the sea, preventing the inflow of southern species - resulting in fewer southern species (Choi, 2004).

In the Northern Hemisphere, as species richness decreases from the tropics to the north, it is generally expected that there are more southern species than northern species in the inland region. However, because Korea is a peninsula, there will be several taxa where the dominant phenomenon

of northern species appears. This survey is difficult to generalize because the number of sites is small, and the sampling method is not the standard for Hemiptera. However, the results of this study strongly indicate the dominance of northern species in Korean Hemiptera, and show the possibility of an inverse diversity pattern of Hemiptera, similar to that of Korean butterflies. To confirm these predictions, it is necessary to collect and investigate Hemiptera using standardized survey methods in many regions of Korea, along with an analysis of the distribution characteristics of Hemiptera in Korea.

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