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The Relationship between Local Distribution and Abundance of Butterflies and Weather Factors

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ABSTRACT : According to the energy hypothesis, the energy input per unit area primarily determines species richness in regions of roughly equal area. Some energy-related ecological research included identification of major climatic variables to determine regional species richness. In this study, the local butterfly species richness was examined to find out whether weather variables affected the local distribution or abundance of butterfly populations. Butterfly monitoring data from May 2001 to April 2002 taken at Mt. Yudal, Mokpo, in the southwestern part of Korea, and six weather variables (monthly mean values of temperature, precipitation, evaporation, wind speed, air pressure, and sunlight) were analyzed. Multiple regression analysis showed that only temperature explained 80% and 70% of the variability of log-transformed number of species and individuals, respectively, indicating that temperature played an important role in local species richness. Furthermore, global warming could affect the abundance and distribution of butterflies regionally as well as locally.

Key words : Butterfly, Evaporation, Global warming, Regression model, Temperature

INTRODUCTION

Species richness is influenced by many abiotic (i.e., climate, habitat heterogeneity, and energy) and biotic factors (i.e., history and positive and negative interactions among populations). Many studies have shown that several climatic variables such as solar radiation, temperature, and precipitation are correlated with the regional richness of plants (Richerson and Lum, 1980; Wright, 1983) and animals (Schall and Pianka, 1978; Wright, 1983; Turner *et al.* 1987, Owen, 1988). The base of these correlations between richness and environmental conditions lies on energy (Currie, 1991).

Hutchinson (1959) first proposed the energy hypothesis stating that energy may determine regional species richness. Connell and Orias (1964), Brown (1981), and Wright (1983) developed this idea. The energy hypothesis predicted that the energy flux per unit of area should be the prime determinant of species richness in regions of roughly equal area (Currie, 1991). In plants, actual evapotranspiration was the best environmental correlate of primary productivity that represented realized energy capture (Rosenzweig, 1968; Lieth, 1975; Richerson and Lum, 1980; Wright, 1983; Currie and Paquin, 1987; Currie, 1991). However, in vertebrates, potential evapotranspiration was the best environmental predictor and species richness was less closely related to primary productivity (Schall and Pianka, 1978; Wright, 1983; Turner *et al.* 1987, Currie, 1991). Since energy available to vertebrates is better characterized by atmospheric energy than by food energy, the total vertebrate richness depends on total regional energy, not just on primary productivity (Currie, 1991).

Energy is closely correlated with regional species richness. The possible effects of climate change on plants and animals thus present a major challenge to ecologists. The impacts of climatic change involve the effects on biodiversity, agricultural production, forestry, insect pests, disease vectors, and the incidence of climate-related diseases (Roy *et al.* 2001, Hay *et al.* 2002). Hence, the ecological effect in abundance or geographical distribution of species or communities followed by climatic change is an important concern (Grabherr *et al.* 1994, Barry *et al.* 1995, Parmeson, 1996; Parmesan *et al.* 1999).

Butterflies are good organisms for studying the effects of environmental change since the activity of these organisms is closely controlled by climate (Pollard, 1988; Dennis, 1993; Roy and Sparks, 2000). In addition, due to high dispersal ability and an annual or more frequent life cycle, the changes in abundance and distribution could be monitored over a relatively short time scale (Roy and Sparks, 2000).

The purpose of this study was to investigate the relationship between abiotic factors and local species richness of butterflies at Mt. Yudal, Mokpo. The environmental factor closely related to available energy appeared to increase the species richness of birds, mammals, amphibians, reptiles, and trees in North America (Currie, 1991). Since the variability in species richness was observed among

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geographical regions and at different spatial scales, the question regarding which factors were likely to control species richness at different spatial scales arose. The size of regional species pools might be affected by factors that act on very large scales such as climate, whereas that of local species pools might be affected by local processes such as biotic interactions (Richerson and Lum, 1980; Wright, 1983; Currie and Paquin, 1987; Currie, 1991). Although in principle, many abiotic and biotic factors affect species richness, it is reasonable to inquire whether one or more factors is responsible for variations at different spatial scales from local to regional and global (Currie, 1991). Thus, this study examined the relationship between weather factors and species richness of butterflies at the local level.

MATERIALS AND METHODS

The data for butterflies were collected from Mt. Yudal, Mokpo, in the southwestern part of Korea (E 126°22' 27"~126°22' 37", N 34°47' 1"~34°47' 20", maximum altitude 228 m). A total of 40 species of butterflies were recorded during the one-year survey from May 2001 to April 2002 (Ki and Choi, manuscript in preparation). Local species richness was determined as the sum of the number of species or individuals observed each month. The numbers of species and individuals were log-transformed.

Descriptors of climatic variables were obtained from Korea Meteorological Administration (http://www.kma.go.kr). Monthly mean values of temperature, evaporation, wind speed, precipitation, sunlight, and air pressure were analyzed.

To identify factors that were important in determining species richness, simple correlations were performed between six climatic variables. Also, nonparametric correlations were performed between these variables and the log-transformed numbers of species and individuals. The Spearman rank correlation coefficient was used to assess correlations analysis between climatic variables and log-transformed numbers of species and individuals. STEPWISE multiple regression analysis was performed to identify the best predictor of numbers of species and individuals at Mt. Yudal, Mokpo. All correlation and regression analyses were performed using SPSS 11.0 for Windows (SPSS Inc., 2001).

RESULTS AND DISCUSSION

Table 1 summarizes the correlations among the six climatic variables. A clear positive relationship was observed between temperature and evaporation. Both temperature and evaporation were positively related to sunlight and negatively with wind speed. However, all associations were weak and statistically insignificant. In the correlation between species richness and climatic variables, the number of species was closely correlated with temperature ($r = 0.873$, $P < 0.05$) while the number of individuals was closely correlated with temperature ($r = 0.857$, $P < 0.05$) and evaporation ($r = 0.821$, $P < 0.05$) (Fig. 1; Table 2). Associations of decrease between wind speed and both temperature and evaporation were statistically insignificant.

Temperature and sunlight (or solar radiation) were found to be closely correlated to the richness of several animals (Schall and Pianka, 1978; Turner *et al.* 1987). Currie (1991) found that annual potential evapotranspiration, solar radiation, and mean annual temperature were the three strongest correlates of species richness of vertebrates. This present study shows that local butterflies co-varied with a climatic variable, temperature. In addition to temperature, evaporation was closely correlated to the abundance of butterflies.

Table 3 gives a summary of regression model relating the number of species and individuals to temperature. Temperature alone explained 83% of the variability in the number of species and more than 70% of the variability in the number of individuals, suggesting a good predictive variable.

Temperature affects ectotherms such as butterflies and other

Table 1. Correlations among climatic factors at Mt. Yudal, Mokpo from May 2001 to April 2002

	Temperature	Precipitation	Evaporation	Wind speed	Air pressure	Sunlight
Temperature	1.000	0.353	0.854*	−0.652	−0.345	0.440
Precipitation	0.353	1.000	0.210	−0.145	−0.548	−0.648
Evaporation	0.854*	0.210	1.000	−0.661	−0.286	0.437
Wind speed	−0.652	−0.145	−0.661	1.000	0.039	−0.180
Air pressure	−0.345	−0.548	−0.286	0.039	1.000	0.121
Sunlight	0.440	−0.648	0.437	−0.180	0.121	1.000

* $P < 0.05$.

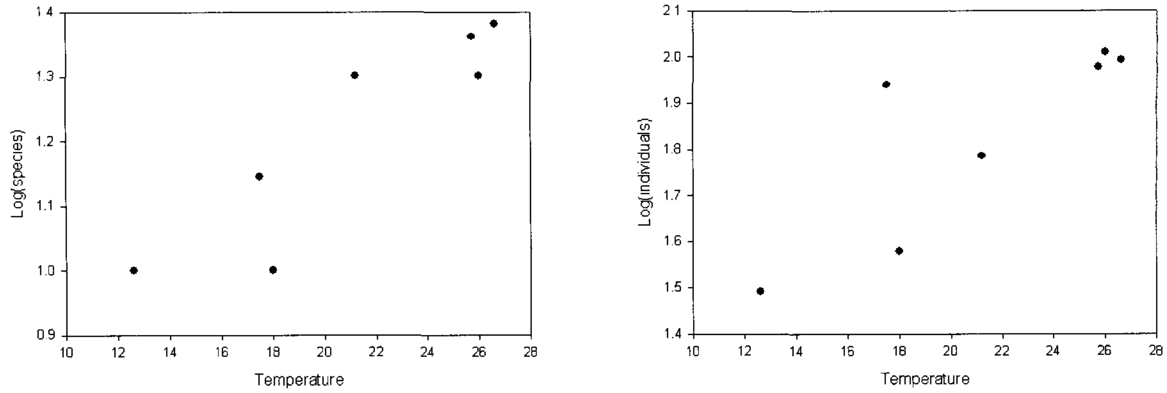

Fig. 1. Scatter-plot between mean monthly temperature from May, 2001 to April, 2002 and species richness of local butterflies at Mt. Yudal, Mokpo. (left) log-transformed number of species; (right) log-transformed number of individuals.

insects in terms of consumption and developmental rate, fitness, distribution, migration, voltinism, larval emergence, survival, and cost to raise body temperature to the flight activity threshold (Beaumount and Hughes, 2002). Roy and Sparks (2000) demonstrated the strong relationship between the first appearance of butterfly adults and temperature: warmer weather tended to produce earlier first and peak appearance.

One of the strongest evidences to support the energy hypothesis was that of Wright (1983). Wright observed that plant and animal richness on islands was related to the total energy received on the island (i.e., area × solar energy per area) (Currie, 1991). This energy hypothesis predicts that energy input per unit area is the prime determinant of species richness. In relation to this, actual evapotranspiration was found as the prime determinant of trees (Rosenzweig, 1968; Lieth, 1975, Currie, 1991).

In this present study, neither actual evapotranspiration nor potential transpiration was included in the analyses. However, temperature and evaporation, which were the main elements in actual evapotranspiration, co-varied in the observed site (Table 1). In addition, strong positive associations between these weather variables and the abundance of butterflies (Table 2) postulated that energy plays an important role in the local species richness of butterflies.

Pollard (1988) suggested that weather during the counts was not important because the largest effect of temperature may have been on late larval or pupal development of butterflies. He also showed that spring-flying butterflies (e.g., *Erynnis tages, Pyrgus malvae, Gonepteryx rhamni*) were positively correlated with temperatures in the previous summer due to an effect of warmth on egg-laying, early larval survival, and sufficient flower-feeding time to survive

Table 2. Spearman rank correlations between abundance of butterfly species and climatic variables at Mt. Yudal, Mokpo

	Temperature	Precipitation	Evaporation	Wind speed	Air pressure	Sunlight
log(species)	0.873*	0.564	0.636	−0.546	−0.255	0.546
log(individuals)	0.857*	0.429	0.821*	−0.643	−0.107	0.679

* P < 0.05.

Table 3. Univariate model predicting the abundance of butterfly species at Mt. Yudal, Mokpo

Dependent variable	Predictor	b	β	t-value	R^2	F
log(species)	temperature	0.028	0.909	4.874**	0.826	23.759**
log(individuals)	temperature	0.033	0.839	3.447*	0.704	11.880*

* P < 0.05. ** P < 0.01.

during winter.

Dry summers were likely to affect egg survival, host plant growth, and habitat structure (Dennis and Shreeve, 1991). Beirne (1955) and Pollard (1988) showed that warm, dry seasons were generally beneficial to populations in the current year but were detrimental in the following year. In the present study, precipitation did not show any significant relationship between numbers of species and individuals (Table 2), but this was primarily because of the short observation period. There were also significant correlations between severe cold and duration of winter months and butterfly appearances (Beirne, 1955; Roy *et al.* 2001).

From these previous studies, it can be concluded that more than one weather variable could have long-term effects on population fluctuations. This present study is a preliminary one showing evidence that the relationship between species richness and weather at the small scale exists. However, the findings from this study suggests that long observation periods implemented at the regional as well as local scale could identify the determinant weather variables and population changes followed by climate changes.

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