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Spatial Distribution of Butterflies in Accordance with Climate Change in the Korean Peninsula

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Abstract: The effects of climate change are becoming apparent in the biosphere. In the 20th century, South Korea experienced a 1.5 °C temperature increase due to rapid industrialization and urbanization. If the changes continue, it is predicted that approximately 15–37% of animal and plant species will be endangered after 2050. Because butterflies act as a good indicator for changes in the temperature, the distribution of butterflies can be used to determine their adaptability to climate patterns. Local meteorological data for the period 1938–2011 were used from the National Forest Research Institute of Korea. Local temperature data were additionally considered among the basic information, and the distribution patterns of butterflies were analyzed for both the southern and northern regions. Southern butterflies (with northern limit) tend to increase in number with significant correlation between the temperature and number of habitats ($p < 0.000$), while northern butterflies (with southern limit) show no statistical significance between the temperature and number of habitats, indicating their sensitivity to temperature change. This finding is in accordance with the conclusion that southern butterflies are more susceptible to climate change when adapting to local environments and expanding their original temperature range for survival, which leads to an increase in the numbers of their habitats.

Keywords: butterflies; global warming; habitat shift; spatial distribution; northern species

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1. Introduction

Industrialization and urbanization are leading to global warming problems that are causing the Earth's temperature to rise rapidly. The effects of this climate change are apparent in the biosphere [1]; thousands of species are migrating toward suitably adapted habitats (area of occupation). Changes in habitat range are actively progressing because of decreased climate-compatible habitats and increased risk of species extinction [1], which are key examples of the risks posed by climate change [2].

Among all living things, insects are sensitive to temperature changes and, of this group, butterflies are useful indicators of climate change; they are easy to examine, well known for their life cycles, and sensitive to the environment [3–5]. Climate change has the potential to seriously affect butterfly populations and has been linked to mass mortality at overwintering sites, population range shifts, and extirpation from fluctuating precipitation levels [6].

Recently, climate change research has been actively conducted on butterflies. In the Northern Hemisphere, 35 species of butterflies moved up 35 to 240 km due to climate change [5], while research into Australian climatic scenarios has shown that more than 80% of unique species are expected to disappear by 2050 [7].

Furthermore, butterfly activity has become rapid with increasing temperature in Britain [8], Spain [9], and North America [10]. In Japan, the great Mormon (*Papilio memnon*) and red Helen (*P. helenus*) species, found in the south, are expanding their distributions [11].

Recently, butterfly research in South Korea has been carried out against the backdrop of climate change. Kwon et al. [12] found that the some of the existing northern groups had decreased in number. Most of these studies have focused on populations, and although data on the changes in the distribution of butterflies on the Korean Peninsula are available, few studies on their relationship with the temperature have been conducted. In the current study, the researcher identified the changes in the butterfly population in the Korean Peninsula over 73 years, from 1938 to 2011. It is significant that the entire region of the Korean Peninsula was surveyed and analyzed for this period (1938–2011) for butterfly distribution. In addition, distribution changes were analyzed using local temperature data, and differences between the southern and northern regions were studied, taking into consideration the distribution patterns and ecological characteristics.

The aim of this work was to identify the changes in the distribution of butterfly habitats as a result of climate change: (1) To correlate temperature and the number of habitats (with the presence of butterflies) for the southern and northern species based on their distribution patterns, and (2) to analyze the differences in the distribution of habitats according to the latitude and to discover changes in the distribution patterns by period.

This study will serve as a basis for the changes in butterfly distribution patterns due to climate change and will serve as a guideline on providing a management plan for butterfly species, helping predict the later disappearance or survival of species.

2. Methods and Study Areas

2.1. Meteorological Data

The nation's weather forecasts began as early as 1904 with Incheon (Station No. 112), and the total number of weather stations was 79 (Figure 1, Appendix A, Table A1). In this study, weather station data were used to calculate the average temperature per cell grid (habitat) considering the period in which the meteorological observatory began and ended.

The overall period was divided into four segments—1938–1955, 1956–1975, 1976–1996, and 1997–2011—according to the availability of data. The average temperature per period was calculated by averaging the periods following the annual average temperature calculations.

2.2. Butterfly Distribution Data

The book "Changing Distribution of Butterflies in Korea" [12] was used as a reference that provided the basic data, as it had compiled all records of butterfly distribution for the period 1938–2011 including the studies of Seok [13] (1938–1955), Kim [14] (1955–1975), Park and Kim [15] (1977–1996), and Kim and Seo [16] (1996–2011). The standard method was used to collect data on in-line transect methods (30 paces/min) and observed butterflies within 10 m of both in-line transects. Butterfly species composition and relative abundances were sampled using transect counts, modified from the method proposed by Pollard and Yates (1993) [17]. Even though the Pollard–Walk method did not exist before the 1970s, the observation was conducted in a manner similar to the line transect method assuming standardized collection of data and quality of data. All butterflies seen within bounds of route (5 m width recorded) and within 5 m ahead were recorded.

Observations were made when butterflies appeared (March to November). In an early publication, Seok [13] showed butterfly appearances by location and later converted them to GPS points so that if one observed the species we created "presence" in each cell. A total of 255 species were observed, which were grouped into three: Southern (with northern limit), Northern (with southern limit), and Miscellaneous (Appendix B). Northern species were defined as species for which the southern boundary in East Asia is located within the Korean peninsula whereas the southern species had a northern boundary of being observed more often in southern areas than northern areas [4]. Butterfly species not classified as Northern or Sothern were defined as "Miscellaneous" species.

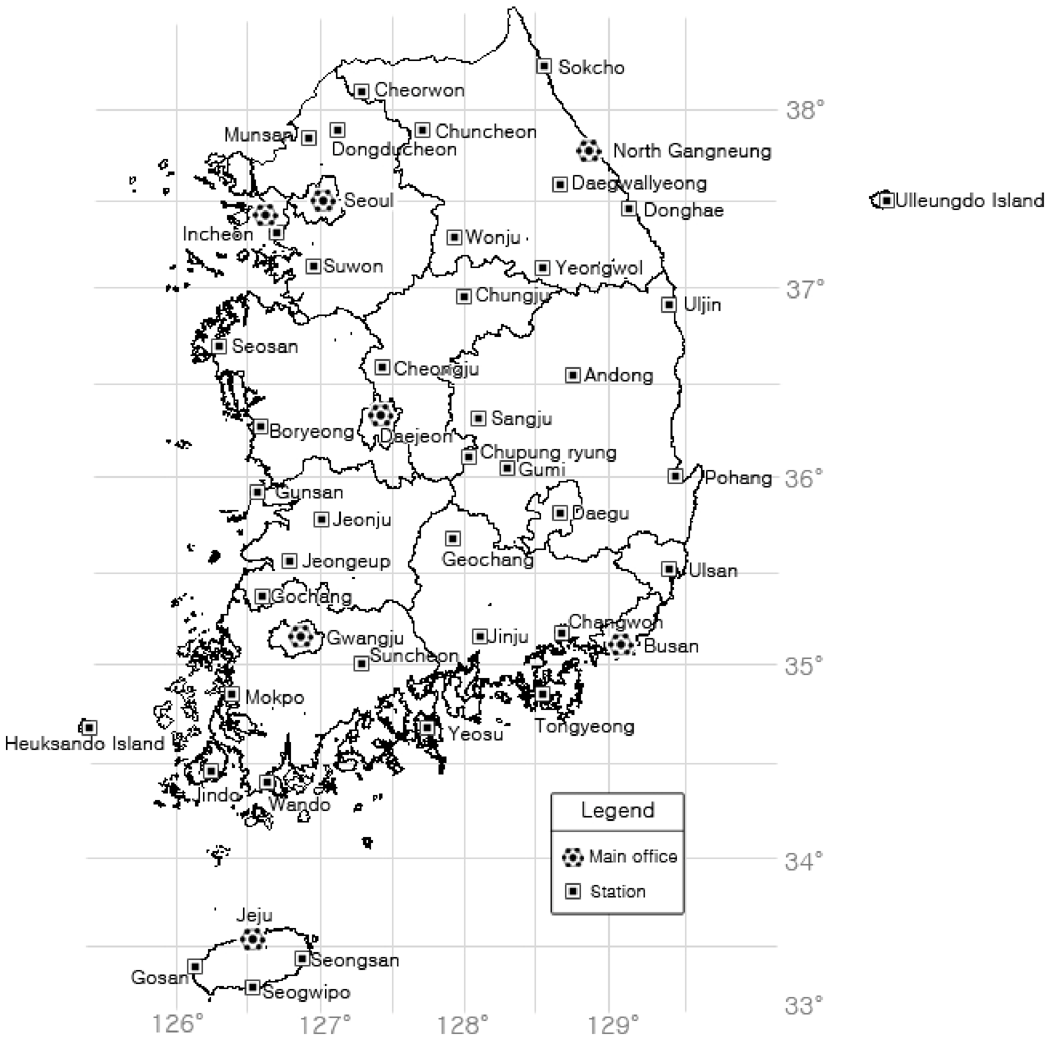

Figure 1. Meteorological observation network operating in Korean Regional Meteorological Office (There are five main offices—Seoul, Noyth Gangneung, Da Daejeon, Gwangju, Busan—and 75 stations).

Cases with no clear limit species frequencies were considered. The number of grid changes over time was indicated for 181 different species of butterfly (out of 225) in Korea that could be analyzed. The grid cell was created on latitude 0.5° (56 km) × longitude 0.5° (44.4 km), and observation was marked in the grid cell, and a total of 99 grid cells were created (9 for longitude, 11 for latitude). In this work, the scope of the data was based on land areas excluding marine areas, and grid species (Cell) were counted using the number of butterflies. The grid-specific temperature data was further considered using the grid and the weather station data therein. The cell grids were used to represent the species "area of occupation" (i.e., habitat) according to the temperature.

2.3. Data Analysis

ANOVA was applied to determine how the temperatures influence the habitat shift, and Tukey HSD, which is applicable for pairwise comparison of means, was applied post-hoc to monitor change in distribution during the four time periods [18]. The correlation between the temperature and butterfly distribution was applied using linear regression with the help of SPSS (IBM, New York, NY, USA, version 21.0).

3. Results

3.1. Change by Periods

During the study periods, there was an increase in annual average temperature according to latitudes (Table 1). The temperature changes by latitude were analyzed and divided into four time segments (<35°, 35° to 36°, 36° to 37°, and >37°) to be determined. For all periods, it was observed that the higher the latitude, the lower the temperature. This also indicated an increase in the latitude temperature over time.

Table 1. Change in annual average temperature according to latitude.

Period / Latitude	Temperature			
	1938–1955	**1955–1975**	**1977–1996**	**1996–2011**
Over 37°	11.4	11.5	11.5	11.9
36–37°	11.6	11.7	12.0	12.4
35–36°	12.9	13.2	13.3	13.9
Under 35°	13.8	14.0	14.3	14.6

Temperature changes were investigated by selecting the representative major regions to identify seasonal changes in temperatures in the Korean Peninsula. The warmest regions were the southern regions, such as Jeju Island, while the middle and northern regions showed lower temperatures. As time went by, the temperature tended to increase (Figure 2).

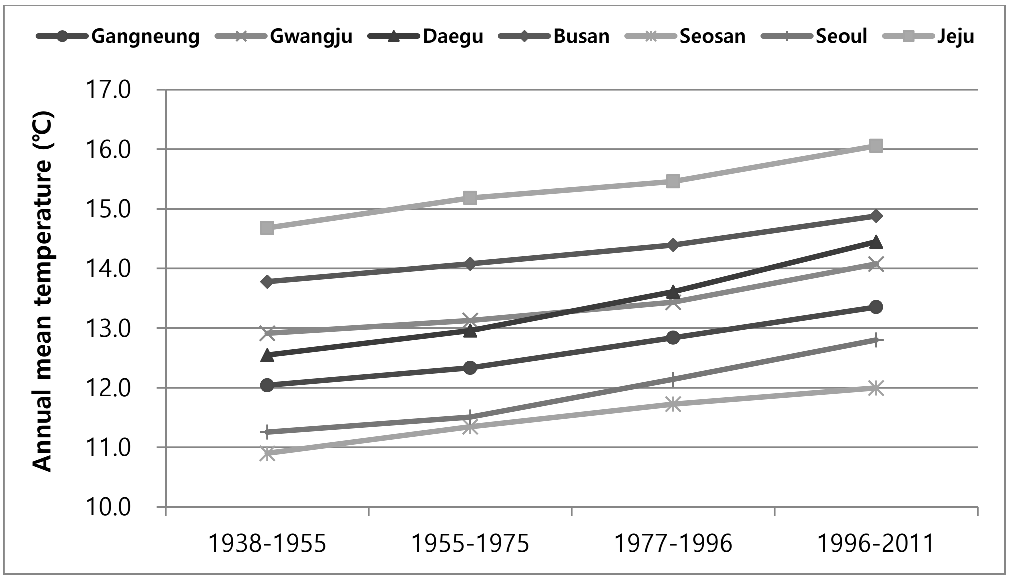

Figure 2. Periodical temperature change in Korean seven major cities.

An ANOVA was conducted to determine whether the habitat temperatures of the southern and northern areas were different among the time periods ($p < 0.05$) (Table 2). The southern region increased in average temperatures over time, and the standard deviation of 1955–1975 was the highest among all periods (12.6 ± 77), showing a large variation in temperature during these periods.

Box plots were applied to identify changes in the historical temperature range. Both the southern and the northern species temperatures became higher as time went by, and the trends were more apparent in southern regions (Figure 3). Looking at the number of seasonal habitats for all butterflies, this number gradually increased over time (Figure 4), except in 1955–1975. Periodic changes in the cell grids in southern and northern butterflies showed that northern species were higher in terms of number of habitats (Figure 3).

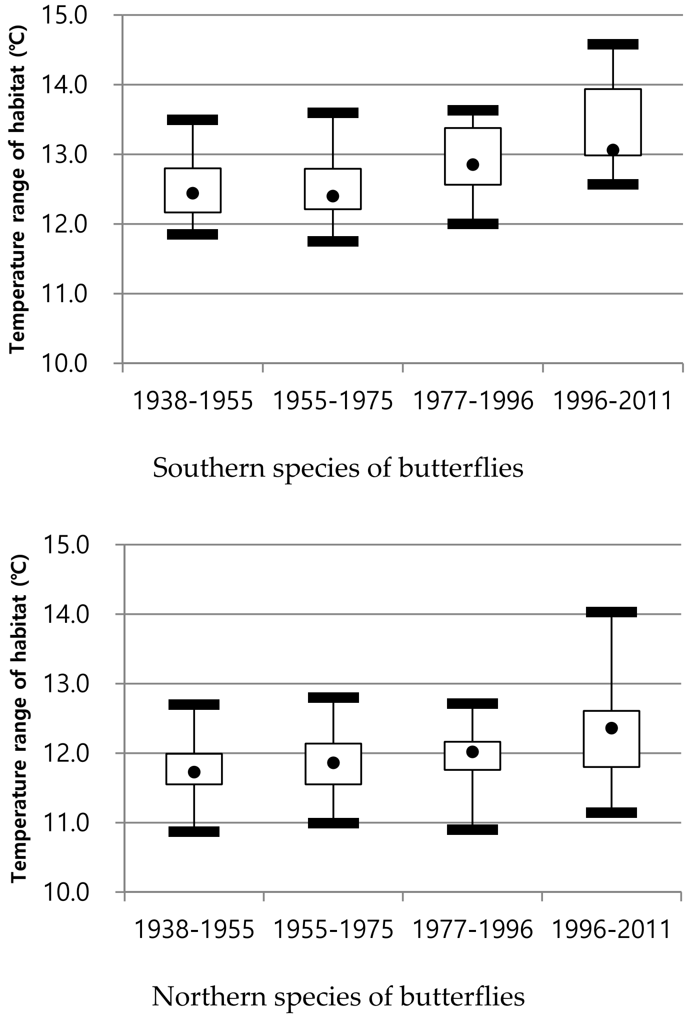

Figure 3. Temperature range of habitat with time periods in southern and northern species during 1938–2011. Box plot of periodical temperature range change in Southern and Northern butterflies (upper bar: 75%, lower bar: 25%, •: median). Both cases showed $p < 0.05$.

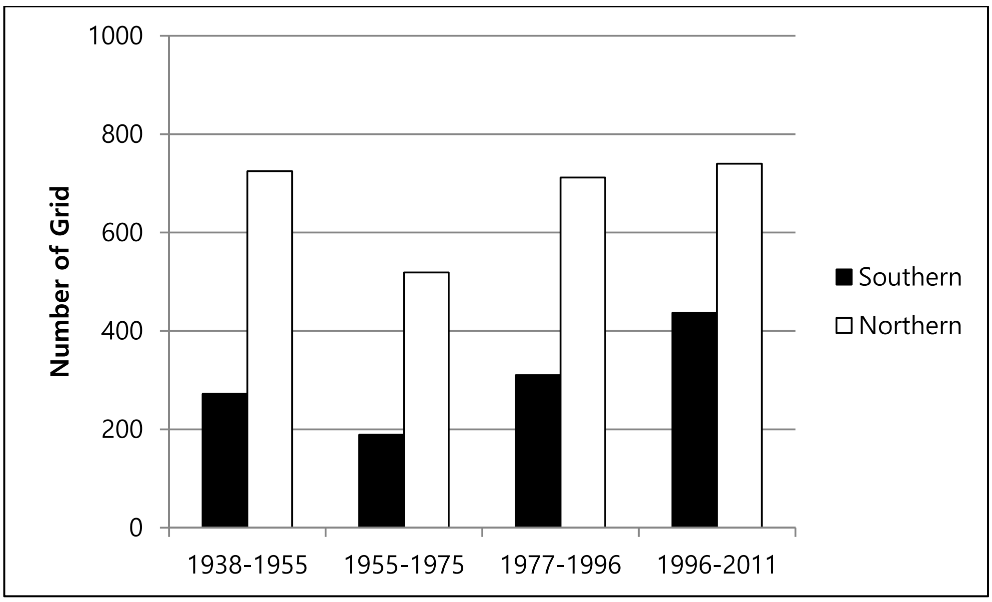

Figure 4. Periodical change in habitat number grids in Southern and Northern butterflies.

Table 2. Temperature changes in Southern and Northern butterflies.

Distribution Pattern	SS	DF	F	*p*
Southern	6.965	3	6.624	0.001 *
Northern	8.330	3	15.419	0.000 *

* $p < 0.05$.

3.2. Change in Number of Habitats According to Temperature

The number of habitats showed different trends: The habitat numbers were classified into four latitudes (<35°, 35° to 36°, 36° to 37°, and >37°) during each period (1938–1955; 1956–1975; 1976–1996, and 1997–2011). A two-way ANOVA was applied for southern and northern species. There was no significance for the southern species; however, for the northern groups, there was significance for latitude ($p < 0.00003$) and year ($p < 0.02$) (Tables 3 and 4), indicating that southern species tend to expand their territories with increasing temperature (Figure 5).

Table 3. Habitat number and percentage (%) according to latitude in Southern butterflies.

Latitude \ Period	1938–1955		1955–1975		1977–1996		1996–2011	
	# of Grids	(%)	# of Grids	(%)	# of Grids	(%)	# of Grids	(%)
Over 37°	78	26.2	53	30.8	89	30.8	136	32.2
36–37°	72	24.2	43	25.0	49	17.0	90	21.3
35–36°	92	30.9	50	29.1	75	26.0	109	25.8
Under 35°	56	18.8	26	15.1	76	26.3	87	20.6
Total	298	100.0	172	100.0	289	100.0	422	100.0

Table 4. Habitat number and percentage (%) according to latitude in Northern butterflies.

Latitude \ Period	1938–1955		1955–1975		1977–1996		1996–2011	
	# of Grids	(%)	# of Grids	(%)	# of Grids	(%)	# of Grids	(%)
Over 37°	396	54.6	265	52.6	445	62.5	463	62.6
36–37°	141	19.4	103	20.4	92	12.9	122	16.5
35–36°	161	22.2	107	21.2	136	19.1	113	15.3
Under 35°	27	3.7	29	5.8	39	5.5	42	5.7
Total	725	100.0	504	100.0	712	100.0	740	100.0

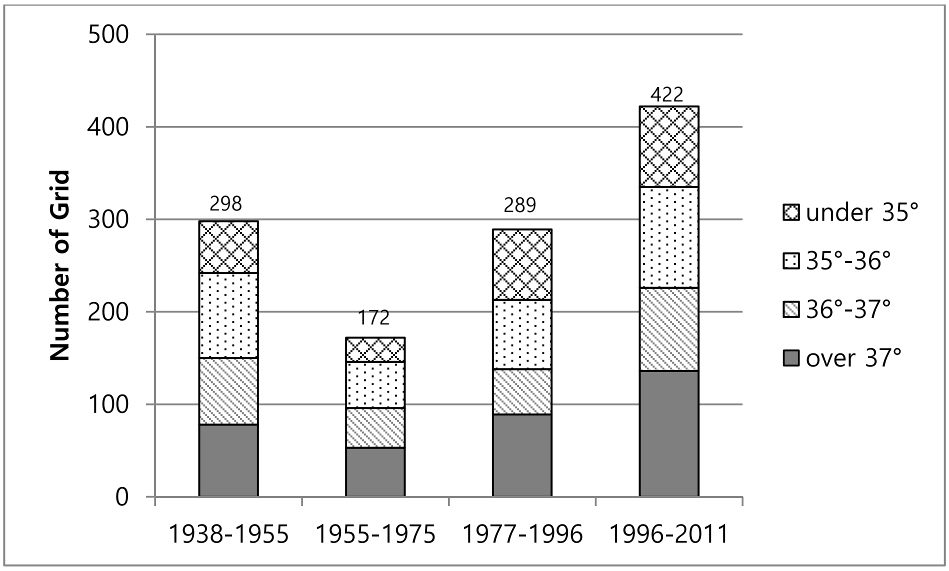

Figure 5. Change in habitat number according to latitude in Southern butterflies.

The number of habitat cells was increasing in higher latitudes (over 37°) for southern butterflies, indicating a northward shift of habitats due to climate change. Findings in species richness showed similar results: The higher the latitude, the greater the richness of species in both groups. According to correlation analysis between latitude and number of species, northern butterflies showed higher significance ($p < 0.001$), and number of species was greatly affected by the latitude. Considering their sensitiveness to temperature, it can be assumed that northern butterflies' species richness and number of habitats will decrease as their habitat becomes less suitable for them. As for southern butterflies, we may expect a sizable increase in both species' richness and number of habitats because climate change has made South Korea a habitable area for them.

The number of habitats varied among periods, with Tukey HSD results showing that for southern species, the number of habitats was different except in 1977–1996, while for northern species it varied except during 1938–1955 and 1977–1996 (Table 5).

Table 5. Multiple comparison results between number of habitat data using HSD analysis (post-hoc) in Southern and Northern butterfly data.

Distribution Pattern	(I) Period	(J) Period	(I)–(J)	*p*
Southern	1938–1955	1955–1975	4.882	0.444
		1977–1996	−2.235	0.902
		1996–2011	−9.706	0.021 *
	1955–1975	1938–1955	−4.882	0.444
		1977–1996	−7.118	0.138
		1996–2011	−14.588	0.000 *
	1977–1996	1938–1955	2.235	0.902
		1955–1975	7.118	0.138
		1996–2011	−7.471	0.110
	1996–2011	1938–1955	9.706	0.021 *
		1955–1975	14.588	0.000 *
		1977–1996	7.471	0.110
Northern	1938–1955	1955–1975	0.866	0.878
		1977–1996	−2.015	0.307
		1996–2011	−2.433	0.157
	1955–1975	1938–1955	−0.866	0.878
		1977–1996	−2.881	0.065
		1996–2011	−3.299	0.025 *
	1977–1996	1938–1955	2.015	0.307
		1955–1975	2.881	0.065
		1996–2011	−0.418	0.984
	1996–2011	1938–1955	2.433	0.157
		1955–1975	3.299	0.025 *
		1977–1996	0.418	0.984

* $p < 0.05$.

4. Discussion

Many studies have already shown that butterflies are among species that have responded the most to climate change, usually in the form of northward or elevation range shifts [19]. Temperatures in the Korean peninsula have increased rapidly since the 1960s due to rapid industrialization and urbanization. The average temperatures for the last period (1996–2011) were higher than those in the initial period (1938–1955) in Gangneung (1.4 °C), Seoul (1.5 °C), and Jeju Island (1.5 °C), with temperatures in most locations increasing by over 1.0 °C on average.

Both the southern and northern communities have seen an increase in temperature such that butterflies must adapt to the local temperatures as the climate changes. In addition, the southern parts had a higher temperature of habitat than the northern areas such that species groups in the southern regions showed an increase in habitat numbers over time (Table 5). It was found that as the temperature increases, the species in southern regions are more sensitive to temperature so that they tend to expand their territories in the face of climate change. Kwon et al. [20] also indicated that southern species tend to expand their territories to the north, meaning that increasing temperature could be an important factor for a habitat shift.

As climate change and global warming increase, many species are also adapting to their local environmental conditions so that a changing distribution will be seen depending on their adaptability [1]. Parmesan [21] indicated that butterflies living at low latitudes moved slowly northward, greatly increasing at higher latitudes. Species in the southern communities tended to move northward, most to temperatures higher than 37 °C, and the same result was found not only in Korea, but also in Britain and Europe [22].

The northern region has a larger temperature range than the south, indicating that climate change has significantly affected the distribution patterns of butterflies, especially during 1996–2011. Habitat shifts in both areas showed significance ($p < 0.05$), indicating that both northern and southern species are sensitive to temperature (Table 5). Choi [23] also demonstrated that species richness at northern altitudes should be increasing due to global warming and species' adaptability to warming temperature. The Korean butterflies were divided into two groups of Palearctic species coming from the continent and Oriental species migrating across the ocean, indicating that northern species from the Palearctic have a chance to expand their habitat due to warming temperature, a trend that was observed in this study [23,24].

An overall decline occurred during 1956–75 due to habitat destruction after the Korean war and the rapid expansion of urbanization in the 1960s and 1970s [25,26]. Artificial factors, such as war, presumably can be important factors that influence the anemogram of species [27]. Artificial disturbances such as temperature changes and wars have a direct impact on the habitat of butterflies and their population, population structure, and species abundance.

Ecological status should be based on both biotic and physical environmental factors. Pianka [28] indicated that butterflies should have their own ecological status depending on the changing environment. The southern and northern species differ in based on their adaptability to temperature zones. The southern species, which are mostly located in the southern regions, have sensitivity to relatively high habitat temperature, while the northern species had a cooler temperature than their southern counterparts.

Why are southern species so sensitive to warming temperature, showing a greater habitat shift than their northern neighbors? Climate change can affect flight times in butterflies. Warmer temperatures will result in more generations of multiple–brooded species, but how this will affect egg-laying periods and other life traits determined by photoperiod (due to climate change) is unknown [29]. However, this study showed the general patterns of southern species expanding their territory to the north. Disease can also harm butterfly populations, with recent studies suggesting that populations whose migration is at risk may be even more susceptible to outbreaks of disease [30,31]. Habitat loss and fragmentation can lead to population declines and local extinctions [32], and the use of herbicides on crops can reduce host and nectar plant availability in agricultural settings [33–35]. However, why the habitat in the north was more significant should be answered with the help of GIS or other techniques that imply spatial analysis of habitat.

As was the case with the studies by Pollard et al. [36,37], Warren et al. [22] in the UK, and Hill et al. [38] in the EU, it was found that butterfly species have gradually extended north as climate changes continue. On the other hand, a study by Parmesan et al. [5] showed that a small proportion of butterflies migrate to lower latitudes. These results are consistent with the finding that most southern species move to upper latitudes when expanding their territory.

In this study, the researcher identified the overview of the Korean Peninsula's butterfly transformation over the 73 years from 1938 to 2011. It is significant that the entire length of this time for butterfly distribution was analyzed on the Korean Peninsula. Additionally, changes in distribution patterns were analyzed by giving consideration to the temperature, by constructing the local temperature data. The distribution characteristics of the southern and northern areas due to temperature changes can be used in various conservation strategies for butterfly populations. If such changes are confirmed, the forecast for the change in the population density can be made together with the change in the weather.

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Conflicts of Interest: No conflict of interests among authors.

Appendix A

Table A1. Meteorological stations operating in Korean Regional Meteorological Office.

	Station	Lat. (N)	Long (E)	H (m)	Hb (m)	Ht (m)	Ha (m)	Hr (m)
90	Sokcho	38°15′	128°33′	18.1	24.3	1.9	10.0	0.7
95	Cheorwon	38°08′	127°18′	153.7	156.4	1.8	12.6	0.6
98	Dongducheon	37°54′	127°03′	109.1	113.6	1.7	10.0	0.6
99	Paju	37°53′	126°45′	29.4	31.4	1.7	10.0	0.5
100	Daegwallyeong	37°40′	128°43′	772.6	773.7	1.8	10.0	0.6
101	Chuncheon	37°54′	127°44′	77.7	77.8	1.5	10.0	0.6
102	Baengnyeongdo	37°57′	124°37′	144.9	146.6	1.8	9.4	0.6
104	Bukgangneung	37°48′	128°51′	78.9	80.3	1.6	10.0	0.5
105	Gangneung	37°45′	128°53′	26.0	27.5	1.7	17.9	0.6
106	Donghae	37°30′	129°07′	39.9	40.6	1.7	10.0	0.6
108	Seoul	37°34′	126°57′	85.8	86.5	1.5	10.0	0.6
112	Incheon	37°28′	126°37′	71.4	73.4	1.5	10.0	1.7
114	Wonju	37°20′	127°56′	148.6	152.2	1.6	10.0	0.6
115	Ulleungdo	37°28′	130°53′	222.8	224.1	1.8	10.0	0.6
119	Suwon	37°16′	126°59′	34.1	35.5	1.5	18.7	0.5
121	Yeongwol	37°10′	128°27′	240.6	240.7	1.5	10.0	0.6
127	Chungju	36°58′	127°57′	115.1	117.7	1.8	10.0	0.5
129	Seosan	36°46′	126°29′	28.9	29.9	1.3	20.2	0.6
130	Uljin	36°59′	129°24′	50.0	50.6	1.8	13.0	0.6
131	Cheongju	36°38′	127°26′	57.2	57.9	1.5	10.0	0.5
133	Daejeon	36°22′	127°22′	68.9	70.1	1.6	19.8	0.6
135	Chupungnyeong	36°13′	127°59′	244.7	246.0	1.5	10.0	0.6
136	Andong	36°34′	128°42′	140.1	142.1	1.7	10.0	0.6
137	Sangju	36°24′	128°09′	96.2	99.4	1.6	10.0	0.5
138	Pohang	36°01′	129°22′	2.3	2.7	1.6	15.4	0.6
140	Gunsan	36°00′	126°45′	23.2	28.3	1.7	15.3	0.6
143	Daegu	35°53′	128°37′	64.1	65.2	1.8	10.0	0.6
146	Jeonju	35°49′	127°09′	53.4	62.4	1.8	18.4	0.6
152	Ulsan	35°33′	129°19′	34.6	35.8	1.5	12.0	0.5
155	Changwon	35°10′	128°34′	37.2	37.9	1.7	10.0	0.5
156	Gwangju	35°10′	126°53′	72.4	75.3	1.5	17.5	0.6
159	Busan	35°06′	129°01′	69.6	70.2	1.6	17.8	0.6
162	Tongyeong	34°50′	128°26′	32.7	33.7	1.5	15.2	0.6
165	Mokpo	34°49′	126°22′	38.0	38.6	1.5	15.5	0.6

Table A1. *Cont.*

	Station	Lat. (N)	Long (E)	H (m)	Hb (m)	Ht (m)	Ha (m)	Hr (m)
168	Yeosu	34°44′	127°44′	64.6	74.6	1.5	20.8	0.6
169	Heuksando	34°41′	125°27′	76.5	77.9	1.7	9.0	0.6
170	Wando	34°23′	126°42′	35.2	28.4	1.6	15.4	0.5
172	Gochang	35°20′	126°35′	52.0	53.2	1.5	10.0	1.7
174	Suncheon	35°01′	127°22′	165.0	180.4	1.8	10.3	0.6
175	Jindo	34°28′	126°19′	476.5	477.8	1.6	10.0	0.5
176	Daegu	35°52′	128°39′	49.0	50.2	1.8	10.0	0.6
184	Jeju	33°30′	126°31′	20.4	21.1	1.8	12.3	0.6
185	Gosan	33°17′	126°09′	74.3	75.6	1.8	10.0	0.6
188	Seongsan	33°23′	126°52′	17.8	20.1	1.5	10.0	0.6
189	Seogwipo	33°14′	126°33′	49.0	50.2	1.9	10.0	0.6
192	Jinju	35°09′	128°02′	30.2	31.5	1.5	10.0	0.7
201	Ganghwa	37°42′	126°26′	47.0	47.3	1.6	12.0	0.6
202	Yangpyeong	37°29′	127°29′	48.0	48.6	1.7	10.0	0.6
203	Icheon	37°15′	127°29′	78.0	91.0	1.9	10.0	0.5
211	Inje	38°03′	128°10′	200.2	201.5	1.5	10.0	0.5
212	Hongcheon	37°41′	127°52′	140.9	147.2	1.6	13.0	0.5
216	Taebaek	37°10′	128°59′	712.8	715.3	1.7	16.0	0.6
221	Jecheon	37°09′	128°11′	263.6	263.9	1.5	13.3	0.5
226	Boeun	36°29′	127°44′	175.0	176.4	1.5	10.0	0.5
232	Cheonan	36°46′	127°07′	21.3	22.6	1.8	9.5	0.6
235	Boryeong	36°19′	126°33′	15.5	18.9	1.6	9.8	0.5
236	Buyeo	36°16′	126°55′	11.3	12.3	1.7	9.5	0.5
238	Geumsan	36°06′	127°28′	170.4	171.6	1.5	10.1	0.5
243	Buan	35°43′	126°42′	12.0	13.3	1.8	10.0	0.6
244	Imsil	35°36′	127°17′	247.9	248.7	1.7	10.0	0.6
245	Jeongeup	35°33′	126°51′	44.6	46.0	1.7	10.0	0.6
247	Namwon	35°24′	127°19′	90.3	94.7	1.8	10.0	0.6
248	Jangsu	35°39′	127°31′	406.5	408.3	1.6	10.0	0.6
260	Jangheung	34°41′	126°55′	45.0	45.3	1.9	10.2	0.5
261	Haenam	34°33′	126°34′	13.0	14.2	1.4	10.0	0.6
262	Goheung	34°37′	127°16′	53.1	54.4	1.6	10.0	0.6
271	Bongwhoa	36°56′	128°54′	319.8	322.3	1.6	10.0	0.6
272	Yeongju	36°52′	128°31′	210.8	211.7	1.5	10.0	0.5
273	Mungyeong	36°37′	128°08′	170.6	171.8	1.5	10.0	0.6
277	Yeongdeok	36°31′	129°24′	42.1	43.5	1.6	10.0	0.6
278	Uiseong	36°21′	128°41′	81.8	84.0	1.5	10.0	0.6
279	Gumi	36°07′	128°19′	48.9	48.9	1.5	10.0	0.6
281	Yeongcheon	35°58′	128°57′	93.6	94.5	1.7	10.0	0.5
284	Geochang	35°40′	127°54′	226.0	227.2	1.5	10.0	0.5
285	Hapcheon	35°33′	128°10′	33.1	34.1	1.5	10.0	0.6
288	Miryang	35°29′	128°44′	11.2	12.1	1.5	10.0	0.5
289	Sancheong	35°24′	127°52′	138.1	139.4	1.5	10.0	0.6
294	Geoje	34°53′	128°36′	46.3	47.5	1.5	10.0	0.5
295	Namhae	34°48′	127°55′	45.0	46.2	1.8	10.0	0.7

H: Height of observation field above mean sea level; Hb: Height of barometer above mean sea level; Ht: Height of thermometer above ground; Ha: Height of anemometer above ground; Hr: Height of raingauge above ground.

Appendix B

Table A2. List of butterflies investigated in this study with their scientific names and distribution.

Family	Scientific Name		Distribution Pattern
Papilionidae	Parnassius stubbendorfii	Menetries, 1849	Northern
	Parnassius bremeri	Bremer, 1864	Northern
	Luehdor fiapuziloi	Erschoff, 1872	Northern
	Sericinus montela	Gray, 1852	Miscellaneous
	Byasa alcinous	Klug, 1836	Miscellaneous
	Graphium sarpedon	Linnaeus, 1758	Southern
	Papilioxuthus	Linnaeus, 1767	Miscellaneous
	Papilio machaon	Linnaeus, 1758	Miscellaneous
	Papilio memnon	Linnaeus, 1758	Southern
	Papilio helenus	Linnaeus, 1758	Southern
	Papilio protenor	Cramer, 1775	Southern
	Papilio macilentus	Janson, 1877	Southern
	Papilio bianor	Cramer, 1778	Miscellaneous
	Papilio maackii	Menetries, 1858	Miscellaneous
Pieridae	Leptidea amurensis	Menetries, 1859	Northern
	Leptidea morsei	Fenton, 1882	Northern
	Aporia crataegi	Linnaeus, 1758	Northern
	Artogeia napi	Linnaeus, 1758	Northern
	Pieris melete	Menetries, 1857	Miscellaneous
	Artogeia canidia	Sparrman, 1768	Miscellaneous
	Pieris rapae	Linnaeus, 1758	Miscellaneous
	Pontia daplidice	Linnaeus, 1758	Miscellaneous
	Anthocharis scolymus	Bulter, 1866	Miscellaneous
	Gonepteryx maxima	Bulter, 1885	Northern
	Gonepteryx aspasia	Menetries, 1858	Miscellaneous
	Catopsilia pomona	Fabricius, 1755	Southern
	Eurema mandarina	de l'Orza, 1869	Southern
	Eurema laeta	Boisduval, 1836	Southern
	Eurema brigitta	Stoll, 1780	Southern
	Colias erate	Esper, 1805	Miscellaneous
Lycaenidae	Curetis acuta	Moore, 1877	Southern
	Taraka hamada	H.Druce, 1875	Southern
	Spindasis takanonis	Matsumura, 1906	Northern
	Arhopala japonica	Murray, 1875	Southern
	Arhopala bazalus	Hewitson, 1862	Southern
	Artopoetes pryeri	Murray, 1873	Northern
	Coreana raphaelis	Oberthur, 1880	Northern
	Ussuriana michaelis	Oberthur, 1880	Northern

Table A2. *Cont.*

Family	Scientific Name		Distribution Pattern
Lycaenidae	Shirozua jonasi	Janson, 1877	Northern
	Thecla betulae	Linnaeus, 1758	Northern
	Protantigius superans	Oberthur, 1914	Northern
	Japonica saepestriata	Hewitson, 1865	Miscellaneous
	Jopnica lutea	Hewitson, 1865	Miscellaneous
	Araragi enthea	Janson, 1877	Northern
	Antigius attilia	Bremer, 1861	Miscellaneous
	Antigius butleri	Fenton, 1882	Northern
	Wagimo signata	Butler, 1881	Northern
	Neozephyrus japonicus	Murray, 1875	Northern
	Chrysozephyrus smaragdinus	Bremer, 1861	Northern
	Chrysozephyrus brillantinus	Staudinger, 1887	Northern
	Chrysozephyrus ataxus	Westwood, 1851	Southern
	Favonius orientalis	Murray, 1875	Northern
	Favonius korshunovi	Dubatolov et Sergeev, 1982	Northern
	Favonius koreanus	Kim, 2006	Northern
	Favonius ultramarinus	Fixsen, 1887	Northern
	Favonius cognatus	Staudinger, 1892	Northern
	Favonius taxila	Bremer, 1861	Northern
	Favonius yuasai	Shirozu, 1947	Northern
	Favonius saphirinus	Staudinger, 1887	Northern
	Satyrium herzi	Fixsen, 1887	Northern
	Satyrium pruni	Linnaeus, 1758	Northern
	Satyrium prunoides	Staudinger, 1887	Northern
	Satyrium eximius	Fixsen, 1887	Northern
	Satyrium latior	Fixsen, 1887	Northern
	Satyrium walbum	Knoch, 1782	Northern
	Callophrys ferrea	Butler, 1866	Southern
	Callophrys frivaldszkyi	Kindermann, 1853	Northern
	Rapala caerulea	Bremer et Grey, 1853	Miscellaneous
	Rapala arata	Bremer, 1861	Miscellaneous
	Lycaena dispar	Haworth, 1803	Northern
	Lycaena phlaeas	Linnaeus, 1761	Miscellaneous
	Niphanda fusca	Bremer et Grey, 1853	Miscellaneous
	Chilades pandava	Horsfield, 1829	Southern
	Jamides bochus	Stoll, 1782	Southern
	Lampides boeticus	Linnaeus, 1767	Southern
	Zizeeria maha	Kollar, 1844	Southern
	Zizina otis	Fabricius, 1787	Southern
	Cupido argiades	Pallas, 1771	Miscellaneous

Table A2. *Cont.*

Family	Scientific Name		Distribution Pattern
Lycaenidae	Tongeia fischeri	Eversmann, 1843	Miscellaneous
	Udara albocaerulea	Moore, 1879	Southern
	Udara dilectus	Moore, 1879	Southern
	Celastrina argiolus	Linnaeus, 1758	Miscellaneous
	Celastrina sugitanii	Matsumura, 1919	Northern
	Celastrina oreas	Leech, 1893	Northern
	Scolitantides orion	Pallas, 1771	Northern
	Shijimiaeoidesdivina	Fixsen, 1887	Northern
	Maculinea arionides	Staudinger, 1887	Northern
	Maculinea teleius	Bergstrasser, 1779	Northern
	Maculinea kurentzovi Sibatani	Hirowatari, 1994	Northern
	Plebejus argus	Linnaeus, 1758	Northern
	Plebejus argyrognomon	Bergstrasser, 1779	Miscellaneous
Nymphalidae	Plebejus subsolanus	Eversmann, 1851	Northern
	Lybythea lepita	Moore, 1858	Southern
	Parantica sita	Kollar, 1844	Southern
	Parantica melaneus	Cramer, 1755	Southern
	Danaus genutia	Cramer, 1779	Southern
	Danaus chrysippus	Linnaeus, 1758	Southern
	Melanitis leda	Linnaeus, 1758	Southern
	Melanitis phedima	Cramer, 1780	Southern
	Coenonympha amaryllis	Stoll, 1782	Miscellaneous
	Coenonympha hero	Linnaeus, 1761	Miscellaneous
	Coenonympha oedippus	Fabricius, 1787	Northern
	Lopinga achine	Scopoli, 1763	Miscellaneous
	Lasiommata deidamia	Eversmann, 1851	Miscellaneous
	Kirinia epimenides	Menetries, 1859	Northern
	Kirinia epimenidas	Staudinger, 1887	Northern
	Mycalesis francisca	Stoll, 1780	Southern
	Mycalesis gotama	Moore, 1858	Southern
	Lethe marginalis	Motschulsky, 1860	Miscellaneous
	Lethe diana	Butler, 1866	Miscellaneous
	Ninguta schrenckii	Menetries, 1858	Northern
	Aphantopus hyperantus	Linnaues, 1758	Northern
	Melanargia halimede	Menetries, 1858	Miscellaneous
	Melanargia epimede	Staudinger, 1887	Northern
	Oeneisurda	Eversmann, 1847	Northern
	Oeneis mongolica	Oberthur, 1876	Northern
	Minois dryas	Scopoli, 1763	Northern

Table A2. *Cont.*

Family	Scientific Name		Distribution Pattern
Nymphalidae	Eumenis autonoe	Esper, 1783	Northern
	Ypthima argus	Butler, 1866	Miscellaneous
	Ypthima multistriata	Butler, 1883	Miscellaneous
	Ypthima motschulskyi	Bremer et Grey, 1853	Miscellaneous
	Erebia cyclopius	Eversmann,1844	Northern
	Erebia wanga	Bremer, 1864	Northern
	Argynnis paphia	Linnaues, 1758	Miscellaneous
	Argynnis childreni	Gray, 1831	Miscellaneous
	Argynnis zenobia	Leech, 1890	Northern
	Argynnis sagana	Doubleday, 1847	Miscellaneous
	Argynnis laodice	Pallas, 1771	Miscellaneous
	Argynnis ruslana	Motschulsky, 1866	Miscellaneous
	Argynnis anadyomene	C. et R. Felder, 1862	Northern
	Argynnis niobe	Linnaeus, 1758	Miscellaneous
	Argynnis vorax	Butler, 1871	Miscellaneous
	Argynnis nerippe	Felder,1862	Miscellaneous
	Argynnis aglaja	Linnaeus, 1758	Northern
	Argyreus hyperbius	Linnaeus, 1763	Southern
	Brenthis daphne	Bergstrasser, 1780	Northern
	Brenthis ino	Rottemburg, 1775	Northern
	Boloria thore	Hubner, 1803–1804	Northern
	Boloria oscarus	Eversmann,1844	Northern
	Boloria perryi	Butler, 1882	Northern
	Boloria selene	Schiffermuller, 1775	Northern
	Limenitis camilla	Linnaeus, 1764	Miscellaneous
	Limenitis doerriesi	Staudinger, 1892	Northern
	Limenitis helmanni	Lederer, 1853	Northern
	Limenitis homeyeri	Tancre, 1881	Northern
	Limenitis sydyi	Lederer, 1853	Northern
	Limenitis amphyssa	Menetries, 1859	Northern
	Limenitis moltrechti	Kardakoff,1928	Northern
	Limenitis populi	Linnaeus, 1758	Northern
	Seokia pratti	Leech, 1890	Northern
	Neptis sappho	Pallas, 1771	Miscellaneous
	Neptis philyra	Menetries, 1858	Northern
	Neptis philyra	Staudinger, 1887	Northern
	Neptis speyeri	Staudinger, 1887	Northern
	Neptis rivularis	Scopoli, 1763	Northern
	Neptis pryeri	Butler, 1871	Miscellaneous
	Neptis andetria	Fruhstorfer, 1912	Northern

Table A2. *Cont.*

Family	Scientific Name		Distribution Pattern
Nymphalidae	Neptis alwina	Bremer et Grey, 1853	Miscellaneous
	Neptisthisbe	Menetries, 1859	Northern
	Neptis tshetverikovi	Kurentzov, 1936	Northern
	Neptisilos	Fruhstorfer, 1909	Northern
	Neptis raddei	Bremer, 1861	Northern
	Dichorragia nesimachus	Doyere, 1840	Southern
	Apatura ilia	Schiffermuller, 1775	Northern
	Apaturametis	Freyer, 1829	Northern
	Apatura iris	Linnaeus, 1758	Northern
	Mimathyma schrenckii	Menetries, 1859	Northern
	Mimathyma nycteis	Menetries, 1859	Northern
	Chitoriaulupi	Doherty, 1889	Miscellaneous
	Dilipafenestra	Leech, 1891	Miscellaneous
	Hestina persimilis	Westwood, 1850	Southern
	Hestina assimilis	Linnaeus, 1758	Southern
	Sasakiacharonda	Hewitson, 1863	Miscellaneous
	Sephisa princeps	Fixsen, 1887	Miscellaneous
	Cyrestis thyodamas	Doyere, 1840	Southern
	Araschnia levana	Linnaeus, 1758	Northern
	Araschnia burejana	Bremer, 1861	Northern
	Vanessa cardui	Linnaeus, 1758	Miscellaneous
	Vanessa indica	Herbst, 1794	Miscellaneous
	Polygonia c–aureum	Linnaeus, 1758	Miscellaneous
	Polygonia c–album	Linnaeus, 1758	Northern
	Nymphalis l–album	Esper, 1780	Northern
	Nymphalis xanthomelas	Esper, 1781	Northern
	Nymphalis antiopa	Linnaeus, 1758	Northern
	Aglais urticae	Linnaeus, 1758	Northern
	Aglias io	Linnaeus, 1758	Northern
	Kaniska canace	Linnaeus, 1763	Miscellaneous
	Junonia almanda	Linnaeus, 1758	Southern
	Junonia orithya	Linnaeus, 1758	Southern
	Hypolimnas misippus	Linnaeus, 1764	Southern
	Hypolimnas bolina	Linnaeus, 1758	Southern
	Euphydryas davidi	Oberthur, 1881	Northern
	Melitaeaambigua	Menetries, 1859	Northern
	Melitaea britomartis	Assmann, 1847	Northern
	Melitaea protomedia	Menetries, 1858	Northern
	Melitaea scotosia	Butler, 1878	Northern

Table A2. *Cont.*

Family	Scientific Name		Distribution Pattern
Hesperiidae	Choaspes benjaminii	Guerin–Meneville, 1843	Southern
	Burara aquilina	Speyer, 1879	Northern
	Burara striata	Hewitson, 1867	Southern
	Lobocla bifasciata	Bremer et Grey, 1853	Miscellaneous
	Satarupa nymphalis	Speyer, 1879	Northern
	Daimio tethys	Menetries, 1857	Miscellaneous
	Erynnis montanus	Bremer, 1861	Miscellaneous
	Pyrgus maculatus	Bremer et Grey, 1853	Miscellaneous
	Pyrgus malvae	Linnaeus, 1758	Northern
	Cartero cephalus	Graeser, 1888	Northern
	Cartero cephalus silvicola	Meigen, 1828	Northern
	Heteropterus morpheus	Pallas, 1771	Northern
	Leptalina unicolor	Bremer et Grey, 1853	Miscellaneous
	Isoteinon lamprospilus	C. et R. Felder, 1862	Southern
	Aeromachus inachus	Menetries, 1859	Miscellaneous
	Thymelicus leoninus	Butler, 1878	Miscellaneous
	Thymelicus sylvaticus	Bremer, 1861	Miscellaneous
	Ochlodes similis	Leech, 1893	Northern
	Ochlodes venatus	Bremer et Grey, 1853	Miscellaneous
	Ochlodes ochraceus	Bremer, 1861	Northern
	Ochlodes subhyalina	Bremer et Grey, 1853	Miscellaneous
	Hesperia florinda	Butler, 1878	Northern
Hesperiidae	Potanthus flavus	Murray, 1875	Miscellaneous
	Polytremis zina	Evans, 1932	Northern
	Pelopidas jansonis	Butler, 1878	Southern
	Peolpidas siensis	Mabile, 1877	Miscellaneous
	Peolpidas mathias	Fabricius, 1798	Southern
	Parnara guttata	Bremer et Grey, 1853	Southern

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