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Local change of butterfly species in response to global warming and reforestation in Korea

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Abstract

Background: It is expected that the successful nationwide reforestation and global warming will greatly change the butterfly fauna in South Korea. We compared current data (2002 to 2007) regarding the abundance and presence of butterfly species at two sites in the central portion of the Korean Peninsula with similar data from the late 1950s and early 1970s for the same sites. The expected changes were documented by an abundance change of butterflies at the two study sites in a previous study. Using the same data, the most greatly changed species and the change of species presence were analyzed.

Results: Population changes of 99 butterfly species which occurred at both sites were significantly correlated between the two sites. The greatly increased species included three southern (S) species and one northern (N) species. However, the species showing great decline included five N species and no S species.

Conclusions: This change is consistent with the expectation of northward movement of butterfly species due to global warming. The current status of the greatly changed species is discussed along with other studies. The binary data (presence/absence) in the present study support the expected changes of butterfly species based on global warming and reforestation. The interactive effect of two environmental changes was also recognized, as well as the change of abundance in the previous study.

Keywords: Climate change; Habitat change; Species change; Binary data; Korea

Background

Climate change has impacted the global distribution and abundance of organisms, which is one of the reasons for a recently increased incidence of extinctions. Approximately 15% to 37% of animal and plant species are predicted to be exposed to the risk of extinction after 2050 (Thomas et al. 2004). Insects are highly dependent on temperature for their poikilothermic properties and rapidly adapt and/or migrate following changing thermal conditions due to their high mobility (Kiritani and Yukawa 2010; Feng et al. 2011). Most butterflies rapidly respond to habitat and climate change due to their high fecundity and short generation time (Feest et al. 2011). Butterflies have been most frequently studied to determine the impacts of climate change due to their popularity and well-known taxonomy, distribution, and ecology. In Europe, 35 butterfly species have migrated northward by 35 to 240 km during the last century (Parmesan et al. 1999). The analysis of 51 butterfly species in the UK showed that many northern species disappeared in lowlands and were restricted in highlands during the twentieth century (Hill et al. 2002). In Finland, 48 butterfly species migrated northward by an average of 60 km (Pöyry et al. 2009). In Spain, adult butterflies of 17 species appeared earlier in the spring of 2002 than in 1988 (Stefanescu et al. 2003). In Japan, southern species such as *Papilio memnon*, *Papilio protenor*, *Zizeeria maha*, and *Argyreus hyperbius* are increasing their distributional ranges (Yoshio and Ishii 2010). In *P. memnon*, the northward shift was not related with physical changes such as diapauses and cold tolerance (Yoshio and Ishii 1998, 2001) but was related with Japanese climate warming (Kitahara et al. 2001). Various evidences of Japanese insects were reported for phenological shifts and northward range shifts due to climate warming (Ogawa-Onishi and Berry 2013). The northward movement of butterflies caused local change of butterfly communities, in which northern species decreased but southern species increased (Kwon et al. 2010).

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Kwon et al. (2010) showed that northern butterfly species respond differently to vegetation change compared to southern species, suggesting that climate change and habitat change interact to influence organisms. Habitat change caused by human land use may hinder the migration of butterflies. In the UK, generalist butterfly species with high mobility increased their distributional range as predicted, whereas specialist species with low mobility did not follow the predicted range (Warren et al. 2001). As habitats were greatly fragmented, butterflies could not migrate between fragmented habitats (Thomas et al. 2001). Butterfly diversity was highly correlated with plant diversity (Humpden and Nathan 2010), and anthropogenic disturbances such as fires, livestock grazing, and logging and change of land use also significantly influenced butterfly assemblages (Balmer and Erhardt 2000; Cleary 2003; Franzén and Ranius 2004; Honda and Kato 2005).

In South Korea, the annual average of temperature has increased approximately 1.5°C since 1912, which is twice the global average (IPCC 2007; Choi and Choi 2011). The mean temperature increased approximately 0.6°C in coastal regions, whereas it increased about 1.5°C to 2.5°C in inland areas (Choi and Choi 2011). Seasonal change (i.e., shortening of winter), increased incidence of heavy rainfalls, large forest fires, mass death of pines due to spring drought, and large typhoons have also followed the increase of temperature (Ro et al. 2000; Kim et al. 2007; Allen et al. 2010; Choi and Choi 2011; Youn et al. 2011). The pine caterpillar, *Dendrolimus spectabilis* (Butler), increased its number of generations from univoltinism in the 1960s to 1980s to bivoltinism in the late 1990s in response to warming of the Korean climate (Kwon et al. 2002). Furthermore, as a result of successful governmental reforestation programs and a nationwide change from firewood to fuel energy in South Korea, the denuded vegetation of the 1960s has been transformed into well-grown forests since the 1990s (Bae and Lee 2006; Kwon et al. 2010). Accordingly, climate change and vegetation change may significantly influence butterfly communities in South Korea.

In the previous study (Kwon et al. 2010), past data (late 1950s and early 1970s) and recent data (from 2002 to 2007) from study sites in the mid-area of Korea were used to show that global warming or/and reforestation significantly changed the abundance of butterflies. In the present study, we attempted to test the impacts of global warming and reforestation on the change of species composition in local butterfly communities in Korea. For the present study, it was assumed that new occurrence and local extinction may be different between northern species and southern species due to global warming, and also differ between forest species and grassland species due to reforestation. In addition, population changes of several butterfly species that most greatly decreased or increased in abundance were compared with those of other studies.

Methods

Study sites and butterfly survey

Two sites, Gwangneung (GN) and Aengmubong (AM), which are located in the middle portion of Korea, were selected because past butterfly abundance data from the late 1950s (Kim and Shin 1960) and early 1970s (Kim 1973) were available for these sites. The majority of the GN forest is an experimental forest maintained by the Korea Forest Research Institute. The AM site is composed of a mountain with an elevation of 622 m. The GN (37°45′8″N and 127°9′24″E) and AM (37°45′14″N and 126°55′23″E) sites are located 8.1 km northeast and 9.5 km northwest of Seoul, respectively. The distance between the GN and AM sites is 21.2 km. The annual mean temperature between the two study periods increased by 1.2°C (Korea Meteorological Administration 2009). In the study area covering the two study sites, the area of forests increased 1.7-fold, whereas that of grasslands declined by 20% (Kwon et al. 2010).

In the previous studies, the butterfly survey was carried out weekly in 1958 at the GN site (27 survey days) and biweekly from 1971 to 1972 at the AM site (23 survey days), using net collection. The lengths of the survey routes are 4 km at the GN site and 4.3 km at the AM site. In the recent studies, the butterfly survey was conducted on dates comparable to the survey dates of the past studies from 2002 to 2006 at the GN site (27 survey days), and from 2006 to 2007 at the AM site (23 survey days). The butterflies were counted using the line transect method (Pollard and Yates 1993; Yamamoto 1975). Biased results due to different survey methods were not found (Kwon et al. 2010). Details on the survey methods, dates, environments, and locations of the study sites are shown in Kwon et al. (2010).

Data analysis

The butterfly species were classified with their distributional patterns and habitat types. The distributional patterns of butterfly species were classified into three types: Korean northerly distributed species (hereafter, N species), Korean southerly distributed species (S species), and miscellaneous species (M species). The distributional pattern of the butterfly species was determined based on the local distributions in Korea, Japan, and East Asia. Butterfly habitats were determined based on their larval habitats and classified as either forest inside (FI), forest edge (FE), or grassland (GL). Details for the definition of the distributional patterns are shown in Kwon et al. (2010).

Although the number of individuals was recorded in both studies, the survey methods used were different.

We used the rank of abundance to standardize the heterogeneous data. The rank (%) of a species was then estimated using the following formula: RP = 100 × (Rank of each species / Rank of the most abundant species). The difference in the rank (%) of abundance between the past and present periods was then used to represent the abundance change of each species. The values of the abundance change were normally distributed at both sites (Kwon et al. 2010). The values of the 99 species at both sites were compared using correlation analysis. To identify the effects of global warming on abundance, the number of N species which increased (i.e., positive value of abundance change) or decreased (i.e., negative value) at both sites was compared with that of S species using Fisher exact test (Zar 1999).

In addition to evaluating the change in abundance, qualitative data regarding the presence or absence of each species was also analyzed. The butterfly species that were present in the past survey but absent in the recent survey were classified as 'local extinct species,' while butterfly species that were absent in the past survey but present in the recent survey were classified as 'newly occurred species.' Species that occurred in both the past and recent surveys were classified as 'unchanged species.' The frequencies (e.g., number of species) of the three groups were compared based on their distributional patterns (N, S, and M) and on their habitat types (FI, FE, and GL), or compared based on their two-way interaction using log-linear analysis of frequency (StatSoft 1999). The three distributional patterns were used as a categorical variable to evaluate the effects of global warming, while the three habitat types were used to evaluate the effects of reforestation. All analyses were conducted using STATISTICA ver. 6.1 (Tulsa, OK, USA).

Results

Changes in the abundance of butterfly species that occurred at the GN and AM sites were significantly correlated (Figure 1; $r = 0.54$, $P << 0.0001$). The positive correlation strongly suggested that the changes observed in the present study may be general trends of populations in the study area, which were caused by exogenous environmental factors rather than stochastic events. Fifteen of the N species had negative values of abundance change at both the GN and AM sites, while eight species had positive values at both sites. In the S species, five species had negative values, and five species had positive values at both sites. The difference between the N and S species was not significant (Fisher exact test, $x^2 = 0.68$, $P = 0.46$). However, when only the butterfly species that exhibited extreme changes (>50% change) were considered, the difference between the N and S species was significant (Fisher exact test, $x^2 = 5.63$, $P = 0.048$). The greatly increased species comprised three S species and one N species, whereas the greatly declined species comprised five N species and no S species.

The qualitative data (i.e., frequency of local extinct species, unchanged species, and newly occurred species) in the present study support the expected changes of butterfly species based on global warming and reforestation, which is comparable with the abundance change (Kwon et al. 2010). At both the GN and AM sites, the number of local extinct species was highest among the N species, whereas the number of unchanged species was highest among the M and S species (Figure 2; $x^2 = 22.8$, $df = 4$, $P < 0.001$ at GN; $x^2 = 29.55$, $df = 4$, $P < 0.0001$ at the AM site). Similar to the distributional patterns, the frequencies (i.e., number of species) of local extinct, unchanged, and newly occurred species were significantly different among the habitat types at both the GN and AM sites ($x^2 = 16.17$, $df = 4$, $P < 0.05$ at GN; $x^2 = 17.83$, $df = 4$, $P < 0.05$ at the AM site). When the habitat types were evaluated, the number of newly occurred FI species was higher than that of the local extinct FI species. However, the reverse was true when the FE and GL species were evaluated. In addition, local extinct and newly occurred species were more frequently observed among the GL species than among the FE species.

Frequencies of local extinct, unchanged, and newly occurred species clearly showed interactive patterns (Figure 3; $x^2 = 8.067$, $df = 4$, $P < 0.1$ at GN; $x^2 = 9.68$, $df = 4$, $P < 0.05$ at AM site). Most of the newly occurred species were FI species when the N species were considered, while most local extinct species were GL and FE species. The reverse was true when the S species were evaluated, and intermediate results were observed when the M species were considered. Newly occurred species were only found among the FE and GL species when the S species were evaluated, whereas they were found in all groups (FI, FE, and GL) when the M species were evaluated. In addition, one local extinct S species was an FI species at both the GN and AM sites. The occurrence pattern of the local extinct species among M species was more similar to that of N species than to that of S species. The proportion of unchanged species of N species was much lower than that of the M and S species. These findings indicate that the populations of the N species were more unstable and/or more mobile than those of the M and S species, and that species change due to the Korean reforestation was different between N and S species groups.

Discussion

Similar trends of abundance change for 99 species of butterflies between GN and AM sites demonstrated that long-term change in abundance of butterfly species commonly occurred in the mid-region of the Korean Peninsula. The change may not be caused by stochastic yearly variation, because the study years of the previous and present studies differed between the GN and AM sites. The most

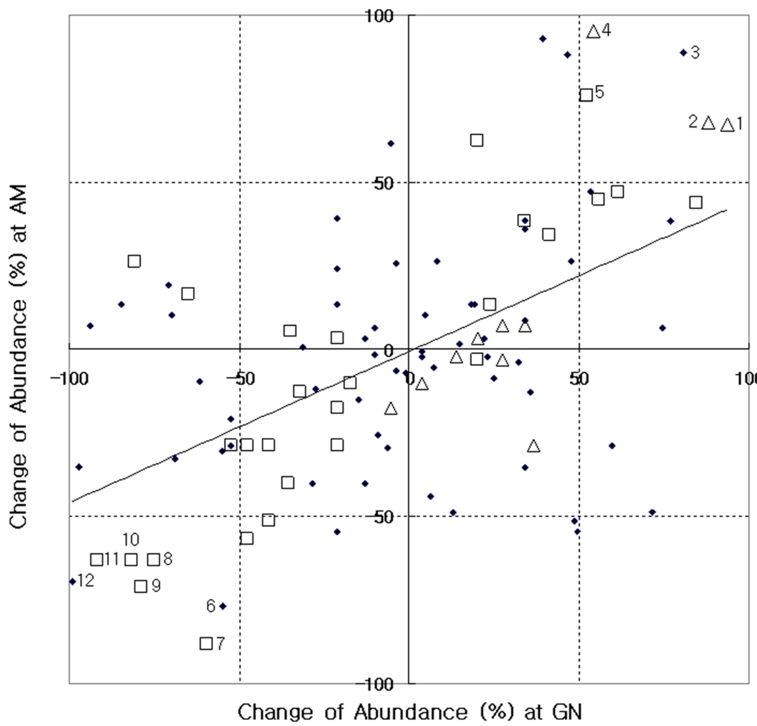

Figure 1 Abundance change of butterfly species that occurred at both the GN and AM sites. Estimation of the abundance change is described in the text. Values for the GN site are significantly correlated with those of the AM site ($r = 0.54$, $P < < 0.0001$), and the line represents the regression line between the values of the two sites. The open rectangles and triangles indicate N and S species respectively, and the solid dots indicate the M species. The species that showed the greatest changes are as follows: 1 *Pieris canidia*, 2 *Pseudozizeeria maha*, 3 *Argyronome ruslana*, 4 *Mycalesis francisca*, 5 *Ussuriana michaelis*, 6 *Coenonympha hero*, 7 *Melitaea britomartis*, 8 *Neptis rivularis*, 9 *Gonepteryx rhamni*, 10 *Nymphalis xanthomeles*, 11 *Coenonympha oedippus*, and 12 *Sericinus montela*.

increased species were mostly S species, but the most decreased species were mostly N species (Figure 1). This finding strongly suggests that the local change of abundance might be driven by northward movements of butterfly species. During the northward movement, the abundance of N species on the Korean Peninsula would decrease, whereas that of S species would increase. The prediction was ascertained by Kwon et al. (2010). The change of abundance would also change the chance of collection (previous survey) or observation (present survey) of species, which was represented as the frequency change of newly occurred or local extinct species in the present study. The effect of reforestation was found in the species change as well as in the abundance change (Kwon et al. 2010), and the interactive effect of global warming and reforestation was also found in the species change as well as in the abundance change (Kwon et al. 2010). Accordingly, the change of butterfly species occurred in parallel with the change of butterfly abundance in response to environmental changes. In the newly occurred species, most species are FI species in the N species, but all species are FE or GL species in the S species (Figure 3). This finding strongly indicates that the N species would be affected by the Korean reforestation, but the S species would be more affected by climate change rather than by the vegetation change, which was ascertained by the change of abundance (Kwon et al. 2010).

Of the 99 butterfly species observed at both study sites, *Nymphalis xanthomeles* showed one of the greatest declines in number. Indeed, *N. xanthomeles* was abundant (20th most abundant among 86 species) at the GN site in the late 1950s, moderately abundant (44th most abundant among 103 species) at the AM sites in the early 1970s, and absent from both sites in the early 2000s. This species was commonly found in the central part of the Korean Peninsula prior to the early 1980s; however, it is now found only in the highlands of Gangwon Province, which is the coldest area of the country. In 2007, only one individual of this species was found at 1 of 133 surveyed localities in the central region of Korea, which was located at Mt. Gariwang in Jeongseon in Gangwon Province (Kim, unpublished work). This species has also shown a decline in occurrence in the southern part of the Korean Peninsula (Choi 2004). In addition, this species has a high potential for expansion to arctic regions, as indicated by outbreaks that were observed in the northeastern part of the Russian plain during

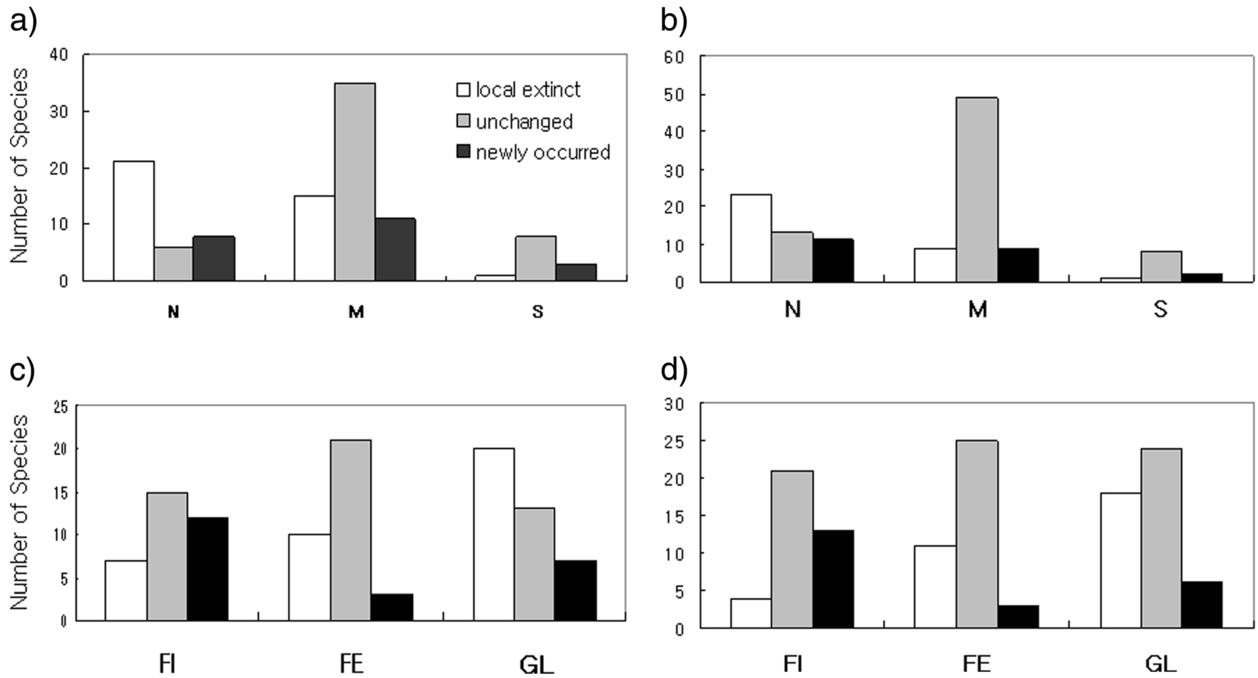

Figure 2 Number of species according to the distributional patterns or the habitat types. Number of species in local extinct, unchanged, and newly occurred butterfly species according to the distributional patterns or the habitat types at the GN site **(a, c)** and AM site **(b, d)**. N, northern species; M, miscellaneous; S, southern; FI, forest inside; FE, forest edge; and GL, grassland.

2003 to 2005 (Chernov and Tatarinov 2006). These findings indicate that a northward shift in the distribution of the species is likely in the eastern part of Eurasia.

Local extinction of past-abundant species was also observed for four of the N species, *Neptis rivularis*, *Coenonympha oedippus*, *Melitaea britomartis*, and *Gonepteryx rhamni. N. rivularis* is distributed in the southern part of the Palaearctic region, ranging from Japan to central Europe (Konvicka et al. 2002). In Japan, Inoue (2003) reported that *N. rivularis* was present in the Ogawa Forest Reserve in the Ibaraki Prefecture in the northern portion of Japan during 1976, but was not found between 1996 and 2002. However, in the Khan Khentej region of the northern part of Mongolia, *N. rivularis* was one of the most abundant species and showed an increasing trend between 2000 and 2003 (Chuluunbaatar 2004). The occurrence of *C. oedippus* has declined in the southern part of the Korean Peninsula (Choi 2004). Loss of grasslands as result of reforestation may also be related to the rapid decline of the species in addition to global warming. In Europe, *C. oedippus* has declined significantly over the last several decades, and it is now the most seriously threatened nonendemic species in Europe (Kudrna 1986). The decline in Europe was caused by a loss of habitats, such as wet or swampy meadows and heath in forests or bogs. However, from 2000 to 2003, *C. oedippus* was a dominant species, with a stable population in West Khentej in Mongolia (Chuluunbaatar 2004). *M. britomartis* is also another N and GL species that was abundant throughout the central part of the Korean Peninsula prior to the 1980s, but is now represented by only a few populations in small separated patches of grasslands. The species is also endangered in Sweden (Franzén 2004). The combined effects of habitat loss and temperature rise may significantly deteriorate the adaptability of these species in the Korean Peninsula.

The decline in the abundance of *G. rhamni* (9 in Figure 1) is contrasted with the expansion of the species in northern European countries such as the UK and Finland (Gutierrez and Thomas 2000; Kuussaari et al. 2007). This species was observed in abundance in the mid-western part of the Korean Peninsula prior to the early 1990s, but no individuals have been observed in that area in the early twenty-first century. In Korea, *G. rhamni* feed primarily on *Rhamnus davurica* and usually inhabit the forest edge. Gutierrez and Thomas (2000) showed that the British distribution of the species closely follows the range of its host plants, *Rhamnus catharticus* and *Frangula alnus*. The host plant commonly occurs in the southern portion of Korea (Kim and Kim 2011). Therefore, it is likely that the observed decline of the species has occurred independently of changes in the population of the host plant and that it is instead dependent on global warming.

Neither *P. maha* nor *M. francisca* was collected at the GN or AM sites during the past study periods; however,

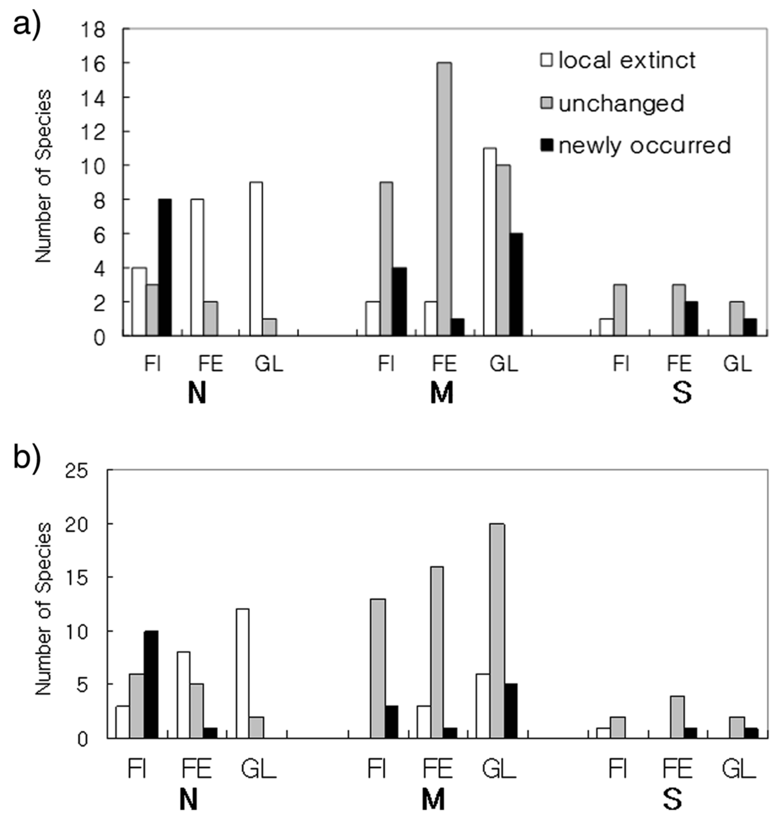

Figure 3 Number of species according to habitat type. Number of species in local extinct, unchanged, and newly occurred butterfly species according to habitat types for each distribution pattern at GN site **(a)** and AM site **(b)**. N, northern species; M, miscellaneous; S, southern; FI, forest inside; FE, forest edge; and GL, grassland.

they were both frequently observed during the present study period. Despite a decline in habitat (e.g., grasslands), *P. maha* increased in abundance in the central portion of the Korean Peninsula since the early 1990s. Such an increase may be possible because this species has recently been able to overwinter in the central part of the Korean Peninsula (Kim, unpublished work). The rapid increase in the minimum temperature may allow those insects to withstand winter. Although the northern boundary of *P. maha* on the Korean Peninsula was known to be approximately 38°N (Seok 1973), it is likely that a northward shift of the distributional boundary has occurred. Unfortunately, current information regarding the distributional change of this species in North Korea is not available due to the rigid political boundary between South and North Korea. *M. francisca*, which overwintered in the central part of the Korean Peninsula in the past, has a distribution that reaches further north than that of *P. maha*, with a northern margin of range of about 40° to 42°N in Korea and Japan (Joo et al. 1997; Fukuda et al. 1982, 1983, 1984a, 1984b). This species is also abundant in the lowlands in Busan and Ulsan, which are located in the southernmost area of the Korean Peninsula (Kim, unpublished work), while it also inhabits highlands above 1,500 m in Vietnam (Monastyrskii 2007).

Conclusions

The present study shows that simple binary data (presence/absence) can be useful in the assessment of impacts of global warming on local butterfly fauna. Such data may be more easily obtained at low costs and can be used to identify impacts of climate change using nonparametric statistics, as evidenced in the present study. Such qualitative data may also be much more available than abundance data in many regions, because most data concerning butterfly fauna in the world are binary rather than quantitative. The binary data obtained from museum collections can be also a rich source for use in assessment of impacts of climate change on local butterfly fauna. Impacts of climate change occur in all spectrums ranging from the local to global scale. The impacts in the different scales may be closely correlated with each other. However, most studies on impacts of climate changes on butterflies have concentrated on distributional changes at regional or global scales, whereas local changes at community levels are very rarely reported. As shown in the present study and previous study (Kwon et al. 2010), butterfly communities changed as butterflies moved globally.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
T-SK designed the experiment for the present study and wrote the manuscript. S-SK surveyed the recent butterfly fauna. CML analyzed data. All authors read and approved the final manuscript.

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