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Original article

Effects of Climate Change on the Occurrence of Two Fly Families (Phoridae and Lauxaniidae) in Korean Forests

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Abstract Using data from flies collected with pitfall traps in 365 forests on a nationwide scale in Korea, the abundance and distribution changes of two families (Phoridae and Lauxaniidae) in Korean forests were predicted at the genus level according to two climate change scenarios: RCP 4.5 and RCP 8.5. The most suitable temperature for the 17 major genera was estimated using a weighted average regression model. *Stichillus* and *Anevrina* displayed the lowest optimum temperature with 7.6°C and 8.5°C in annual mean temperature, respectively, whereas *Chonocephalus* had the highest optimum temperature with 12.1°C. Among thirty genera, seven genera (four from Phoridae and three from Lauxaniidae), which showed their abundance in a bell-type or linear pattern along the temperature gradient, were used for predicting the distribution changes according to the future climate change scenarios. All the taxa of this study are expected to decrease in abundance and distribution as a function of temperature increase. Moreover, cold-adapted taxa were found to be more affected than warm-adapted taxa.

Key words: Diptera, climate change, prediction, distribution, global warming, optimum temperature

INTRODUCTION

Flies are one of the most abundant and diverse insects in terrestrial ecosystems and approximately 122,000 species of flies are currently known (McGavin, 2001). Flies are major decomposers in ecosystems and play a key role in the nutrient cycle and in the flow of energy. They also play a variety of other roles such as plant feeders, pollinators, and natural predators. Furthermore, flies are important in the food web as they link producers and consumers. Forest flies are considered to have great potential as bioindicators of disturbed forests because they can reflect the effects of environmental disturbances (Kwon *et al.*, 2013a). Kwon (2017) reported that the composition of flies collected from six locations in the Baekdu-daegan mountain range in South Korea is closely

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related to temperature. He also noted that Phoridae and Lauxaniidae are common and abundant among the 67 families found in South Korea.

There are approximately 4,000 species in Phoridae worldwide (Brown *et al.*, 2015), and three species in three genera have been reported in a recently published list of Korean insects (Paek *et al.*, 2010). Phorid flies are small and have a wide variety of feeding habits and ecological niches (Disney, 1994). Phoridae is the most abundant and common genus, having the highest occurrence among flies in South Korea, and is influenced by the mean annual temperature and low temperatures (Kwon *et al.*, 2015). The temperature at the collection sites of this family was, on average, 9.9°C and ranged from 3.2∼14.1°C in South Korea (Kwon *et al.*, 2018). When the temperature increases, the abundance is expected to decrease by 22.9% and 51.6% according to the future climate scenarios in RCP 4.5 and RCP 8.5, respectively (Lee *et al.*, 2015).

Lauxaniidae is a large family with approximately 1,800 species worldwide, most of which are distributed in the tropical regions of Asia and America, and a few are found in the tropical regions of Africa (Merz, 2004). In South Korea, 10 species in 2 genera were recorded in a recently published list of Korean insects (Paek *et al.*, 2010), whereas Lee (2010) reported 93 species in 19 genera in his doctoral dissertation. Most species are decomposers, and some burrow in fallen leaves (Papp and Shatalkin, 1998). The abundance of Lauxaniidae had a negative correlation with rainfall and altitude, and a positive correlation with maximum temperature (Kwon *et al.*, 2015). Furthermore, Lauxaniidae abundance displayed a bell-shaped distribution pattern with the highest value between 9°C and 11°C (optimum temperature: 10.1°C), with the annual mean temperature in the range of 3.2∼14.1°C. Generally, the abundance of species distributed with a bell shape against temperature changes displays the highest value at the optimum temperature and lowest values at extreme temperatures (Dormann, 2011). However, if the survey is performed in a small area where the temperature is higher or lower than the optimum temperature, a linear distribution pattern (increase or decrease according to the temperature gradient) would appear.

Lee *et al.* (2015) reported the change in distribution of flies due to climate change at the family level in South Korea and predicted that the abundance of Lauxaniidae would decrease greatly to 25% and 56% after 50 years, according to the future climate scenarios in RCP 4.5 and RCP 8.5, respectively. However, they did not consider the effects of climate change on the genus/species level. In addition to this, Kwon *et al.* (2018) presented the distribution of four families, Phoridae, Lauxaniidae, Empididae, and Dolichopodidae, and predicted their distribution according to climate change scenarios. However, they only roughly reported the distribution of taxa in response to future climate change scenarios.

Although many studies have been conducted on climate change using flies, most have focused on pest species (Wall *et al.*, 2011; Rose and Wall, 2011; Durel *et al.*, 2015). Therefore, studies on the influence of climate change on flies that are not pests are relatively rare. In this study, we estimated the optimum temperature for major genera in two families of Korean forest flies (Phoridae and Lauxaniidae), and predicted the distribution of major selected genera in these two families according to future climate change scenarios.

MATERIALS AND METHODS

1. Sampling sites and taxonomic identification

In this study we used the forest fly dataset reported by Kwon *et al.* (2018). Flies were collected using pitfall traps at 365 forest sites in South Korea between mid-May and mid-September for four years (2006 to 2009) (Kwon *et al.*, 2014a). To select the sampling sites as evenly as possible, eight sites were randomly selected in a grid of 0.5° latitude and 0.5° longitude on the geographical map (Kwon *et al.*, 2018). In the study area, 12 high mountains with altitudes of 1100 m or higher were included, and 4∼7 sampling sites in each high mountain were selected at intervals of 200∼300 m in altitude. The sampling sites were selected from healthy forests, more than 30 years old, with abundant lower vegetation. The tops of the mountains, which were composed of open habitats such as grassland and bushlands, were also selected as sampling sites (Kwon *et al.*, 2018).

At each sampling site, 10 pitfall traps made of plastic containers (diameter: 9.5 cm, depth: 6.5 cm) were lineally installed at 5 m intervals and left for 10∼15 days. About one third of the volume of the container traps was poured with automobile antifreeze as preservation liquid. Automobile antifreeze is widely used as a preservation liquid because it does not attract insects and has little evaporation, making it suitable for the preservation of insect specimens (Greenslade and Greenslade, 1971).

The specimens were isolated from the collected pitfall traps and preserved in 100% ethyl alcohol for taxonomic identification. All specimens were identified at the family level and in morphospecies. Among the identified specimens, two families (Phoridae and Lauxaniidae) were identified at the genus or species level. Phoridae was identified to the genus level based on the method used by Disney (1994, 1998) and Lauxaniidae was identified to genus level based on Lee's method (2012).

2. Temperature data

The annual mean temperature (MAT) was estimated at each sampling site from a digital climate change map of the Korean forest (Yun *et al.*, 2013) that was provided by the Meteorological Administration, and the National Agricultural and Forest Meteorological Center (Kwon *et al.*, 2013b). MATs were calculated on an average from 1971 to 2008 on $30 \times 30\ m^2$ grid scales. The details of the environmental factors at the sampling sites were reported by Kwon *et al.* (2013b). A future climate change scenario based on the 5^{th} evaluation report of the Intergovernmental Panel on Climate Change (IPCC) was provided by the Korea Meteorological Administration. Meanwhile, the average temperature data were estimated for 2011∼2015 and 2056∼2065 for current and future temperatures using RCP 4.5, RCP 8.5, and climate change scenarios. These were then used to predict the future distribution of target taxa. Scenario RCP 4.5 is an intermediate scenario with peak emissions around 2040, whereas RCP 8.5 is the basis for worst-case climate change scenarios with a continuous rise in emissions throughout the 21st century (Meinshausen *et al.*, 2011).

3. Modeling procedure

The modeling was conducted in two phases. First, the optimum temperatures for the distribution of 17 genera (13 in Phoridae and 4 in Lauxaniidae) were calculated using MATs of the sampling sites. Second, seven genera (four in Phoridae and three in Lauxaniidae) that showed a bell-shaped or linear pattern of abundance along the temperature gradient were selected (Kwon *et al.*, 2018). Subsequently, predictions of their distribution changes were made according to two future climate change scenarios: RCP 4.5 and RCP 8.5. The differences in abundance between the current and future periods were estimated for both scenarios.

The change in the distribution of target taxa was predicted using MATs of the sampling sites where the taxa were collected. MATs of the sampling sites were grouped into six temperature ranges: 3∼7°C, 7∼9°C, 9∼11°C, 11∼13°C, 13∼15°C, and 15∼17°C, and the average abundance (number of individuals per site) of each taxon in each temperature range was calculated (Kwon *et al.*, 2018). Comparing the average values of abundance among the six temperature ranges, taxa that have a linear or bell-shaped (normal distribution) pattern might have a high correlation with temperature. In general, a bell-shaped pattern is expected, in which the abundance is highest at the optimum temperature and decreases whilst approaching either extreme value (Dormann, 2011). However, if the survey is performed in a narrow region where the temperature is higher or lower than the optimum temperature, a linear pattern (increase or decrease according to the temperature gradient) will appear. As a result of the analysis, three genera in Phoridae and four genera in Lauxaniidae showed this distribution pattern (Table 1).

Using the average of the abundance in each temperature range, the change in the abundance of each taxon was predicted along with the change in temperature. The projected periods are: 2010∼2015 and 2056∼2065. Since this survey

Table 1. Abundance of flies in Phoridae and Lauxaniidae. Abundance is average of the number of individuals collected in 10 pitfall traps at a site. Abundance in high temperature ranges (>15°C) was estimated by the approximate nearest neighbor method (Kwon *et al*., 2014a).

Family	Genus	Temperature range						
		3∼7°C	7∼9°C	9∼11°C	11∼13°C	13∼15°C	15∼17°C	17∼19°C
Phoridae	*Anevrina*	0.38	0.48	0.28	0.01	0.00	0.00	0.00
Phoridae	*Conicera*	0.81	7.18	3.79	2.61	0.76	0.22	0.06
Phoridae	*Gymnophora*	0.41	1.44	0.74	0.15	0.03	0.01	0.00
Phoridae	*Megaselia*	47.56	153.59	109.22	60.45	20.07	6.66	2.21
Lauxanidae	*Homoneura*	0.25	0.87	0.95	1.58	0.66	0.27	0.11
Lauxanidae	*Minettia*	0.44	1.69	8.45	4.06	0.38	0.04	0.00
Lauxanidae	*Sapromyza*	0.06	0.57	1.41	0.46	0.00	0.00	0.00

was conducted only in forests, the analysis was applied only to forests. Temperature ranges above 15°C rarely appear at present; therefore, there are no data on the average abundance. As a result, the abundance of these temperature ranges was estimated using the approximate nearest neighbor method (Kwon *et al.*, 2014b). The data for the projection are provided in Kwon *et al.* (2018) and ArcGIS 10.1 was used for all GIS-related analyses.

RESULTS AND DISCUSSION

1. Temperature range of flies

Megaselia [occurrence sites: 291 (79.5%)] was the most common genus among the 20 genera in Phoridae, while genus *Minettia* [occurrence sites: 159 (43.3%)] was the most abundant among the nine genera in Lauxaniidae (Table 2). Optimum MATs for the major selected genera ranged from 8.5°C (*Stichillus*) to 12.1°C (*Chonocephalus*) for Phoridae and from 7.2°C (*Minettiella*) to 10.5°C (Homoneura) for Lauxaniidae. The results indicate that *Stichillus*, *Anevrina*, and *Minettiella* are adapted to relatively colder temperatures, whereas *Chonocephalus* is adapted to the warmth. Therefore, these three genera would be more easily influenced than other taxa owing to global warming because cold-adapted species are more vulnerable to climate change than warm-adapted ones (Li *et al.*, 2013).

2. Prediction of distribution change

Seven of the selected genera displayed a consistent decrease in their abundance in response to the future climate change scenarios RCP 4.5 and RCP 8.5, as shown in Fig. 1a. In particular, *Anevrina* in Phoridae displayed the highest abundance decrease in both RCP 4.5 and RCP 8.5, whereas from Lauxaniidae it was *Sapromyza*. Moreover, the abundance decrease was higher in RCP 8.5 (slope = 18.965) than in RCP 4.5 (slope = 11.843). This was owing to the characteristics of each scenario. RCP 4.5 is an intermediate scenario, whereas RCP 8.5 is the basis for worst-case climate change scenarios (Meinshausen *et al.*, 2011). Genus such as *Anevrina*, which has a low optimum temperature, displayed a more significant abundance decrease than genera with high optimum temperatures. These results support the hypothesis that cold-adapted species are more vulnerable to climate change than warm-adapted species (Li *et al.*, 2013, 2014; Kwon *et al.*, 2016). Lee *et al.* (2015) predicted the changes in abundance of flies at

Table 2. Optimum and tolerance values of annual mean temperature (MAT), abundance, and occurrence for major genera in the two families: Phoridae and Lauxaniidae. Only the genera which showed more than 2% frequency were represented.

Family	Genus	Abundance	Occurrence (%)	MAT (°C)*	
				WA	TOL
Phoridae	*Megaselia*	32124	291 (79.5)	9.6	1.7
	Conicera	1266	169 (46.2)	9.8	1.8
	Borophaga	733	33 (9.0)	9.9	0.8
	Stichillus	337	45 (12.3)	7.6	1.9
	Gymnophora	210	68 (18.6)	9.1	1.6
	Dohrniphora	142	55 (15.0)	11.0	1.5
	Anevrina	76	39 (10.7)	8.5	1.6
	Puliciphora	61	32 (8.7)	10.3	1.5
	Chonocephalus	53	19 (5.2)	12.1	0.9
	Diplonevra	50	29 (7.9)	9.4	2.5
	Hypocera	38	18 (4.9)	9.9	1.6
	Phora	26	18 (4.9)	8.9	3.5
	Triphleba	13	11 (3.0)	10.4	1.8
Lauxaniidae	*Minettia*	1650	159 (43.3)	10.4	1.1
	Homoneura	389	111 (30.3)	10.5	1.7
	Sapromyza	265	84 (23.0)	10.1	1.3
	Minettiella	15	9 (2.5)	7.2	1.8

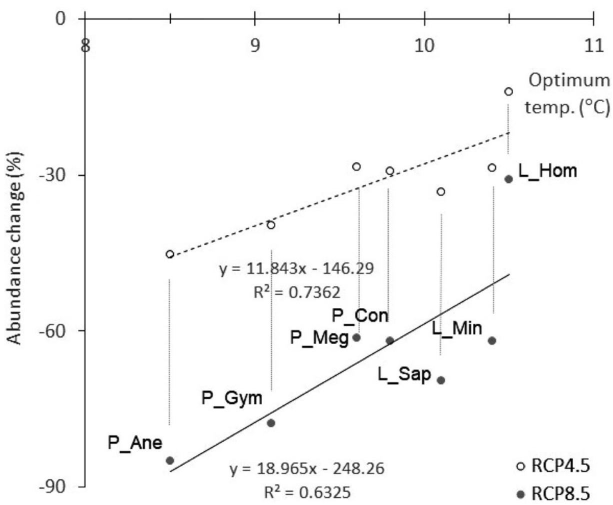

Fig. 1. Abundance changes (%) of seven selected taxa, from current to future periods, according to the future climate change scenarios: RCP 4.5 and RCP 8.5. Optimum temp.: optimum temperature; P_Ane: *Anevrina*, P_Gym: *Gymnophora*, P_Meg: *Megaselia*, and P_Con: *Conicera*, in Phoridae; L_Sap: *Sapromyza*, L_Min: *Minettia*, and L_Hom: *Homoneura* in Lauxaniidae.

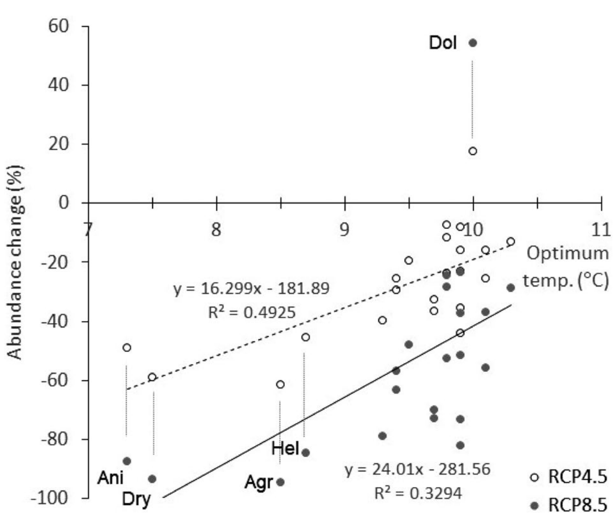

Fig. 2. Abundance changes (%) of 22 families, from current to future periods, according to the future climate change scenarios: RCP 4.5 and RCP 8.5. Optimum temp.: optimum temperature, Ani: Anisopodidae, Dry: Dryomyzidae, Agr: Agromyzidae, Hel: Heleomyzidae, Dol: Dolichopodidae. Data from Lee *et al.* (2015).

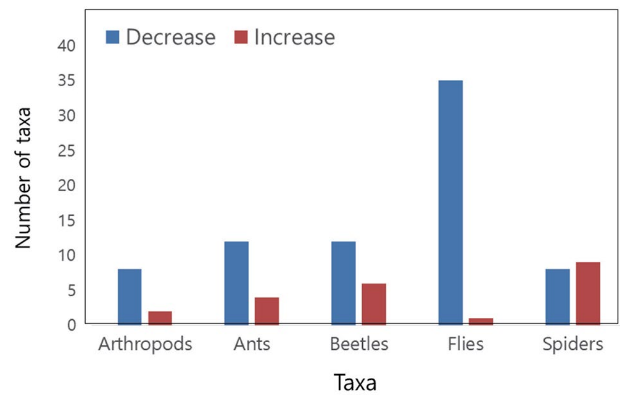

Fig. 3. Expected change of abundance (at the national level) of five arthropod taxa due to climate warming. Prediction of abundance has been conducted using the Species Temperature Distribution Model (STDM) of Kwon *et al.* (2014a). Data taken from Lim *et al.* (2018). The data for the flies used in this study were pooled from the family level (Lee *et al.*, 2015) and the genus/species level. Arthropods are at the order level and other taxa are at the species level.

the family level, showing that the abundance of families was more influenced by RCP 8.5 than RCP 4.5. They showed that all families, except Dolichopodidae, decreased in abundance owing to global warming (Fig. 2b).

Climate change can positively or negatively influence the distribution and abundance of species. Most studies have reported that many species might lose their habitats and, consequently, see a decrease in their abundance. Figure 3 shows changes in the projected abundance of five arthropod taxa, according to future climate change scenarios, using the pooled results of changes in the national abundance of these five taxa (Lim *et al.*, 2018). The methods of prediction were the same as those used in this study. Arthropods were analyzed at the order level, while other taxa such as ants, beetles, and spiders, were analyzed at the species level. Most taxa, except spiders, were expected to lose more taxa rather than gain taxa. In particular, in the case of flies, a decrease was expected in 97% of taxa. Why is it that more taxa are expected to decrease than to increase in future South Korea? This might be owing to the geographical location of the peninsula (Lee *et al.*, 2015). In the case of Korean butterflies, the diversity increases towards the north owing to the peninsula effect. When analyzing the distribution type for butterflies, the northern species with the southern margin as their border is 50.2%, which is much higher than that for southern species with the northern margin as their boarder (18.2%) (Kwon *et al.*, 2021). In the northern hemisphere, as species diversity gradually decreases from the equator to the northern pole, it is generally expected that more southern species than northern species will exist in the inland temperate regions. However, in the case of the peninsula, the northern species are dominant because the inflow of southern species is blocked by the sea. Thus, as the cold-adapted northern species dominate in most taxa, it is likely that the abundance of most taxa would decrease as the temperature increases.

Currently, many studies are being conducted to predict the distribution change of species due to climate change using various species distribution models. Most of them are based on the multidimensional niche theory and distribution models that consider various environmental factors are mainstream (Dormann, 2011). Because these models use machine learning algorithms or non-linear complex statistical techniques, black box models with unknown structures (e.g., equations) or statistical models with many explanatory variables are mainly used. In contrast, the Species Temperature Distribution Model (STDM) used in this study predicts the influence of temperature change only. However, the prediction results are not expected to be significantly different from those of existing complex models (Kwon, 2014). Li *et al.* (2013) calculated the optimum temperature of each species using a weighted average regression model and successfully evaluated the effect of climate change on the distribution of aquatic insects. Generally, sophisticated and complex models provide more information with higher prediction power than simple models. Nevertheless, in cases where similar results are obtained regardless of the model complexity, a simpler model is preferred because of the efficiency and lower modeling costs (Crawley, 2007; Lee *et al.*, 2015; Kwon *et al.*, 2018).

In conclusion, among the 17 major genera belonging to the two families of Phoridae and Lauxaniidae, *Stichillus* and *Anevrina* displayed the lowest optimum temperature with 7.6°C and 8.5°C of annual mean temperature, respectively; whereas, *Chonocephalus* had the highest optimum temperature with 12.1°C. Seven of the selected genera showing a bell-type or linear pattern for their abundance along the temperature gradient, were used to predict the distribution changes according to the future climate change scenarios. All the projected taxa are expected to decrease in abundance and distribution as a function of temperature increase. Moreover, cold-adapted taxa were found to be more affected than warm-adapted taxa.

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