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Prediction of Spring Emergence of *Osmia cornifrons* Radoszkowski in Korea, China and Japan under Future Climate

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Abstract

The Japanese hornfaced bee, *Osmia cornifrons* Radoszkowski (Hymenoptera: Megachilidae), which overwinter as diapausing adult in cocoon, is an important pollinator of fruits including apple in China, Japan, Korea and United States. The synchronization of spring emergence of *O. cornifrons* with apple blossom is critical for successful pollination. In present study, we predicted spring emergence of *O. cornifrons* in Korea, China and Japan based on the degree day model using a two-parameter Weibull function under the future climate scenarios of RCP 2.6 and 8.5. The predicted initial emergence Julian dates of *O. cornifrons* in 2025, 2030, 2040, 2050, 2060, and 2080 were earlier 8.9, 6.3, 8.67, 16.0, 7.1, and 31.1 days, respectively under RCP 8.5 scenario than that in 2015. There was linear relationship between latitude and predicted initial emergence Julian date. Emergence period was not influenced by the initial emergence date under RCP 2.6, but it becomes longer as *O. cornifrons* emerge earlier under RCP 8.5 scenario. Our predictions could help to develop the pollination strategy under the climate change conditions.

Key words: *Osmia cornifrons*, Climate change, Representative Concentration Pathway, Temporal mismatching

INTRODUCTION

The Japanese hornfaced bee, *Osmia cornifrons* Radoszkowski (Hymenoptera: Megachilidae) is a solitary bee. Each female *O. cornifrons* makes her own nest, provisioning the cells for her offspring. The male hornfaced bee emerges earlier about one week than pear trees bloom in the spring. Females emerge 2 or 3 days later after emerging males, depending upon weather conditions. The size of females is larger than that of males (Yamada *et al*., 1971; Jeong and Jung, 2011).

Osmia cornifrons was found can be developed into an effective pollinator of sweet pepper under glasshouse conditions (Kristjansson and Rasmussen, 1990). West and McCutcheon (2009) had evaluated that *O. cornifrons* can be successful pollinator of commercial highbush blueberry. Moreover, *O. cornifrons* has been applied as pollinator in apple orchards in China, Japan, Korea and United States (Yamada *et al*., 1971; Xu *et al*., 1995; Lu *et al*., 2002; Lee *et al*., 2008; Matsumoto *et al*., 2008; Lee *et al*., 2009; Matsumoto *et al*., 2009; Matsumoto and Maejima, 2010).

As with most solitary bees, *O. cornifrons* has a short adult phase with most of the life span spent undergoing development and diapause inside nests. Thus, it is necessary to ensure that adult bees are active when their target crops are in bloom to maximize crop pollination. The spring emergence model of *O. cornifrons* had been developed in USA and Korea (White *et al*., 2009; Ahn *et al*., 2014). The relationship between emergence rates of *O. cornifrons* females and temperature was described with

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*Corresponding author. E-mail: cjung@andong.ac.kr linear and nonlinear functions, and the spring emergence of *O. cornifrons* was described with a two-parameter Weibull distribution model (Ahn *et al*., 2014). The lower developmental threshold and the thermal constant of Korean population of *O. cornifrons* female were estimated to 7.98°C and 112.43DD (degree days), respectively (Ahn *et al*., 2014). According to the spring emergence model and the daily average temperature under future climate, we can predict the spring emergence frequency of *O. cornifrons*.

The Intergovernmental Panel on Climate Change (IPCC) has documented increased global temperatures, a decrease in snow and ice cover, and changed frequency and intensity of precipitation (IPCC, 2014). IPCC focus on four emissions trajectories to describe four possible climate futures, which were known as representative concentration pathways (RCPs), and have labelled them RCP2.6, 4.5, 6.0 and 8.5, based on a radiative forcing (2.6, 4.5, 6.0, and 8.5 W/m^2). The most important effect of climate change on plant-pollinator interactions can be expected to result from global warming. Global warming can influence the phenology of pollinators by producing shorter diapause duration and an earlier spring emergence (Bale and Hayward 2010).

Although the spring emergence model of *O. cornifrons* had been developed in the previous study in Korea (Ahn *et al*., 2014), the effect of climate change on the spring emergence was not clear. Therefore, the objective of this study was to predict the spring emergence of *O. cornifrons* under RCP 2.6 and 8.5 scenarios in Korea, China and Japan, and discover the effect of climate change on the predicted spring emergence of *O. cornifrons*.

MATERIALS AND METHODS

Study sites and climate data

In total, 9 main apple production sites from Korea (Gwangju, Andong and Chuncheon), China (Jinan, Taiyuan, Zhengzhou and Xian) and Japan (Aomori and Iwate) were selected (Table 1). These 9 sites were representative major apple production areas from Korea, China and Japan, which need pollination service in apple orchards. Daily temperature data in these sites from January to May in 2020, 2025, 2030, 2040, 2050, 2060, and 2080 based on RCP 2.6 and 8.5 scenarios were obtained from the Meteorological Administration (KMA) and Climate Change Information Center (CCIC). Daily temperature data from January to May in 2015 were collected from websites (www.climate.go.kr and www.accuweather.com).

DD model and emergence distribution model

The equation 1 was applied to calculate the cumulative degree-days. The lower developmental threshold (7.98°C) and the thermal constant (112.43 DD) estimated by Ahn *et al*. (2014) were applied to equation 1 and 2.

$$\sum_1^n DD = \int_1^n (T_a - T_0)dT \quad \text{Eq.1}$$

Where DD is daily DDs, T_a is daily average temperature, and T_0 is the lower developmental threshold.

Cumulative emergence frequency of *O. cornifrons* adults was analyzed using two-parameter Weibull function (Equation 2, Weibull, 1951).

$$F(x) = 1 - \exp(-(x/a)^b) \quad \text{Eq.2}$$

Table 1. The locations of the 9 sites from Korea, China and Japan

Nationality	Location	Latitude	Longitude
Korea	Gwangju	N35° 05'	E126° 50'
	Andong	N36° 33'	E128° 45'
	Chuncheon	N37° 51'	E127° 46'
China	Jinan	N36° 39',	E117° 18'
	Taiyuan	N37° 48'	E112° 41'
	Zhengzhou	N34° 40'	E113° 34'
Japan	Xian	N34° 23'	E108° 40'
	Aomori	N40° 47'	E140° 45'
	Iwate	N39° 40'	E140° 58'

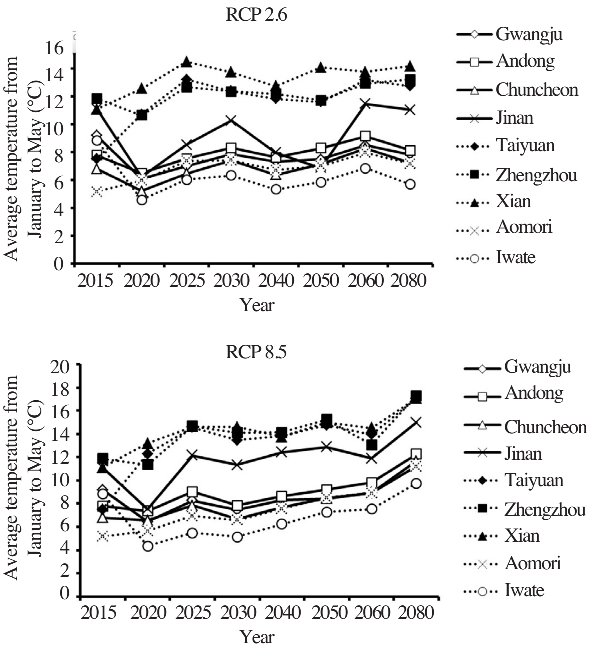

Fig. 1. The average temperature from January to May in different years in 9 sites under RCP 2.6 and 8.5 scenarios.

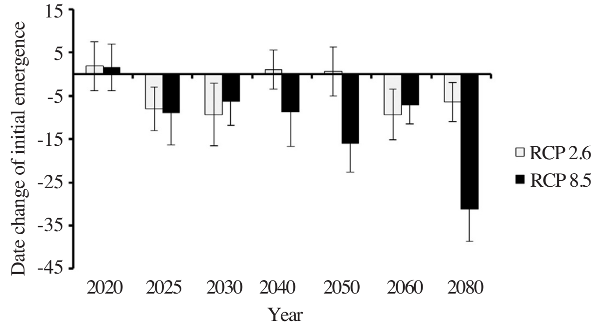

Fig. 2. Date change of initial emergence based on RCP 2.6 and 8.5 scenarios compared with 2015. Initial emergence date means the date of 10% emergence.

Where F(x) is the cumulative frequency at normalized time x, a is the scale parameter and b is the parameter of curve shape. Normalized time x was calculated by dividing the cumulative DDs by thermal constant. The values of a and b calculated by Ahn *et al*. (2014) were applied (a=1.0219, b=3.3601).

The date of 10% cumulative emergence estimated by the model was assumed as the initial emergence date of *O. cornifrons*. The emergence period of *O. cornifrons* was calculated by the days between 10% and 90% cumulative emergence distribution.

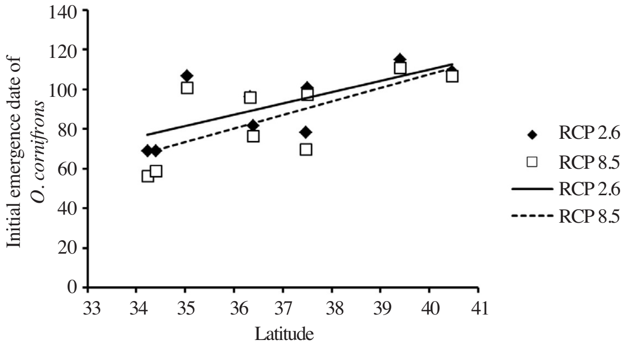

Fig. 3. The relationship between latitude and predicted initial emergence date of *Osmia cornifrons* under future climate (RCP 2.6 and 8.5). The initial emergence date were the mean values of 8 years (2015, 2020, 2025, 2030, 2040, 2050, 2060 and 2080).

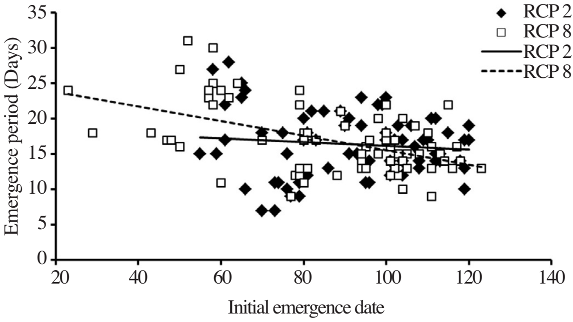

Fig. 4. The relationship between initial emergence date and total emergence period of *Osmia cornifrons* in different regions under RCP 2.6 and 8.5.

Statistical analysis

Date was expressed as Julian date which is the number of days from January 1. Predicted initial emergence date changes of different years were compared with ANOVA, the data from 9 sites in different year were assumed as 9 replications. Regression analyses of latitude and initial emergence date, and initial emergence dates and emergence periods were conducted suing SAS 9.2 package.

RESULTS

The average temperature change under future climate

Fig.1 showed the average temperature from January to May in different years in 9 sites under RCP 2.6 and 8.5 scenarios. The spring emergence model of *O. cornifrons*

Table 2. Predicted spring emergence of *Osmia cornifrons* under RCP 2.6 scenario at 9 sites in Korea, China and Japan

Site	Accumulative emergence (%)	2015	2020	2025	2030	2040	2050	2060	2080
Gwangju	10	90[a]	119	106	112	110	113	100	103
	50	100	125	115	120	119	122	114	112
	90	109	136	125	127	127	127	123	122
Andong	10	100	98	91	94	101	100	91	95
	50	112	113	101	109	107	111	98	102
	90	117	120	111	117	113	118	106	106
Chuncheon	10	102	108	94	102	104	108	93	96
	50	114	118	107	115	110	117	99	102
	90	119	122	113	119	116	121	108	107
Jinan	10	81	89	76	70	85	96	75	81
	50	87	103	81	80	102	103	87	88
	90	99	110	91	88	106	110	93	93
Taiyuan	10	101	79	73	61	82	86	65	79
	50	110	85	77	69	96	91	78	83
	90	115	90	80	78	103	99	90	88
Zhengzhou	10	80	77	70	59	80	66	62	58
	50	88	83	74	68	83	85	69	80
	90	97	86	77	74	100	90	90	85
Xian	10	83	73	66	55	76	65	61	74
	50	91	80	72	64	82	77	68	80
	90	100	84	76	70	86	88	83	85
Aomori	10	118	113	99	107	110	112	109	104
	50	124	121	112	116	119	120	122	111
	90	132	128	121	123	127	126	126	121
Iwate	10	104	120	112	115	120	119	119	111
	50	112	130	122	123	130	127	125	123
	90	118	139	132	133	137	132	129	131

Note: [a]means Julian date from 1 January.

was built based on the cumulative degree-days, which was related to the temperature change from January to May. The predicted average temperature in Korea, China and Japan increase 3.79, 6.2 and 3.48°C, respectively, from 2015 to 2080 under RCP 8.5 scenario, while which did not change much under RCP 2.6 scenario.

Predicted emergence frequency under future climate

The emergence frequencies of *O. cornifrons* in 9 cities under RCP 2.6 and 8.5 scenarios were predicted using the distribution emergence model (Table 2 and Table 3). Compared to 2015, the predicted initial emergence date changes of *O. cornifrons* in 2020, 2025, 2030, 2040, 2050, 2060, and 2080 were significant different under RCP 2.6 (ANOVA, df=62, F=36.3, $P<0.0001$) and 8.5 scenarios (ANOVA, df=62, F=39.04, $P<0.0001$) (Fig. 2). The initial emergence dates in 2025, 2030, 2040, 2050, 2060, and 2080 were predicted to occur 8.9±7.4, 6.3±5.6, 8.7±8.0, 16.0±6.7, 7.1±4.3, and 31.1±7.6 days earlier than that in 2015, respectively, under RCP 8.5 scenario (Table 3).

The relationship between latitude and initial emergence date

There was linear relationship between latitude and predicted initial emergence date of *O. cornifrons* under future climate (Fig. 3). Initial emergence occurred later in the sites with higher latitude; $y=5.67x-116.9$ (df=8,

Table 3. Predicted spring emergence of *Osmia cornifron*s under RCP 8.5 scenario at 9 sites in Korea, China and Japan

Site	Accumulative emergence (%)	2015	2020	2025	2030	2040	2050	2060	2080
Gwangju	10	90[a]	113	111	104	107	100	101	79
	50	100	122	119	115	119	115	108	90
	90	109	128	124	124	126	122	117	103
Andong	10	100	103	95	98	103	94	94	80
	50	112	111	105	106	112	100	102	89
	90	117	115	111	113	118	108	107	97
Chuncheon	10	102	104	96	102	105	94	95	80
	50	114	111	107	106	115	101	103	89
	90	119	114	113	115	120	109	108	98
Jinan	10	81	88	81	80	79	64	81	58
	50	87	93	89	92	95	73	90	76
	90	99	100	94	97	101	89	94	83
Taiyuan	10	101	78	62	77	58	60	79	43
	50	110	85	77	81	77	65	83	47
	90	115	90	85	86	88	71	91	61
Zhengzhou	10	80	80	50	57	50	47	79	29
	50	88	87	60	76	67	56	83	44
	90	97	91	66	80	77	64	92	47
Xian	10	83	70	57	58	52	48	60	23
	50	91	81	63	75	72	61	81	43
	90	100	87	81	80	83	65	84	47
Aomori	10	118	114	111	111	110	100	101	89
	50	124	124	116	118	121	112	107	99
	90	132	128	120	127	128	118	113	110
Iwate	10	104	123	116	115	117	108	105	98
	50	112	129	122	129	128	118	113	111
	90	118	136	129	137	133	123	118	118

Note: [a]means Julian date from 1 January

$R^2=0.48$, $P=0.0385$) and $y=6.81x-164.77$ (df=8, $R^2=0.50$, $P=0.0335$) under RCP 2.6 and 8.5 scenarios, respectively.

The relationship between initial emergence date and emergence period

The linear relationship between predicted initial emergence date and emergence period of *O. cornifrons* was only significant under RCP 8.5 even though with lower determinant power (Fig. 4). As *O. cornifrons* emerge earlier, the emergence period will become longer; $y=-0.027x+18.852$(df=71, $R^2=0.01$, $P=0.3707$) under RCP 2.6 and $y=-0.1028x-25.844$($R^2=0.25$, $P<0.0001$) under 8.5 scenario.

DISCUSSION

When plants and pollinators respond differently to climate variation, phenological mismatch may occur. Several studies have detected different phenological sensitivities to a warming climate between plants and insects (Gordo and Sanz, 2005; Parmesan, 2007; Forrest and Thomson, 2011; Kudo and Ida, 2013). The phonological date of apple full blooming was reported to become earlier by 1.0-2.3 days per decade in Japan (Sugiura *et al*., 2013). Fujisawa and Kobayashi (2010) found that apple flowering date was closely correlated to the mean air temperature throughout March and April and the flowing date responded to the long-term climate change at $-3.8°C^{-1}$ in northern Japan. According to these researches and the climate change scenario of RCP 8.5 in Aomori, the flowering date was predicted to become about 15 days earlier in 2080 than that in 2015. While the 50% cumulative emergence date of *O. cornifrons* become 25 days earlier from 2015 to 2080 (Table 3). Thus, the mismatch between phenology of *O. cornifrons* and apple blooming maybe happen under the future climate condition.

In present study, the predicted emergence dates of *O. cornifrons* in Korea, China and Japan showed earlier as the temperature increase under future climate. Our predictions could help to develop the planned pollination strategy under the climate change conditions. Based on the finding of our study, temporal mismatches between wild population of *O. cornifrons* and apple blossom would be predicted. The population of *O. cornifrons* were collected and stored under cold temperature, controlling the time of release them could match their emergence with apple blooming and alleviate the pollinator deficits. To accurately predict and monitor the impact of climate change on crop pollination, further studies such as effect of climate change on the mortality of pollinators, the shift of pollinator distribution range, and on co-occurrence of plant and pollinator species in space may be required.

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