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Latitude and Altitude Affects the Distribution and Population Features of *Osmia* spp. in Korea

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Abstract

Reports of a global decline in pollinator populations, especially mason bees, have raised concerns regarding the maintenance of pollination interactions. Although addressing local factors causing bee decline is a potential mitigation strategy at the landscape scale, regional rates and high-latitude threats to bee diversity are unclear. We investigated the distribution of mason bees (*Osmia*. spp. (*O. pedicornis, O. cornifons, O. taurus*, and *O. satoi*) and measured species richness and species ratios at regional, latitudinal, and altitudinal scales. We examined the association between bee species richness and three putative environmental conditions: high-low, altitude-dependent, and latitude-dependent. The species richness of the *O. pedicornis* bee was the highest and it was found between latitudes 35° and 37°, and at 500–600 m in both the northern and southern hemispheres, showing an inverse latitudinal gradient of bee species richness in South Korea. Mason bee species richness and global climate are important predictors of flowering plant diversity. Climate change threatens bee and vascular plant diversity; however, the overlap between bee abundance and plant diversity can be improved by employing suitable conservation strategies.

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Introduction

The most efficient pollen vectors for crop pollination comprise over 16,325 documented species of entomophilous insects globally (Michener, 2007). Bees are prominent pollinators that play vital roles in natural ecosystems and agricultural domains, ranging from vegetables, fruits, seed crops, and edible oil crops to dairy and major food crops (Michener, 2000). Notably, approximately 70% of 124 economically significant crops require pollinator bees (Klein *et al*., 2007), encompassing over 400 crops worldwide and more than 130 crops in the United States. Thus, reproduction is heavily dependent on pollinators (James and Pitts-Singer, 2008).

Bees are widely recognized for their pivotal role in pollination and thus are commercially cultivated for agricultural purposes and mainly venomous bee species as utilized as important pollinators (Free, 1993; Dag and Kammer, 2001). Mason bees, a subset of solitary bees, have emerged as key crop pollinators; specifically the *O.* spp. These bees belong to the Megachilidae family within the order Hymenoptera and are predominantly distributed in Ganwon-do, comprising 339 species (Michener, 2007). Mason bees generally exhibit annual life cycles and engage in nesting and reproductive activities within a single season. Adult females establish partitions within suitable cavities such as bamboo tubes before laying their eggs in individual chambers. The eggs mature through the larval

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and pupal stages, leading to the development of cocoons in the fall, where they remain dormant during winter until emerging as adults the following spring (Torchio, 1989; Bosch and Kemp, 2010; Lee *et al*., 2016).

The Korean context has seven distinct types of *O.* spp. (Lee and Woo, 1994), with five species distributed across various production areas and apple orchards. The dominant species included *O. cornifrons*, *O. pedicornis*, and *O. taurus*, as highlighted in previous studies (Kwon *et al*., 1997; Lee *et al*., 2002). Osmia bees are important pollinators of a range of crops, including apples, blueberries, and almonds, extending their global importance (Yamada *et al*., 1971; Maeta, 1978; Maeta and Kitamura, 1981; Torchio, 1981, 1985; Bosch, 1994; Bosch and Kemp, 2001). In Japan, *O. cornifrons* was identified as a valuable orchard pollinator during the 1960s, particularly in apple orchards in Aomori Prefecture, where it contributed to approximately 40% of apple pollination (Maeta and Kitamura, 1964, 1965; Yamada *et al*., 1971). The effectiveness of *O. cornifrons* as a pollinator is noteworthy because it touches flower heads and is better at pollinating fruits than honeybees (Maeta and Kitamura, 1981).

A considerable number of apple orchards do not have the optimal honeybee density necessary for fruit production, leading to the recognition of the demand for alternative pollinators within these orchards (Lee *et al*., 2010; Lee *et al*., 2014; Torchio 1982). Consequently, there is a requirement for pollinators capable of replacing bees in apple orchards. In Japan, seven species of *O.* spp. are distributed, and since the 1970s, it has been propagated and employed in apple orchards (Maeta, 1978; Sekita and Yamada, 1993). In Korea, an initial instance involved certain pioneering farmers in the Gyeongbuk region importing *O. cornifrons* that were used in Japanese apple orchards in the early 1990s with adoption growing throughout the mid-2000s, facilitated by agricultural technology centers in apple-producing regions (Lee *et al*., 2002, 2010). Subsequently, efforts have been undertaken to study the collection and utilization of locally native *O.* spp., resulting in the identification of new species, such as *O. cornifrons*, *O. pedicornis*, *O. satoi*, and *O. taurus* (Kwon and Huh, 1995; Kwak *et al*., 2023). Support groups, such as the Yecheon-gun Insect Research Institute and the Gyeongsangbuk-do Agricultural Resource Management Service, facilitated the collection and sale of Osmia bees in South Korea (Yoon *et al*., 2013).

O. spp. development was also investigated by Lee *et al*. (2016), and the duration of egg development for female and male bees was approximately 3.6 days and 3.1 days, respectively. Throughout the larval stage, the width of the head ranged from 0.7 mm to 1.3 mm across the first to fifth stages, with the most substantial growth occurring during the second stage. Larval length ranged from 3.7 mm to 13.6 mm, peaking during the fourth stage. The weight of larvae ranged from 4.5 mg to 78.3 mg, with the greatest increase occurring during the third stage. The overall duration of larval development from the first to the fifth stages was approximately 14.0 days for females and 13.2 days for males. The spinning phase took 2.2 days for females and 2.3 days for males, while pre-pupation lasted approximately 55.5 days for females and 55.8 days for males. Pupation took approximately 26.4 days for females and 25.3 days for males. The average lifespan of female adults was approximately 21.8 days, whereas that of male adults was approximately 24.4 days. The total period from egg to adult for *O. cornifrons* females was approximately 123.5 days, and for males, it was 124.1 days (Lee *et al*., 2016).

However, while both *O. pedicornis* and *O. cornifrons* were employed, the dissemination process did not distinctly classify male and female cocoons based on their reproductive capacities. This has caused a problem because the number of Osmia bees changes over time, and this affects their efficiency in pollinating crops.

To address these challenges and optimize the pollination effect of Osmia bees, this study aims to rectify the distribution of Osmia bees by systematically classifying and disseminating *O. pedicornis* and *O. cornifrons* based on gender and fertility attributes. This study further investigated various aspects of Osmia bee biology and distribution, including cocoon number, and regional distribution, by employing techniques such as the installation of bamboo tubes to examine species diversity and collection amounts in specific mountainous regions. The objective of the study was to determine the dynamics affecting mason bee diversity, abundance, and community composition given the local flower availability and landscape context, and investigate potential geographical (altitude and latitude) patterns in species occurrence across South Korea.

Materials and Methods

Setting *Osmia* bee trap nests

Trap nests are artificial nesting materials strategically positioned in locations where wild bee populations are present. In this study, we specifically deployed materials tailored to the

Table 1. Summary of *Osmia.* spp (*O. cornfrons, O. pedicornis, O. taurus, O. satoi*), cocoon rate, species rate and regional rate of different collecting regional sites (A) The latitude, longitude and altitude of different region collected *O.* spp. (B) Regional rate of *Osmia* species, collected by trap nests at different area (C) Rate of *Osmia* species collected by trap nests at different region

(A) The latitude, longitude and altitude of different region			
Regional	**Location**	Latitude and longitude	Altitude
Gangwon	Yeongwol A	37°09′51″N, 128°25′44″E	244
	Yeongwol B	37°11′46″N, 128°22′57″E	217
	Jeongseon A	37°17′04″N, 128°45′03″E	689
	Jeongseon B	37°18′22″N, 128°49′38″E	544
	Jeongseon C	37°18′32″N, 128°48′01″E	572
	Jeongseon D	37°18′45″N, 128°48′52″E	555
Chungbuk	Danyang	37°02′02″N, 128°25′37″E	503
Jeonbuk	Jinan A	35°43′35″N, 127°22′34″E	285
	Jinan B	35°43′25″N, 127°26′10″E	410
	Jinan C	35°43′20″N, 127°26′12″E	410
Jeonnam	Gurye	35°12′50″N, 127°34′26″E	203
Gyeongbuk	Bonghwa	36°48′21″N, 128°53′18″E	213
	Sangju A	36°34′09″N, 128°24′28″E	133
	Sangju B	36°35′23″N, 128°05′21″E	173
	Andong	36°47′23″N, 128°51′05″E	313
Gyeongnam	Geochang A	35°47′06″N, 127°59′35″E	579
	Geochang B	35°46′38″N, 128°00′14″E	410
	Geochang C	35°49′25″N, 128°04′02″E	700
	Hapcheon	35°37′37″N, 128°05′34″E	438

(B) Regional rate of *Osmia*. spp (%)						
Regional	**Location**	***O. c.***	***O. p.***	***O. t.***	***O. s.***	**Total**
Gangwon	Yeongwol	0.2	4.6	7	3.1	4.2
	Jeongseon	**29.8**	**59.7**	18.1	4.8	**44.9**
Chungbuk	Danyang	14.7	**20.3**	12.3	3.1	17.1
Jeonbuk	Jinan	11.7	0.9	5.3	**26.9**	4.9
Jeonnam	Gurye	0	0	0	0	0
Gyeongbuk	Bonghwa	0.8	0.2	1	5.9	0.8
	Sangju	0	0.3	0	2.2	0.3
	Andong	7.2	7.5	3.8	**54.1**	9.6
Gyeongnam	Geochang	**35.7**	6.5	**32.3**	0	14.9
	Hapcheon	0	0	**20.2**	0	3.2
Average		100	100	100	100	100

(C) Rate of species collected by trap nest (%)						
Regional	**Location**	***O. c.***	***O. p.***	***O. t.***	***O. s.***	**Total**
Gangwon	Yeongwol	0.6	**68.2**	26.7	4.4	100
	Jeongseon	10.7	**82.2**	6.5	0.6	100
Chungbuk	Danyang	13.8	**73.5**	11.5	1.1	100
Jeonbuk	Jinan	**38.5**	11.1	17.3	33.2	100
Jeonnam	Gurye	0	0	0	0	0
Gyeongbuk	Bonghwa	17.2	15.5	20.7	**46.6**	100
	Sangju	0	**60**	0	40	100
	Andong	12	**47.9**	6.3	33.8	100
Gyeongnam	Geochang	**38.4**	26.9	**34.7**	0	100
	Hapcheon	0	0	**100**	0	100
Average		16.1	**61.9**	16	6	100

Osmia. spp (*O. cornfrons*. *O. pedicornis, O. taurus, O. satoi*) collected in the order of Gangwon Jeongseon> Danyang> Andong> Geochang ($p<0.05$). *O. cornfrons* are collected most frequently in Geochang, *O. pedicornis,* in Jeongseon, *O. taurus,* in Geochang, and *O. satoi* in Andong ($p<0.05$). *O. pedicornis* were the dominant species in 5 regions, *O. taurus* were dominant in 2 regions, and *O. satoi* were dominant in 1 region ($p<0.05$). Statistical analysis: chi-square test: X_{24}=1852.682, p=0.0001.

Osmia species. These nests were established across 20 sites in South Korea (Table 1A).

Each trap nest comprised bundles containing 50 bamboo straw pieces, each measuring 15 cm in length and with an inner diameter of 7 mm. Trap nests were collected 30 and 90 days after their installation. This approach aimed to assess the occupancy rate of trap nests. Furthermore, this study identified the plant species from which *O.* spp. collected materials, a process undertaken during the nest-activity season spanning in 2022. The cocoons of *O.* spp. were carefully sorted using the method described by Maeta (1978).

Rate of trap nests used and altitude-latitude range of *Osmia* spp.

An exploration was conducted to determine the utilization rate of trap nests by *O.* spp., considering location, orientation, altitude, and geographical region. Female Osmia bees engage in nest construction within pre-existing cavities, establishing nests characterized by linear arrays of cocoons. Each cocoon is endowed with pollen and nectar that facilitate egg deposition. Adjacent cocoons are demarcated by mud partitions that serve to seal the completed nests (Torchio, 1985; Bosch, 1994). To assess trap nest occupancy rates of *O.* spp. at the selected sites, 381 trap nests were strategically positioned across 20 geographical regions in Korea from Feb. to Mar. in 2022.

The altitude stratification of the trap nests was delineated into five distinct categories: 0–199 m, 200–399 m, 400–599 m, 600–799 m, and > 800 m. The experimental protocol involved the deployment of diverse trap configurations in an apple orchard, as well as the controlled manipulation of residential structures and wall disassembly in Chungju and Jecheon (Korea). This encompassed two distinct types of nest traps: bamboo straw positioned on a single side and on both sides.

Collection and identification

Characteristics of cocoon and sex ratio

Mean cocoon count per tube for *O. pedicornis* and *O. corniformins*. Examination of regional variations. A geographical distribution map of *O. pedicornis* and *O. cornifrons* was generated using the Google Earth program and cross-checking the altitude and latitude. Furthermore, we analyzed the correlation between cocoon length and the soil diaphragm in *O. pedicornis* and *O. corniformis*, as per Maeta's study (1978).

We investigated the sex ratios of *O. pedicornis* and *O. cornifrons* across regions based on cocoon size and placement within the nesting tube by randomly selecting 10 cocoons per group, removing larvae, and observing horn-like projections or pale hair on the head shield. We also assessed the presence of pollen brushes (scopa) on the lower abdomen, classified and analyzed the final numbers, and determined the sex ratio, following the protocols of Maeta (1978) and Torchio and Tepedino (1980). Moreover, in distinct regions, we compared and investigated the size attributes (such as upper and lower dimensions and weight) of male and female cocoons of *O. cornifrons* using *O.* spp. for differentiation.

Statistical analysis

Statistical procedures were conducted utilizing the 'PASW 18' statistical software package (IBM SPSS Statistics version, 2009). To examine the cocoon mass and population size of *Osmia* spp. concerning the sampled regions, a one-way analysis of variance (ANOVA) was employed. Supplementary analyses included post-hoc assessments using Tukey's honest significant difference test, correlation analysis, and t-tests to delve deeper into the data.

Results

In this investigation, a cumulative count of 7,603 *O.* spp. was gathered across 1,894 panels. Among these, a meticulous categorization of 4,824 specimens extracted from 77 panels situated at altitudes ranging 40 - 290 m above ground level (a.g.l) revealed a varied collection spanning 13 distinct orders, as depicted in Fig. 2a and detailed in Table 1.

During an entomological survey across various regions of Korea, 7,603 cocoons were meticulously collected from February to March 2022. Among the cocoon samples, the collection rate of *O.* spp. was approximately 95.8%.

Based on the cocoon numbers following collection, differentiation of *O.* spp. among the four species (*O. cornifrons*, *O. pedicornis*, *O. taurus*, and *O. satoi*) was observed. Notably, the sequence of the highest to lowest collection occurred in the order of Gangwon Jeongseon > Danyang > Andong > Geochang, as detailed in Table 1(B). Further analysis revealed that *O. cornifrons* was the predominant species, with *O. pedicornis* dominating Jeongseon at 82.2%, *O. taurus* in Geochang at 34.7%, and *O. satoi* in Andong at 54.1% ($p<0.05$), as presented in Table 1 (B).

Assessing the percentage distribution of *O.* spp. across regions

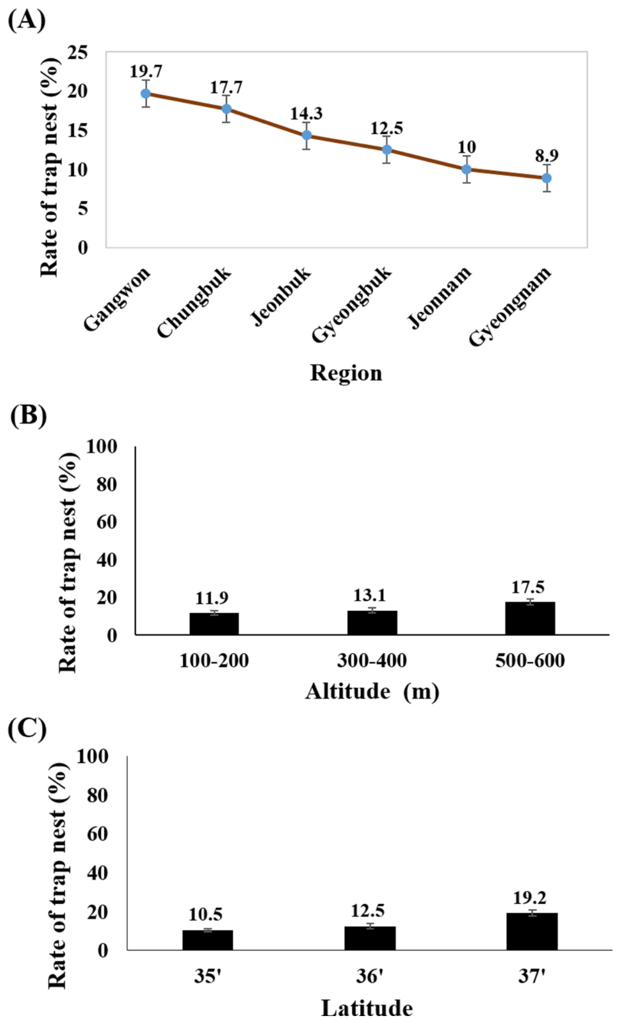
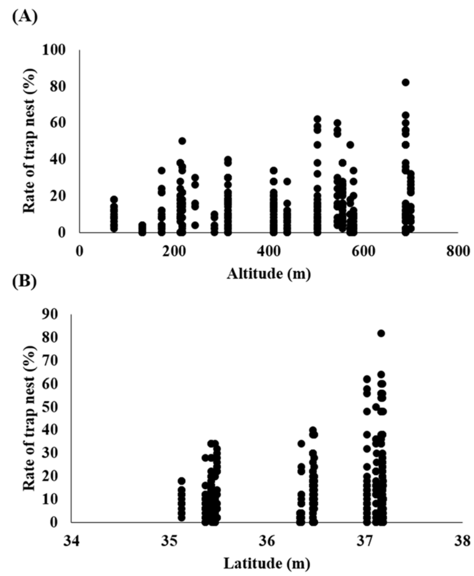


Fig. 1. Collection rate survey of *Osmia* spp. in different Regional Mountain area
(A) Rate of in trap nested by region, Statistical analysis: one-way ANOVA test $F_{5.359}$=6.112, P=0.024. Gangwon-do showed a higher rate of death than other regions (p<0.05) (B) Rate of in trap nested by altitude; Statistical analysis: one-way ANOVA test $F_{2,347}$=4.980, p=0.007. Altitude 100~199: Yeongwol Deulgol-gil/Kimsatgat-ro, Jecheon Worak-ro/Dojeon-ri, Cheondam 2-gil, Gurye Jungsan-ro, Sangju. 8 locations including Dugok-ri and Gumi 2-gil. Altitude 300~399: 1 place in Andong Neolmae-gil. Altitude 400~499: 3 places including Muneundan-ro in Yeongwol, Demisem 2-gil in Jinan, and Haepyeong-ri in Geochang. Altitude 500~599: 3 places including Yeongwol Beodeul-gil, Sogeumgang-ro, and Jinan Demisam 1-gil. Altitude above sea level × coverage ratio correlation analysis: R=0.191, p=0.0001. The rate of loss was high at an altitude of 400 meters higher (p<0.05) (C) Statistical analysis: one-way ANOVA test $F_{2,362}$=13.382, p=0.0001. The rate of nesting was high above 37 degrees north latitude (p<0.05)



	altitude above sea level	Latitude
Young's rate correlation coefficient	0.184	0.255
P	0.0001	0.0001

Fig. 2. Correlation analysis: Pearson correlation analysis. Altitude (A) and latitude (B) are correlated with the survival rate of *Osmia* spp. (A) rate of trap nest by altitude above sea level (rate correlation coefficient = 0.184, p=0.0001; (B) rate of trap nest (%) by latitude (rate correlation coefficient = 0.255, p=0.0001).

using the chi-square test (x_{24}=1852.682, p=0.0001) revealed that *O. pedicornis* was dominant in five regions, *O. taurus* in two, and *O. satoi* in one (p<0.05). Furthermore, regional disparities in *O.* spp. bee cocoon populations were explored using a chi-square test (x_{24}=1852.682, p=0.0001) in Table 1(C). This investigation revealed a different scenario in the Hapcheon region, in which only one species of *O. taurus* was identified. In the Sangju region, the investigation revealed that only two species, *O. pedicornis* and *O. satoi*, contributed 60% and 40%, respectively (Table 1C).

Among these species, *O. pedicornis* was the dominant species, accounting for 59.6%–76.4% of the specimens in the three locations. The average number of *O.* spp. cocoons varied across six locations. The number of cocoons per bamboo straw ranged from 7.6 to 8.5 for *O. cornifrons* and 6.8 to 7.1 for *O. pedicornis* on one side of the straw, while it was between 16.3 to 16.5 for *O. cornifrons* and 13.3 to 13.5 for *O. pedicornis* on both sides of the straw (Data not shown).

The influence of altitude and latitude range on bee percentage

The number of collected *O.* spp. displayed discernible discrepancies across various regions, with a significant variation in mean nest rates (assessed through a one-way ANOVA test, $F_{5.359}$=6.112, P=0.024). More specifically, the nest values revealed that the Gangwon-do region exhibited a higher species rate than the other regions, with the following percentages: Gangwon, 19.7%; Chungbuk, 17.7%; Jeonbuk, 14.3%; Gyeongbuk, 12.5%; Jeonnam, 10%, and Gyeongnam 8.9%. These differences were statistically significant (p<0.05) as shown in Fig. 1 (A).

The trap nesting collection rates of *O.* spp. varied across different regions, as shown in Fig. 1 (B). Specifically, the collection of trap nests encompassed three altitude ranges: Altitude 100-199, Altitude 300-399, Altitude 400-499, and Altitude 500-599. Notably, the results demonstrated collection rates of 11.9% for the altitude range of 100-200, 13.1% for the range of 300-400, and 17.5% for higher altitude ranges. This outcome highlighted a significant increase in Osmia bee presence at elevated altitudes, as evidenced by the results of One-way ANOVA ($F_{2,\ 347}$=4.980, p=0.007). Correlation analysis between the average altitude above sea level and the coverage ratio yielded a correlation coefficient of r=0.191 (p=0.0001), confirming a higher rate of Osmia bees at altitudes of 400 m or above, as shown in Fig. 1 (B).

Further exploration of latitude showed a statistically significant difference between the latitude range of 35-37 degrees, with Osmia bee rates being notably elevated above 37 °N (One-way ANOVA test $F_{2,\ 362}$=13.382, p=0.0001), as presented in Figs. 2 (A; B). Calculating the coefficient variation, altitude above sea level yielded a coefficient of 0.184 (p=0.0001), while latitude displayed a coefficient of 0.255 (p=0.0001).

The total number of *O.* spp. cocoons collected (*O. cornifrons*, *O. pedicornis*, *O. taurus*, and *O. satoi*) revealed distinct preferences for the altitude range. *O. pedicornis* and *O. cornifrons* predominantly occupied the 500–600-meter range, *O. taurus* favored the 400–599-meter range, and *O. satoi* thrived in the 300–499-meter range (p<0.05) (Table A and B).

Analysis of the ratio of *O.* spp. by altitude, as determined by the chi-square test (x_{12}=1258.516, p=0.0001), showed that *O. pedicornis* was mainly collected from 500 to 699 m, *O. cornifrons* from 600 to 699 m, *O. taurus* from 500 to 599 m, and *O. satoi* from 300 to 399 m (p<0.05).

Further statistical examination of the ratio of *O.* spp. by species and altitude using a chi-square test (x_{12}=1281.516, p=0.0001) revealed that *O. pedicornis* and *O. taurus* dominated at altitudes of 400-500 meters, whereas *O. satoi* was prevalence at 300-400 meters (p<0.05), as summarized in Table 2(C).

Discussion

The regional distribution patterns of *Osmia* spp., their natural adversaries, and rival species were investigated, with a particular focus on the occurrence of *O. pedicornis* in Yeongwol, Bonghwa, and Yecheon. This study encompassed a spectrum of species, including *O. cornifron*s, *O. taurus*, *O. satoi*, and *O. pedicornis* bees, with a total of four species identified by region. The findings pertaining to distribution ratios are listed in Table 1.

In the Jeongsun region, *O. pedicornis* was dominant, accounting for the highest proportion at 82.2%, whereas *O. pedicornis*, *O. taurus*, and *O. satoi* contributed 10.7%, 6.5%, and 0.6%, respectively. Within the same habitat, *O. cornifrons* accounted for 35.7% of the samples, with the highest distribution in Geochang. In another case, among the locations studied (Yoon *et al*., 2015), Jeongsun exhibited the most favorable results, with Osmia bee distribution rates of 11.1 ± 17.6% at 30 days and 23.2 ± 22.5% at 90 days.

In this research, altitude was categorized into 0–199 m, 200–399 m, 400–599 m, 600–799 m, and above 800 m. Interestingly, the altitude range of 600–799 m showed the highest distribution rate of Osmia bees, reaching 40.4 ± 3.9%, demonstrating a similar pattern of distribution rates as in previous studies In this investigation, the altitude range over 500-700 m represents the higher distribution of *Osmia* spp. except *O. satoi*. This suggests that higher altitudes are correlated with higher trap nesting rates.

In Korea, seven indigenous species belonging to the Osmia genus have been identified. *O. cornifrons* is distributed throughout all regions of Korea except for Jeonnam. Lee and Woo's research (1994) indicates that the bee primarily has 7 species (*O. imaii* Hirashima, *O. ishikawai* Hirashima, *O. satoi* Yasumatsu et Hirashima, *O. excavate* Alfken, *O. taurus* Smith, *O. cornifrons* (Radoszkowski), *O. pedicornis* Cockerell) which inhabit the central-southern areas of Gangwon, Gyeonggi, Chungbuk, Gyeongnam, and Jeonbuk.

According to another study by Kim *et al*. in 1994, *O. taurus* is documented as the dominant species in the regions of Gyeonggi and Gangwon, while *O. pedicornis* prevails in Chungbuk. Over three years, five species (*O. cornifrons, O, pedicornis, O. satoi, O. taurus,* and *O. jacoti*) were collected from 32 apple orchards throughout the country. Among these, *O. cornifrons* constituted 69.6% of the specimens, *O. pedicornis* accounted for 13.0%, and *O. taurus* represented 11.2%, as reported by Lee *et al*. in 2014.

Upon examining these five species, it was definitively estab-

Table 2. Summary of *Osmia* species (*O. cornfrons*, *O. pedicornis*, *O. taurus*, *O. satoi*) nesting in bamboo traps in the six (above the sea levels) collecting sites at different altitudes and latitudes.

(A) Rate of trap nesting cocoon by Altitude					
Altitude	***O. c.***	***O. p.***	***O. t.***	***O. s.***	**Total**
100-199 m	0	15	0	10	25
200-299 m	16	226	105	41	388
300-399 m	88	351	46	248	733
400-499 m	139	41	364	123	667
500-599 m	275	**2,199**	**523**	31	**3,028**
600-700 m	**705**	1,872	180	5	**2,762**
Average	1,223	4,704	1218	458	7,603
(B) Rate of trap nesting region by Altitude (%)					
Altitude	***O. c.***	***O. p.***	***O. t.***	***O. s.***	**Total**
100-199 m	0	0.3	0	2.2	0.3
200-299 m	1.3	4.8	8.6	9	5.1
300-399 m	7.2	7.5	3.8	**54.1**	9.6
400-499 m	11.4	0.9	29.9	26.9	8.8
500-599 m	22.5	**46.7**	**42.9**	6.8	**39.8**
600-700 m	**57.6**	**39.8**	14.8	1.1	**36.3**
Average	100	100	100	100	100
(C) Rate of trap nesting species by Altitude (%)					
Altitude	***O. c.***	***O. p.***	***O. t.***	***O. s.***	**Total**
100-199 m	0	**60**	0	40	100
200-299 m	4.1	**58.2**	27.1	10.6	100
300-399 m	12	**47.9**	6.3	**33.8**	100
400-499 m	20.8	**6.1**	**54.6**	18.4	100
500-599 m	9.1	**72.6**	17.3	1	100
600-700 m	25.5	**67.8**	6.5	0.2	100
Average	16.1	61.9	16	6	100

O. pedicornis and *O. corniforns* were mostly collected from 500 to 700 meters, *O. taurus* from 400 to 599 meters, and *O. satoi* from 300 to 499 meters (chi-square test: X_{12}=1258.516, p=0.0001). *O. pedicornis* mostly collected from 500 to 699 meters, *O. corniforns* from 600 to 699 meters, *O. taurus* from 500 to 599 meters, and *O satoi* from 300 to 399 meters (chi-square test: X_{12}=1258.516, p=0.0001).

lished, as reported by Lee *et al*. in 2002, that the distribution was in the order: *O. cornifrons, O, pedicornis, O. taurus, O. satoi,* and *O. benefica.* Concerning regional prevalence, *O. pedicornis* emerged as the dominant species in Gyeonggi, Gangwon, Chungbuk, and Gyeongbuk, whereas *O. cornifrons* assumed dominance in Gangwon.

Furthermore, as per the findings of Yoon *et al*. in 2016, the distribution rate of *O. pedicornis* in South Korea varies significantly by region, ranging from 59.6%–76.4%. This variability in distribution is attributed to factors such as variations in the number of traps deployed in each region from year to year, regional environmental changes, and fluctuations in the availability of food sources. These differences in distribution may lead to annual variations in species distribution.

Additionally, the distribution of *Osmia* species differs based on altitude. According to Lee *et al*., 2002 and Yoon *et al*., 2015,

Supplementary Table 1.

Region \ Date	Feb. ~ Mar. 2012		Feb. ~ Mar. 2022		Increased temperature (°C) after 10 years
	Lowest Tem.	Highest Tem.	Lowest Tem.	Highest Tem.	
Youngwol, Gangwon,	-5.9	8.2	-6.5	12.6	avg.1.3 ~ max. 4.4↑
Jeongsun, Gangwon,	-7.5	5.9	-8	10.9	avg.1.2 ~ max. 5.0↑
Jangsu, Jeonbuk,	-5.1	6.4	-6.1	12.9	avg.0.6 ~ max. 6.5↑
Andong, Gyungbuk	-7.2	5.2	-7.4	13.5	avg.1.0 ~ max. 8.3↑

the most extensive distribution occurs at altitudes exceeding 500–600 meters. These research findings indicate a pattern of distribution that closely resembles the results presented in this paper.

In 1978, Maeta *et al*. observed the prevalence of *O. cornifrons* in Japan. He noted that a species that could handle the cold was common in flat areas. *O. cornifrons* were most common in the rough landscapes of the south. Meanwhile, *O. taurus* were found in many places but were dominant only in the mountains. Interestingly, the survey results differ from those described by Maeta. Furthermore, it is evident that at higher latitudes, there is an expansion in the distribution of Osmia bees in this research.

According to Horne *et al*., 2017, assuming an average temperature decrease of 1°C per 150-meter increase in altitude, A-S relationships observed in the field differ from lab-based T-S responses. The maturity of an organism varies systematically with temperature and environmental conditions. Recent analyses that combined data from different studies have shown consistent patterns of size variation in different arthropod groups, suggesting that common underlying factors drive these size changes. Similar to how body size tends to change with increasing latitude, body size also tends to change with increasing altitude where temperature typically decreases.

In the comparative analysis of temperature variations during the trap installation periods of 2012 and 2022, specific locations in Korea exhibited average temperature increases: Yeongwol, by 1.3 °C, Jeongsun by 1.2 °C, Jangsu by 0.6 °C, and Andong by 1.0 °C; maximum temperature increases: Yeongwol, by 4.4 °C, Jeongsun by 5.0 °C, Jangsu by 6.5 °C, and Andong by 8.3 °C, as per data obtained from the Korea Meteorological Administration (Supplementary Table 1). Within the context of a research focused on the distribution survey of *Osmia* spp. conducted in 2012 (Yoon *et al*., 2015), it was ascertained that the in-nested rate within the altitude range of 600 to 799 m was 40.4 ± 3.9%. Examining the findings for the year 2022, the comprehensive trap in-nest rates were observed to be 10% at 100-200m, 13.1% at 300-400m, and 17.5% at 500-600m altitude. The overall average trap in-nest rate for 2022 was less than 20%. These outcomes imply a discernible reduction in the distribution of the species, indicating a 10-year decline attributed to the rise in temperature caused by global warming.

Research has been conducted to investigate the ethological patterns of *O. cornifrons* in association with temperature fluctuations and its reproductive status, as outlined by Lee *et al*. in 2021. Upon scrutinizing the behavioral traits of *O. cornifrons* amid substantial temperature variations in April and consistent temperatures in May, it was determined that the pollination activity and reproductive efficiency of *O. cornifrons* experienced enhancement linked to the apple cultivar in May, characterized by limited temperature fluctuations (Lee *et al*., 2021). This observation was validated an analysis of meteorological conditions and nesting behavior rates. As a result, it is hypothesized that the temperature variance among fruit trees can function as an indicative parameter for the dynamics of pollen vectors.

The mason bee, *Osmia* spp., is a solitary bee that nests in cavities and is primarily used to pollinate apple trees in South Korea. To better understand their characteristics for effective agricultural pollination, a study was conducted in 2022 to examine their distribution, number of cocoons per straw, sex ratios, and cocoon traits across different locations. Four Osmia species, *O. cornifrons*, *O. pedicornis*, *O. taurus*, and *O. satoi*, were collected from six regions at varying altitudes.

We studied the distribution of mason bees (*O. pedicornis*, *O. cornifrons*, *O. taurus*, and *O. satoi*) and examined the species numbers and ratios in different regions, latitudes, and altitudes. Mason bees are a diverse group of bees, similar to many other bees. We checked whether bee species richness was related to environmental factors, such as high-low, altitude, and latitude. *O. pedicornis* had the highest species richness and was found between latitudes 35° and 37° at altitudes of 500-600m in the north and south.

According to Vaudo *et al.* (2020), *O. cornifrons* frequently collects pollen of East Asian origin and readily gathers pollen from novel species within its phylogenetic family, aiding in the establishment of these pollinators. This phylogenetic inclination underscores the effectiveness of *O. cornifrons* in pollinating a diverse array of Rosaceae crops originating from different geographical regions. Furthermore, these results suggest that non-native plants spread around the world and might help their pollinators become established in new habitats. The utilization of pollen by *Osmia* bees escalates in response to the abundance of pollen resources within their nesting habitats. *Osmia* bees have a propensity to preferentially exploit nearby pollen sources when plant species hosting such sources are plentiful; conversely, they tend to resort to more remote pollen sources when local options are scarce (Zurbuchen *et al*., 2010).

A decrease in provisioning activity during specific seasons has been noted in various *Osmia* species, and this phenomenon has been linked to diminished foraging capabilities in aging female bees and/or a decrease in food resources available throughout the nesting period (Torchio and Tepedino, 1980). Similar seasonal decreases in provisioning activity have been recorded in other *Osmia* species that nested in controlled greenhouse environments, where floral resources were maintained at consistent levels (Tepedino and Torchio 1982; Frohlich and Tepedino 1986, Sugiura and Meata 1989).

Reports have shown that Pollinator populations, particularly those of mason bees, are decreasing worldwide. This has raised concerns regarding the continuation of pollination processes. While we understand the local reasons for bee decline and suggest ways to help at the landscape level, we have not explored the threats to bee diversity at the regional and high-latitude levels.

The study demonstrated a robust correlation between cocoon mass and the combined weight of the provisions and post-wintering adult individuals for *O.* spp. Furthermore, the product of cocoon length and width is a reliable proxy for estimating production costs in *O. cornuta*. This parameter is readily measurable and, in contrast to adult body mass, exhibits consistent values from cocoon formation to emergence. Nevertheless, it's worth noting that in certain bee species, adult body weight remains a suitable indicator for assessing the production costs associated with offspring (Bosch and Vicens 2002).

The seasonal decline in the mass of an individual food provision is frequently linked to a reduction in the proportion of female offspring, attributable to the greater body mass of female progeny (Frohlich and Tepedino 1986; Bosch and Vicens, 2005). Elevated temperatures during the later phase of nesting may additionally enhance the foraging behavior of *O. cornifrons* (McKinney and Park, 2012). Consequently, the offspring produced during the spring within this later nesting period tend to exhibit diminished body sizes, potentially leading to increased mortality in winters (Tepedino and Torchio, 1982; Bosch 2008; Sheffield *et al*., 2008) and reduced efficacy as pollinators (Jauker *et al*., 2016). Hence, environmental factors such as temperature and illumination are relevant to foraging efficiency (Nagamitsu *et al*., 2018).

In this study, we affirmed the elevation and geographical latitude at which *Osmia* spp. exhibits its most extensive distribution within South Korea. Furthermore, for *O. cornifrons* and *O. pedicornis*, correlation analysis suggested that the rate of emergence is positively correlated with the cocoon's weight.

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