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Ecological traits and distribution patterns of *Osmia* spp. in different regions and altitudes in South Korea

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Abstract

Solitary bees, such as *Osmia cornifrons*, *O. pedicornis*, *O. satoi*, and *O. taurus* (Hymenoptera: Megachilidae), have the potential for cost-effective and sustainable pollination, necessitating a comprehensive understanding of their ecological traits to implement effective fertilization strategies for various crops. This study investigated the nesting rate of *Osmia* spp. in different regions and altitudes, using various trap types, and found that the highest nesting rate occurred at altitudes of 300–399 m a.s.l. and showing a preference for bamboo-type traps, with the Andong region having the highest nesting rate overall, indicating the influence of altitude, habitat area, and trap type on the density of *Osmia* spp. nests. The distribution and diversity of the four *Osmia* spp. in different regions and altitudes revealed variations in their occurrence, with *O. pedicornis* having the broadest distribution rate, particularly at altitudes above 300 m a.s.l.. The present study found significant differences between species in the cocoon masses of *O. cornifrons*, *O. pedicornis*, and *O. taurus*, with region and altitude influencing the masses of each species too.

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Introduction

Currently, bees (Hymenoptera: Apoidea: Apidae) are the insect family that exhibits the highest rate of crop pollination, encompassing a vast global count of approximately 16,325 known species (Michener, 2007). Bees are essential pollinators and effectively facilitate the pollination of over 400 crops worldwide (James and Pitts-Singer, 2008). Honeybees and mason bees (Megachilidae), both of which possess potent venom attributes, are used to pollinate specific crops (Free, 1993; Deg and Kammer, 2001).

Solitary bees possess distinctive physiological characteristics and complete a single life cycle per year (univoultine) without the presence of queen bees, worker bees, organized colonies, beeswax, or stored honey. Instead, they lay eggs that metamorphose into adults within protective cocoons during autumn and then hibernate throughout the winter season (Bosch and Kemp, 2010; Lee *et al*., 2016a).

The mason bee genus *Osmia* encompasses approximately 319 species in the “Osmia group”, of which only 22 are *Osmia* sensu stricto (true Osmia) (Michener, 2007). In the 1960s, *O. cornifrons*, commonly known as horn shear, was initially used as a pollinator in Japanese apple orchards (Yamada *et al*., 1971). Subsequently, *O. cornuta* and *O. bicornis* were established as effective pollinators in European regions (Bosch, 1994; Krunic and Stanisavljevic, 2006), whereas *O. ribifloris* was specifically

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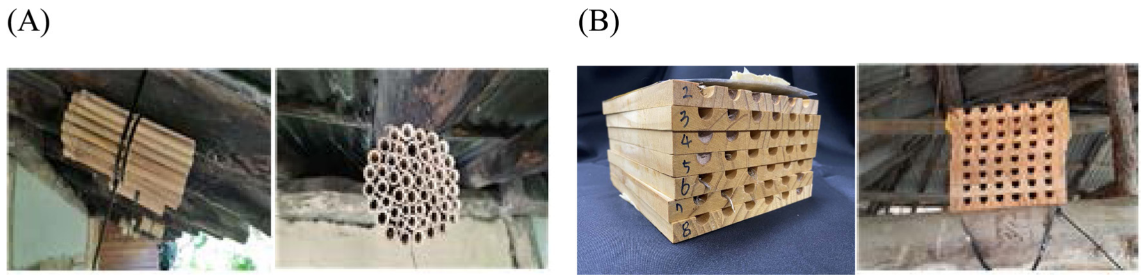


Fig. 1. Trap types for *Osmia* spp. (A) bamboo trap, comprised a bundle of 50 bamboo tubes (B) apartment type trap, 48 holes in total, organized in 8 rows each row having 6 holes.

employed as a pollinator for blueberries (Sampson and Cane, 2000).

In particular, utilizing *O. cornifrons* for blueberry pollination has proved to be a more economically viable and sustainable option compared to the use of commercial bumblebees and honeybees. The deployment of bumblebees necessitates the acquisition of hives, incurring costs ranging from $1,100 to $2,200 per season. Moreover, bumblebees do not offer propagation potential for future pollination endeavors. In comparison, renting three honeybee hives for a 6-week period costs $1,260. In light of these figures, O. cornifrons emerges as a more cost-effective alternative, presenting a promising solution for blueberry pollination while ensuring sustainable pollination practices (West and McCutcheon, 2009). In South Korea, the introduction of *Osmia* spp. for pollination purposes occurred in 1992, after they were brought in from Japan. They were initially released in Cheongsong-gun, Gyeongsangbuk-do, South Korea. Subsequently, they gradually became more widespread and were mainly adopted by local research centers located in areas specializing in apple farming until the early 2000s (Lee *et al*., 2010).

In South Korea, there is a group of seven recognized species of *Osmia*, with the primary research focus being on *O. cornifrons*, *O. pedicornis*, *O. satoi*, and *O. taurus* (Lee *et al*., 2002). Among these four species, *O. cornifrons*, in particular, is recognized for its remarkable pollinator effectiveness (Matsumoto *et al*., 2009), with each bee type exhibiting distinct ecological and physiological characteristics (Lee *et al*., 2016a, 2021; Yoon *et al*., 2015).

To ensure the successful pollination of various crop types, it is imperative to comprehensively understand the ecological characteristics of these four *Osmia* spp. Effective fertilization strategies can be implemented for each crop type by classifying each species according to their specific attributes. The primary objective of this study was therefore to ascertain the geographical distribution and ecological attributes of cocoons of these four species. Because there remains a dearth of knowledge regarding the intricacies of their nesting habits, it is crucial to acquire a detailed understanding of *Osmia* spp. nesting habits to enhance their pollination efficiency within agricultural settings.

Materials and Methods

Setting bait traps to attract *Osmia* spp. to investigate the nesting rate

In 2021, as part of an experimental study on insects, traps were strategically set up in 16 locations across nine cities and counties in six provinces in South Korea. The selected regions included Yeongwol and Jungsun in Gangwon-do, Jecheon in Chungcheongbuk-do, Sangju and Andong in Gyeongsangbuk-do, Jinan and Imsil in Jeollabuk-do, Gurye in Jeollanam-do, and Geochang in Gyeongsangnam-do. The location where *Osmia* spp. collected was recorded, and we verified the accuracy of the altitude and latitude by cross-referencing using Google Earth (Table 1).

For the research project, the investigators utilized two distinct trap types: the A-type trap comprised a bundle of 50 bamboo tubes, with each tube measuring 15 cm in length and featuring a diameter of 7 mm (¢ =7 mm), with bundles having sides of 33.2 cm (Fig. 1A). The B-type trap is an apartment-style trap commonly used in the United States. The B-type trap measured 15 cm wide and 14 cm long, with 48 holes organized in eight rows, with each row having six holes. Each hole in the B-type trap had a diameter of 1 cm (¢ = 1 cm), a length of 14.2 cm, and a hole depth of 6 cm (Fig. 1B).

For optimal trap placement, the traps were installed indoors or on the eaves of man-made structures to ensure minimal interference from rain or wind. The trapping process occurred

Table 1. The rate of trap-in nested by types and different regions

Collected locations		Latitude and longitude	Altitude (m)	The rate of trap-in by types of trap nests (%)		Total rate of trap-in nested (%)
				A	B	
Gangwon	Yeongwol Deulgol-gil	37°11′41″N, 128°22′53″E	217	9	0.5	6.7
	Yeongwol Kimsatgat-ro	37°05′59″N, 128°36′14″E	292	9.6	1	8
	Jeongsun Muneundan-ro	37°16′04″N, 128°44′33″E	435	14.3	0.2	11
	Jeongsun Beodenl-gil	37°18′46″N, 128°48′58″E	555	33.3	4.6	25.1
	Jeongsun Sogeum-river-ro	37°18′32″N, 128°48′01″E	541	9.6	2.1	7.2
Chungbuk	Jechon Wolac-ro	36°56′36″N, 128°13′19″E	168	5.2	2.1	5
	Jechon Dojeon-ri	36°54′08″N, 128°07′37″E	199	14.4	0	14.4
Jeonbuk	Jinan Demiseam-1-gil	35°38′45″N, 127°26′54″E	510	17.8	2.1	15.7
	Jinan Demiseam-2-gil	35°38′43″N, 127°26′57″E	494	13.5	0	13.5
	Imsil Cheondam-2-gil	35°28′32″N, 127°10′24″E	128	8.7	2.1	7.1
Jeonnam	Gure Sadong-gil	35°13′10″N, 127°25′44″E	245			0
	Gure Jungsan-ro	35°09′40″N, 127°29′48″E	110	2.8	0	2.7
Gyungbuk	Sangju Dugok-ri	36°34′06″N, 128°04′22″E	133	3.2	8.3	3.6
	Sangju Gumi-2-gil	36°35′21″N, 128°05′15″E	173	4.8	11.5	5.4
	Andong Neolmae-gil	36°47′20″N, 128°51′12″E	313	33.9	32.3	33.8
Gyungnam	Geochang Haepyung-ri	35°46′13″N, 127°59′04″E	465	8.6	0	7

for approximately 15 d, starting from early until the end of June, coinciding with the nesting activity period of the *Osmia* bees. After this period, the traps were collected and investigated to determine the trap-in nested rate based on region, altitude, habitat, and trap type. The ‘in-nested rate’ calculated as a discriminant between fully blocked, half blocked or unblocked entrances of bamboo traps, and expressed the percentage of successful nesting within a set of 50 bundles (Lee *et al*., 2014).

Trap occupancy and mass of *Osmia* spp. relative to regional altitude

This study focused on assessing the average number of cocoons per bait trap for four *Osmia* spp.: *O. cornifrons*, *O. pedicornis*, *O. satoi*, and *O. taurus*. This study aimed to investigate the influence of region and altitude on cocoon populations and cocoon masses. We also confirmed the regional distribution of each species.

To further characterize the cocoons, they were classified based on their size and location within the traps, thereby facilitating the differentiation between male and female cocoons. Cocoon weights were measured using an electronic balance (SBC31, Scaltec Germany). The width of the molted head and body length were measured using the HySCALER software for image analysis (HySCALER software; version 1.4; Cisvision, Korea).

Mass of adult *Osmia* spp. individuals in various regions

To ascertain the regional distribution of *Osmia* spp., bait traps were disassembled to collect *Osmia* spp. cocoons. The classification process involved considering the shape, color, and size of the cocoon, as well as the shape and color of the excrement, following Maeta's identification method (1978). After examining ten cocoons of each type following molting, the presence of imagos was confirmed. The final identification of adults was based on morphological characteristics, such as the body length, head shape, and hair color, as described by Lee and Woo (1994) and Kwon and Huh (1995) for Korean *Osmia* spp.. Subsequently, the mass of each morphologically identified specimen was determined, as above, considering their respective region of origin.

Statistical analysis

Statistical analyses were performed using the 'PASW 18' statistical software package (IBM SPSS Statistics version, 2009). One-way analysis of variance (ANOVA) was used to analyze the cocoon mass and population size of *Osmia* spp. in relation to the sampled regions. For post-hoc tests, Tukey's honest significant difference test, correlation analysis, and t-tests were used to further investigate the data.

Results and Discussion

In-nested rate of *Osmia* spp. by region, trap type, and altitude

After investigating the nested rate of *Osmia* spp., considering factors such as installation area, altitude, place, and trap types, data were collected from six provinces, nine cities, and counties across the country. Table 1 shows the differences in nested rates among the regions.

Data collection for this paper was conducted on specific dates in June 2021: June 24–25 in Gangwon, June 28–29 in Chungbuk and Gyeongbuk, June 25 in Jeonnam, and June 22 in Gyeongnam. Nationwide communication data were collected at the end of June and sorted by region. The trap nesting rate was thoroughly investigated for each trap type.

The trap nested range varied between the different provinces, ranging from 2.7% at Jeonnam to 19.0% at Gyungbuk, where it was significantly higher any of the other sites (One-way ANOVA, $F_{5,326} = 6.434$, $p = 0.0001$) (Fig. 2). Remarkably, irrespective of the region and altitude, the bamboo-type trap (A-type) exhibited an in-nested rate that was over four times higher than that of the apartment-type lure trap (B-type) (T-test, $t_{1,330} = 3.777$, $p = 0.0001$) (Table 1, Fig. 3).

This study revealed that at altitudes of 100–199 m a.s.l., the in-nested rate was approximately 5.5%, while at 300–399 m a.s.l. it increased significantly to 33.7% (One-way ANOVA, $t_{4,327} = 27.144$, $p = 0.0001$). At altitudes of 400–499 m a.s.l. and 500–599 m a.s.l., the in-nested rates were approximately 9.5% and 16.2%, respectively. Notably, the altitude range of 300–399 m a.s.l. showed the highest trap nesting rate (Fig. 4).

The density of *Osmia* spp. was also the highest (33.8%) at altitudes above 300 m a.s.l., indicating the important ($p < 0.0001$) influence of altitude on the density of *Osmia* spp. These results

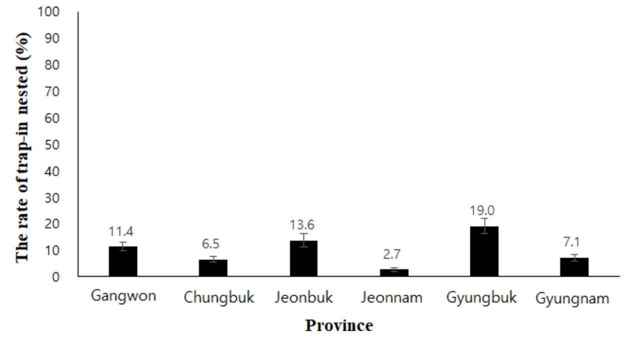
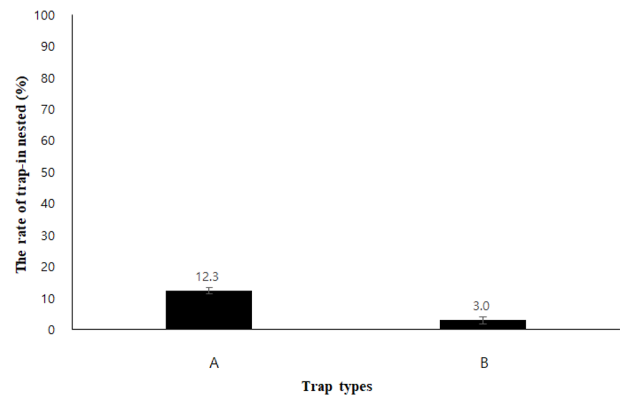


Fig. 2. The *Osmia* spp. rate of trap-in nested by different regions in South Korea (Gangwon, Chungbuk, Jeonbuk, Jeonnam, Gyungbuk, and Gyungnam). This table discovered different trap-in nested rates in distinct provinces, where Gangwon had an approximately 11.4% rate, Chungbuk at 6.5%, Jeonbuk at 13.6%, Jeonnam at 2.7%, Gyungbuk at 19.0%, and Gyungnam at 7.1%. Particularly noteworthy was Gyungbuk, which exhibited the highest in-nested rate among the provinces (as determined by a one-way ANOVA test, F5.326=6.434, p=0.0001).



Type A: bamboo trap, Trap B: Apartment trap

Fig. 3. The *Osmia* spp. cocoon rate of trap-in nested by trap types. Regardless of the region and altitude, the bamboo-style trap (A type) demonstrated an in-nested rate more than four times higher than the apartment-style trap (B type) (T-test, t_{330}=3.777, p=0.0001).

confirmed that the nesting rate of *Osmia* spp. was influenced by factors such as habitat area, environment, and altitude.

In-nested rate of *Osmia* spp. by region

Four *Osmia* spp. were collected from nine cities and counties across six provinces of the country. This study aimed to investigate the distribution of *Osmia* spp. by region (Fig. 2). The data indicated a nested rate of the four species, considering all nine regions. The number of cocoons of each *Osmia* spp. collected from different regions is presented in Table 1.

Lee *et al.* (2021) reported on the presence of *Osmia* spp. in

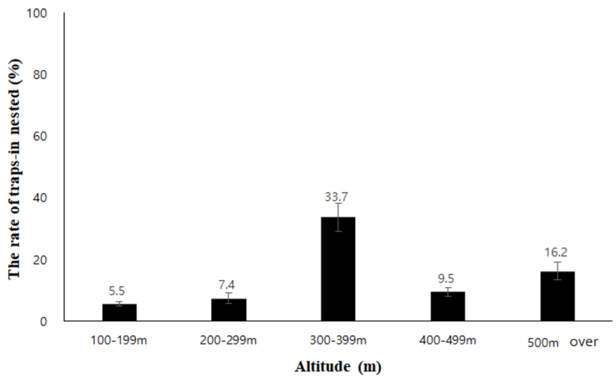


Fig. 4. The *Osmia* spp. cocoon rate of trap-in nested by altitude (100-199, 200-299, 300-399, 400-499, and 500 m over). Concerning the in-nested rate based on altitude, the research findings indicated that at altitudes ranging from 100-199m, the coverage rate was around 5.5%, but at 300-399m, it notably increased to 33.7%. At altitudes of 400-499m and 500-599m, the coverage rates were approximately 9.5% and 16.2%, respectively. Notably, the altitude range of 300-399m exhibited the highest in-nested rate (one-way ANOVA test, $t_{4,327}$=27.144, p=0.0001).

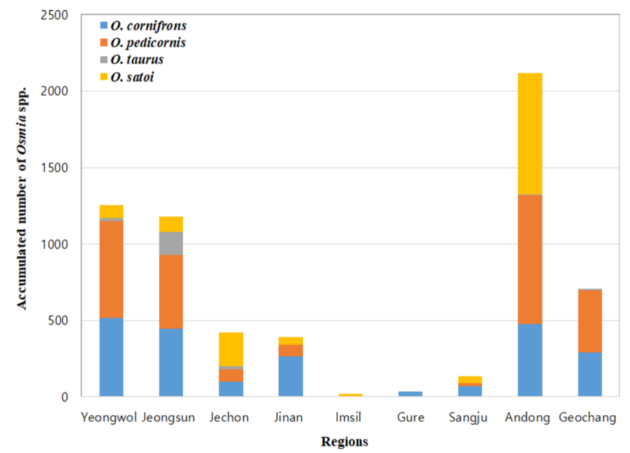


Fig. 5. The accumulated number of *Osmia* spp. (*O. cornifrons, O. pedicornis, O. taurus, O. satoi*) by regions. The distribution of *O. cornifrons* cocoons was highest in the Gangwon area, with 516 in Yeongwol, 444 in Jeongseon, 102 in Jecheon, 263 in Jinan, 35 in Gurye, 70 in Sangju, 475 in Andong, and 292 in Geochang. *O. pedicornis* cocoons showed the highest distribution in Gangwon-do, followed by Gyeongbuk and Gyeongnam, with 632 in Yeongwol, 483 in Jeongseon, 79 in Jecheon, 80 in Jinan, 20 in Sangju, 843 in Andong, and 405 in Geochang. For *O. taurus* cocoons, the highest distribution was in Gangwon-do, with 22 in Yeongwol, 150 in Jeongseon, 17 in Jecheon, 9 in Andong, and 8 in Geochang. Regarding *O. satoi* cocoons, Andong exhibited the highest distribution, with 82 in Yeongwol, 104 in Jeongseon, 225 in Jecheon, 18 in Imsil, 48 in Jinan, 47 in Sangju, and 792 in Andong (chi-square test: x_{24}=1852.682, p=0.0001).

Yeongwol, Yecheon, and Bonghwa. Their findings revealed that *O. pedicornis* and *O. cornifrons* constituted 82.6–90.1% of the four *Osmia* spp. collected in these areas, with a notably high occurrence in the Yeongdong region (near Yecheon in Gyeongbuk Province). Conversely, *O. taurus* were rarely collected across the entire region. *O. satoi* was only found in Yeongwol and Yecheon, with the highest frequency recorded in Andong (Fig. 5).

The total number of cocoons for all *Osmia* spp. in the different regions was as follows: Yeongwol (*n* = 1252), Jungsun (*n* = 1181), Andong (*n* = 2119), Jecheon (*n* = 423), Imsil (*n* = 18), Jinan (*n* = 391), Gurye (*n* = 35), Sangju (*n* = 137), and Geochang (*n* = 705). Andong had the highest abundance of *O. pedicornis*, followed by Yeongwol and Jungsun. Both Yeongwol and Jungsun are situated at altitudes ranging from 400–599 m a.s.l., with an average nested rate of 25.8%. Andong is located at an altitude ranging from 300 m to 399 m a.s.l.. These results indicate that the distribution and diversity of *Osmia* spp. vary depending on the season and collection area. Considering the distribution of *O. pedicornis* by region, it was observed that populations of all four *Osmia* sp. exceeded 100 in Jungsun (*O. c.* 444; *O. p.* 483; *O. t.* 150; *O. s.* 104) (Fig. 5).

Concerning the altitudinal distribution of the four species, most individuals occurred above 300 m a.s.l., with 86.25% at 300 m a.s.l. or higher and 64.63% at 400 m a.s.l. or higher. The occurrence of *O. cornifrons* was also abundant at 90.48% at 300 m or higher, and 57.32% at 400 m or higher, whereas 87.38% of the *O. taurus* were sampled at 400 m a.s.l. and higher. For *O. satoi*, 77.51% of the individuals were sampled at 300 m a.s.l. or higher. In conclusion, this study demonstrated the diversity of species in different regions, with *O. pedicornis* being the most widely distributed, occurring at 40.60% of the sites (Fig. 6).

These findings indicate that various species of *Osmia* bees were found in the Republic of Korea between 2013 and 2014, and that our results were consistent with this previous research. During that period, *O. pedicornis* was identified as the most prevalent species, making up 59.6% of the total (Yoon *et al*., 2015).

Regional variation in mass of *Osmia* spp.

The mass of *O.* spp. cocoon results for the four species (*O. cornifrons*, *O. pedicornis*, *O. taurus*, and *O. satoi*) were analyzed using one-way ANOVA tests. We found a significant difference between sites for *O. cornifrons* ($F_{3,41}$ = 30.070, *p* = 0.0001).

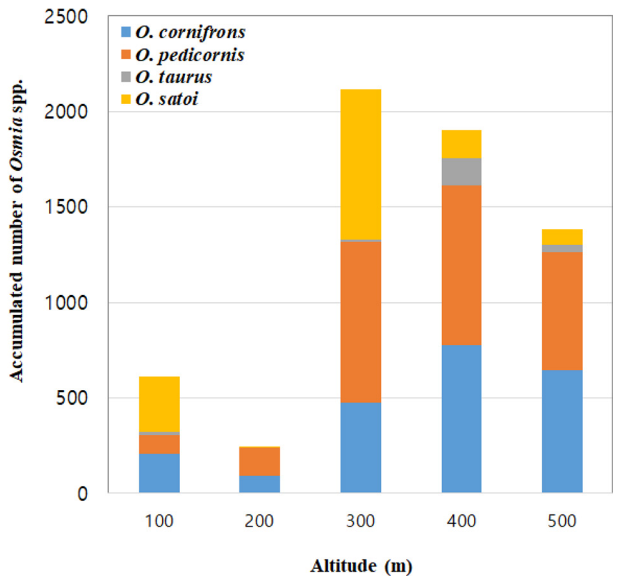


Fig. 6. The accumulated number of collected *Osmia* spp. by altitude (m). The Figures presents weight data of *Osmia* spp. at various altitudes. At 300m altitude, the weights of *O. cornifrons*, *O. pedicornis*, and *O. taurus* showed a significant increase compared to other altitudes. At 500m altitude, *O. cornifrons* exhibited the highest weight, while *O. satoi* showed the lowest weight (chi-square test: x_{12}=1281.516, p=0.0001).

Fig. 7 present cocoon weight data of *Osmia* spp. in different regions. *O. cornifrons* showed the highest weight in Andong, while *O. pedicornis* exhibited the highest weight in Andong as well. *O. taurus* displayed the highest weight in Andong, and *O. satoi* showed the highest weight in Andong and the lowest in Geonchang. The statistical analysis was conducted using one-way ANOVA and Welch's ANOVA tests (Bee species: one-way ANOVA test $F_{3,41}$=30.070, p=0.0001; *O. cornifrons*: $F_{3,2535}$=55.721, p=0.0001; *O. pedicornis*: Welch's $F_{7,383.819}$, p=0.0001, *O. taurus*: Welch's $F_{6,137.075}$, p=0.0001; *O. satoi*: $F_{4,201}$=2.764, p=0.029; Total $F_{8,6234}$=32.472, p=0.0001). These results indicate significant differences in the weight among the different species and that regions influence the weight of *O. cornifrons*, *O. pedicornis*, and *O. taurus*.

Effect of altitude on the mass of *Osmia* spp.

The weight data of *O.* spp. cocoon were as followed corresponding to different altitudes (m).

O. cornifrons: 0.072 ± 0.023 g (100 m), 0.083 ± 0.027 g (200 m), 0.092 ± 0.026 g (300 m), 0.080 ± 0.027 g (400 m), 0.076 ± 0.027 g (500 m) (Fig. 8A).

O. pedicornis: 0.039 ± 0.011 g (100 m), 0.038 ± 0.014 g (200 m), 0.062 ± 0.021 g (300 m), 0.047 ± 0.021 g (400 m), 0.056 ± 0.024 g (500 m) (Fig. 8B)

O. taurus: 0.023 ± 0.012 g (100 m), 0.042 ± 0.011 g (200 m), 0.041 ± 0.018 g (300 m), 0.032 ± 0.016 g (400 m), 0.034 ± 0.011 g (500 m) (Fig. 8C)

O. satoi: 0.042 ± 0.013 g (100 m), not specified in 200 m. 0.052 ± 0.009 g (300 m), 0.043 ± 0.016 g (400 m), 0.035 ± 0.008 g (500 m) (Fig. 8D)

It displays the weight data of O. spp. corresponding to different altitudes. At 100m altitude, the weights were as follows: *O. cornifrons* 0.072 ± 0.023 g (d), *O. pedicornis* 0.039 ± 0.011 g (d), *O. taurus* 0.023 ± 0.012 g (b), and *O. satoi* 0.042 ± 0.013 g (ab). Meanwhile, at 200m altitude, the weights were: *O. cornifrons* 0.083 ± 0.027 g (b), *O. pedicornis* 0.038 ± 0.014 g (d), and *O. taurus* 0.042 ± 0.011 g (a), and *O. satoi* (not specified).

At an altitude of 300m, the weights were as follows: *O. cornifrons* 0.092 ± 0.026 g (a), *O. pedicornis* 0.062 ± 0.021 g (a), *O. taurus* 0.041 ± 0.018 g (a), and *O. satoi* (0.052 ± 0.009). It was noted that the weight significantly increased at 300m compared to other altitudes.

At 400m altitude, the weights were: *O. cornifrons* 0.080 ± 0.027 g (b), *O. pedicornis* 0.047 ± 0.021 g (c), *O. taurus* 0.032 ± 0.016 g (ab), and *O. satoi* 0.043 ± 0.016 g (ab).

At 500m altitude, the weights were: *O. cornifrons* 0.076 ± 0.027 g (cd), *O. pedicornis* 0.056 ± 0.024 g (b), *O. taurus* 0.034 ± 0.011 g (ab), *O. satoi* 0.035 ± 0.008 g (b), with a total sum of 0.063 ± 0.028 g (ab).

When examining the distribution of *Osmia* bees based on altitude in Korea in 2013 and 2014, we found that over 40.4% of the bees were found at elevations ranging from 600 to 799 meters (Yoon *et al.*, 2015). According to the Korean Meteorological Administration, the mean temperature in Yeongwol, Gangwon-do, rose 0.8 °C from 2011 to 2021. In these findings, it becomes imperative to investigate this phenomenon, as alterations in the vegetation composition of *Osmia* habitats could potentially influence the population, genetic, and geographical dispersion of each species, contingent upon the altitude gradient. Furthermore, food scarcity can have a dual impact on the reproductive success of *Osmia* species. Firstly, it can directly reduce reproductive success through nutrient limitation (Yoon *et al.,* 2015). Secondly,

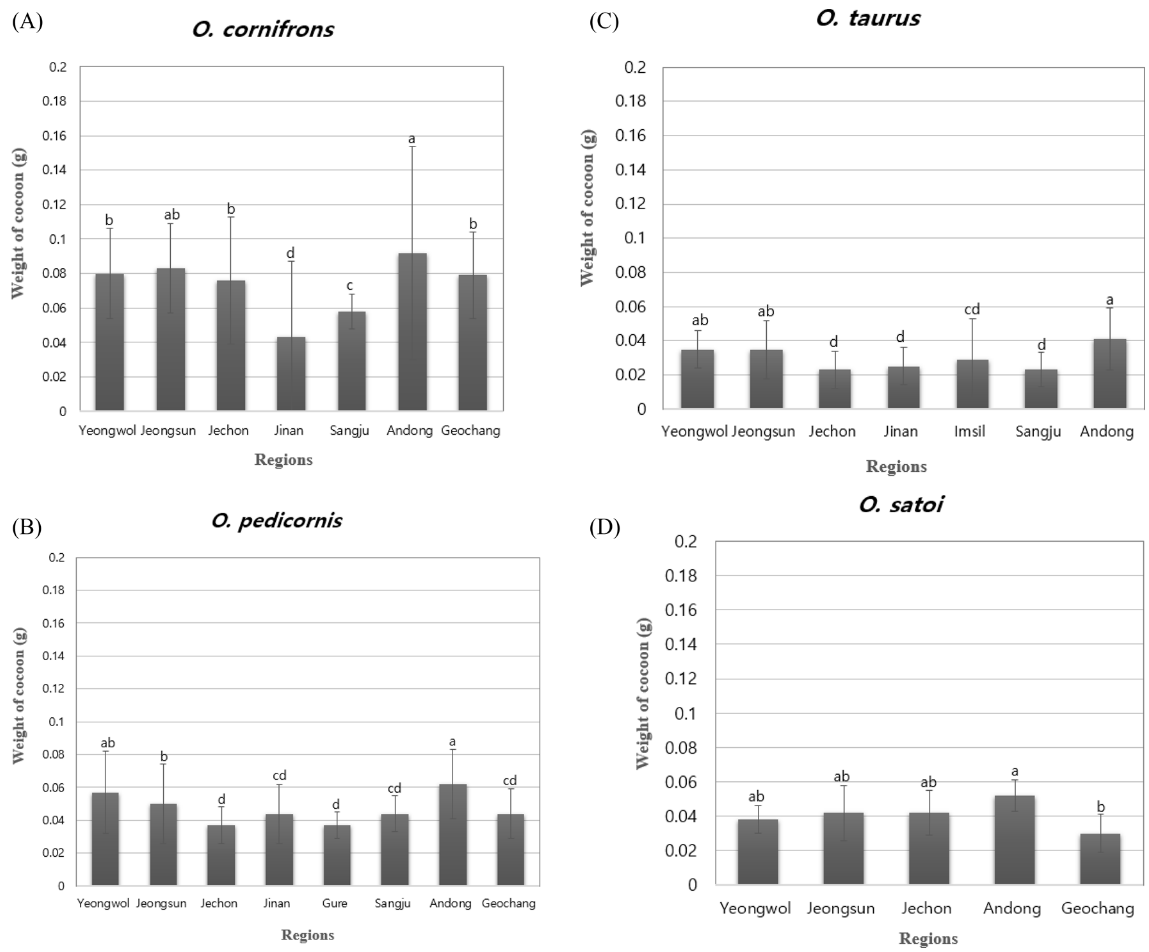


Fig. 7. The weight of collected *Osmia* spp. coccoon by region (A) *O. cornifrons*, (B) *O. pedicornis*, (C) *O. taurus*, (D) *O. satoi.* The Figures presents weight data of *Osmia* spp. in different regions. *O. cornifrons* showed the highest weight in Andong, while *O. pedicornis* exhibited the highest weight in Andong as well. *O. taurus* displayed the highest weight in Andong, and *O. satoi* showed the highest weight in Andong and the lowest in Geonchang. The statistical analysis was conducted using one-way ANOVA and Welch's ANOVA tests (Bee species: one-way ANOVA test $F_{3,41}$=30.070, p=0.0001; *O. cornifrons*: $F_{3,2535}$=55.721, p=0.0001; *O. pedicornis*: Welch's $F_{7,383.819}$, p=0.0001, *O. taurus*: Welch's $F_{6,137.075}$, p=0.0001; *O. satoi*: $F_{4,201}$=2.764, p=0.029; Total $F_{8,6234}$=32.472, p=0.0001).

in cases of food limitation, the vulnerability to parasitic infestations tends to escalate (Goodell, 2003). Despite the significance and biodiversity of the available plant resources, several bee species face threats due to the destruction and fragmentation of their nesting environments (Kamel *et al*., 2007).

To ensure the effective utilization of *Osmia* spp. in agricultural settings, there is a need for comprehensive research into their physiological and ecological characteristics, particularly focusing on their fecundity and overwintering habits. Additionally, floral preferences vary among different *Osmia* spp., and the pollen harvesting rate can be influenced by the sex ratio. Therefore, it is crucial to develop guidelines for releasing *Osmia* spp. based on the sex ratio and number of female bees (Lee *et al*., 2016b).

To lay the groundwork for this investigation, the present study aimed to examine the distribution ratio and number of cocoons of *Osmia* spp. in relation to the altitude of each collection area, with the goal of facilitating the successful dissemination of these species.

Offspring survival plays a vital role in sustaining bee populations and providing essential pollination services. Parasitism and disease can have adverse effects, leading to reduced offspring survival and affecting population dynamics (Ulbrich and Seidelmann, 2001).

Meanwhile, cocoon sizes, including their length and width, offer a reliable estimate of the production costs for *Osmia* spp. This metric is easily obtainable and, unlike body mass, remains consistent from

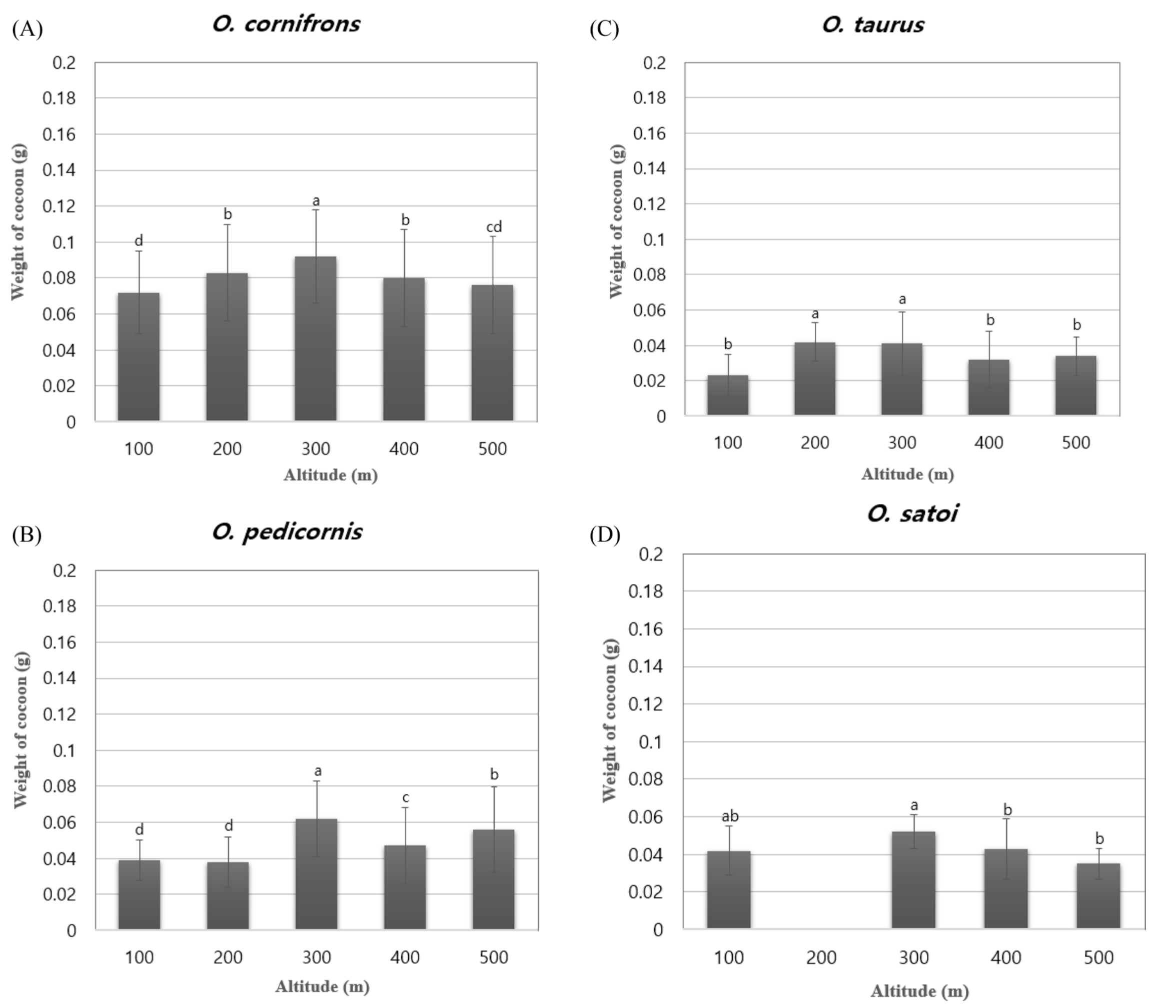


Fig. 8. The weight of the *O.* spp.cocoon (A) *O. cornifrons*, (B) *O. pedicornis*, (C) *O. taurus*, (D) *O. satoi.* by altitude (m). The Figures presents weight data of *Osmia* spp. at various altitudes. At 300m altitude, the weights of *O. cornifrons*, *O. pedicornis*, and *O. taurus* showed a significant increase compared to other altitudes. At 500m altitude, *O. satoi* exhibited the lowest weight. The statistical analysis was conducted using one-way ANOVA and Welch's ANOVA tests (Bee species: one-way ANOVA test $F_{3,41}$=30.070, p=0.0001; *O. cornifrons*: $F_{3,2537}$=39.685, p=0.0001; *O. pedicornis*: Welch's $F_{4,549.986}$, p=0.0001, *O. taurus*: Welch's $F_{4,37.341}$, p=0.0001; *O. satoi*: $F_{3,202}$=4.748, p=0.003; Total $F_{4,6242}$=12.925, p=0.0001).

the cocoon-spinning phase to emergence. Nevertheless, in certain bee species, adult body mass serves as an adequate measure of offspring production costs (Bosch and Vicens, 2005). Therefore, it is considered necessary to investigate the relationship between the size of cocoons and the mass of adult bees.

Additional research is imperative to maintain pollination services in landscapes influenced by human activities. Further studies should focus on investigating the effects of landscape on pollinator populations and communities, as well as exploring the intricate interactions between plants and pollinators (Taki and Kevan., 2007). Understanding these dynamics is crucial to promote and preserve pollination services in human-affected environments.

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