PNIE PROCEEDINGS OF THE NATIONAL INSTITUTE OF ECOLOGY OF THE REPUBLIC OF KOREA

Original Article

PNIE 2023;4(1):1-8
https://doi.org/10.22920/PNIE.2023.4.1.1
pISSN 2765-2203, eISSN 2765-2211

Estimating the Population Size and Spatial Distribution of Three *Scarites* Species (Carabidae) in Sohwang Coastal Sand Dune Habitats, Boryeong, Korea

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ABSTRACT

In this study, we aimed to quantify the population size and spatial distribution of three predatory *Scarites* species in coastal sand dunes. In June and August 2014, 252 pitfall traps were utilized to conduct a trapping web analysis at three distinct sites with varying vegetation dominance values. *Scarites sulcatus* had the largest estimated population in a 10 m^2 area with a habitat density of 36.6 in a *Vitex rotundifolia* community area (site B) in the June survey. In contrast, *Scarites aterrimus* had the largest population size with a habitat density of 2.9 in a *Calystegia soldanella* community area (site A) in the August survey. Spatial distribution analysis revealed that *S. sulcatus* dominated the *Vitex rotundifolia* community without preference for a particular site, whereas *S. aterrimus* and *Scarites terricola pacificus* were primarily observed on the beach. The results indicated that the three *Scarites* species in the Sohwang coastal sand dune region exhibited differences in their spatial and temporal distributions in the coastal dune ecosystem in order to avoid competition and predation. In conclusion, our findings can be utilized to estimate the population density of the genus *Scarites* on the Korean Peninsula. The outcomes of this study will contribute to estimating insect population densities on the Korean Peninsula and developing investigative assessment methodologies.

Keywords: Population size, *Scarites* species, Spatial distribution

Introduction

Coastal sand dunes are a type of coastal terrain formed by wind-blown sand deposited behind sandy beaches or tidal sand flats (Ryu, 2014). Numerous varieties of coastal sand dunes have developed on the western coast of Korea based on the surrounding undulations and coastal currents. In addition, the majority of warm and damp coastal sand dunes are covered with vegetation; this facilitates the deposition and accumulation of sand because the germination and growth of vegetation increase surface irregularities (Kahng, 2006).

Coastal sand dunes and tidal mudflats are iconic coastal ecosystems of major ecological value because they serve as a transition zone between marine and terrestrial eco-

Received October 27, 2022; **Revised** December 6, 2022; **Accepted** December 7, 2022

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systems while also fulfilling a buffering function as an ecotone (Van der Maarel, 2003; Walker *et al*., 2003). Despite their modest size, coastal sand dunes exhibit higher biodiversity than numerous other ecosystems; moreover, they contain specialized flora and fauna that are distinct from those of inland ecosystems (Kutiel *et al*., 2000).

Insects are the primary and secondary consumers in food webs within an ecosystem; they constitute the center of an ecosystem (Triplehorn *et al*., 2005). In addition, insects in coastal sand dunes play an important role as consumers and decomposers of various organisms that wash ashore. However, the rapid expansion of the tourism industry in recent years has reduced the surface area of coastal sand dunes owing to the construction of various infrastructure, such as camping sites and parking lots, in and around coastal sand dunes (Choi *et al*., 2011). These developments have caused the destruction and disruption of sand dunes and contributed to the decline and loss of insect biodiversity in these areas (Shin & Bae, 2015).

In Korea, research on insects inhabiting coastal sand dunes has primarily focused on emerging species (Han, 2010; Yahiro & Lee, 1995). For example, ecological studies have investigated the behavior and life cycle of *Scarabaeus typhon* inhabiting the coastal sand dunes of Shindu-ri. Changes in the insect population of the Goraebul coastal sand dunes have also been documented (Min *et al*., 2018; Shin & Bae, 2015).

The objective of this study was to quantify the population size and analyze the spatial and temporal distributions of three predatory *Scarites* species (i.e., *Scarites aterrimus*, *Scarites sulcatus*, and *Scarites terricola pacificus*) in the Sohwang coastal sand dunes. These species occur together are endemic to this area and serve as indicators of coastal sand dunes. This phenomenon is rare in Korea. *Scarites* species are the most voracious sand dune predators, preying on Lepidopteran and Coleopteran larvae as well as earthworms (Larochelle & Larivieve, 2003; Yamazaki & Sugiura, 2006).

Materials and Methods

Study area

The Sohwang coastal sand dunes are situated in Sohwang-ri, Ungcheon-eup, Boryeong-city, and Chungcheongnam-do and cover an area of approximately 121,358 m^2. This area has restricted public access because of the nearby military base and is subsequently well preserved. The Sohwang coastal sand dune area was designated an ecology and landscape conservation area by the Ministry of Environment in 2005.

Pinus thunbergii forest serves as a windbreak on the gradually sloping terrain at the rear. The zones between the sand dunes and *P. thunbergii* accommodate *Robinia pseudoacacia* communities. In addition, there are other sand dune vegetation types, such as *Elymus mollis*, *Vitex rotundifolia*, *Carex kobomugi*, and *Calystegia soldanella* present. In this dune vegetation area, a total of 12 families and 23 species of vascular plants have been surveyed, including nine families and 14 species of coastal sand dune vegetation, and three species of naturalized plants (Lee, 2011).

Three sites within the Sohwang sand dune vegetation were selected to investigate the *Scarites* species. Site A, which was dominated by *Calystegia soldanella,* contained *P. thunbergii*, which attracted frequent visitors from the general public. Site B, which was dominated by *Vitex rotundifolia*, formed a dune hill with *Robinia pseudoacacia*. Site C was characterized by a large expanse of dune vegetation dominated by *Elymus mollis* (Table 1).

Survey method

Our surveys were conducted on five consecutive days in June and August 2014 in a phased manner (first phase: June 21-25; second phase: August 30-September 3) while *Scarites* species imagoes were active. Trapping webs (TWs) were deployed on beaches and dune vegetation areas, and a mark-release-recapture method was used for quantitatively investigating *Scarites* species. TWs were installed at three different sites on the Sohwang coastal sand dunes, subdivided into *Calystegia soldanella*, *Elymus mollis*, and *Vitex rotundifolia* areas based on vegetation dominance values, in order to assess the insect density contingent on each vegetation type. The TWs encompassed an area of 28×28 m from the shore to the sand dune vegetation with 12 lines extending from a central point, seven circles at 2 m intervals, and 84 pitfall traps (PFTs) at the intersections of the lines and circles (Fig. 1). Regardless of the number of days in question, opportunistic captures were

Table 1. Dominant plants and coverage at different sites

Site	Dominant plant communities	Coverage (%)	Beach length (m)	Remark
A	*Calystegia soldanella, Carex kobomugi*	50-60	13	A lot of floating matter
B	*Vitex rotundifolia, Elymus mollis*	90-100	8	A little floating matter
C	*Elymus mollis, Carex kobomugi*	80-90	34	A lot of floating matter

Adapted from Lee. Development of Assessment Technique of Ecosystem Health and System Construction through the Species Diversity Index in Coastal Dune Ecosystem; 2011.

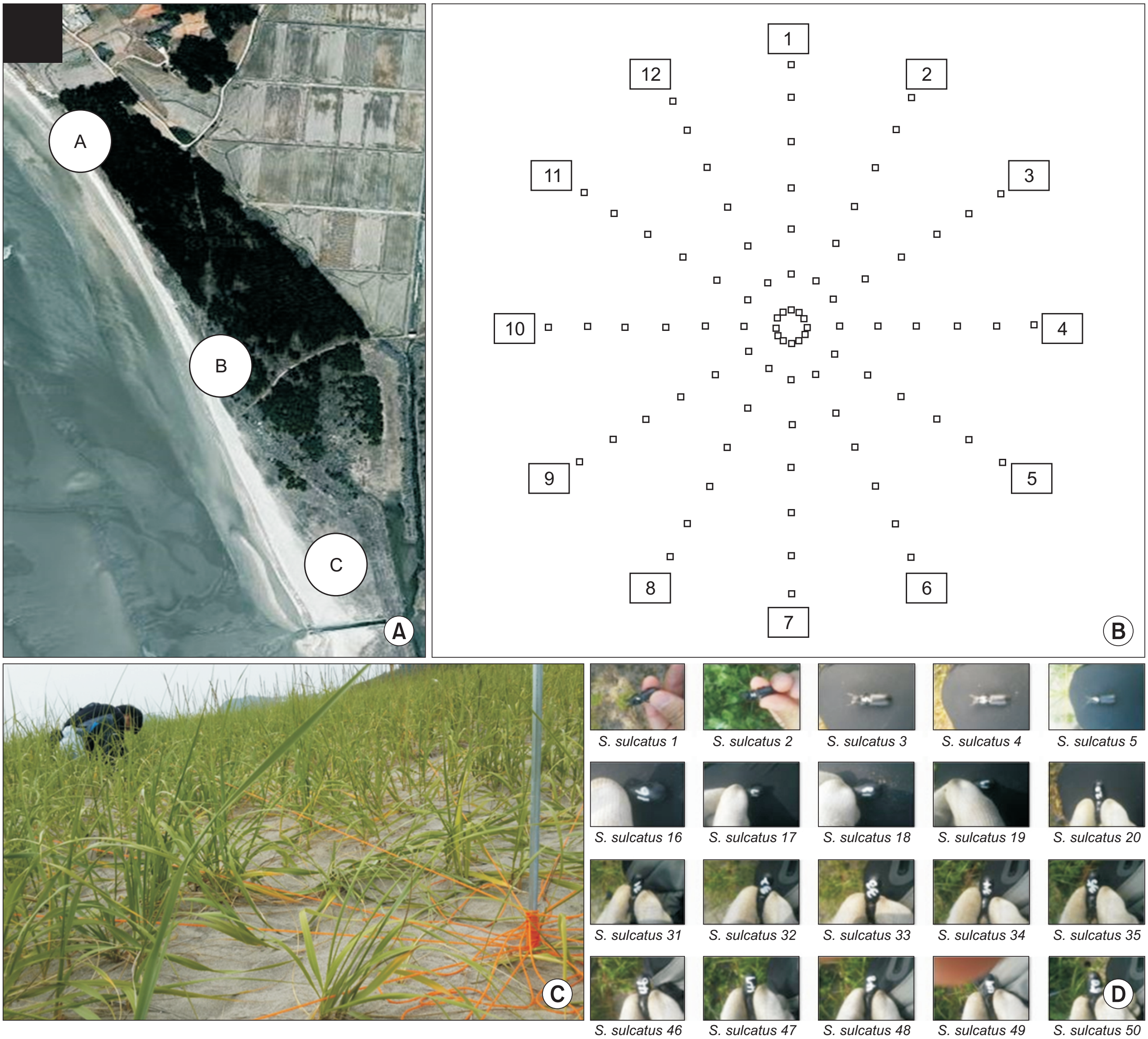

Fig. 1. Sites of quantitative survey on sand dune insects and pit-fall traps conducted in Sohwang sand dune. (A) Trapping web installation site. (B) Trapping web design. (C) Trapping web installation. (D) Markings on *Scarites sulcatus*captured in pit-fall traps.

conducted when the daily sample size was minimal. If the population size was sufficient, the number of captured individuals would likely decrease over time.

Estimation of population size

First, the threshold was calculated using the model proposed by Anderson *et al.* (1983) to estimate ground beetle population density. The threshold was calculated as follows:

$$V = \frac{1}{C_T}\sqrt{2/\left(1+\sum n_i\right)}$$

where ^{c}T represents the area enclosed by the circle beyond which data are truncated, and n_i denotes the total number of unmarked insects captured by traps in circle *i*.

Next, the estimation value was calculated as below.

$$\grave{D} = f\sum n_i$$

where *f* represents an absolute value.

The Fourier-series (F-s) model was adopted to establish the goodness-of-fit of the estimate. The F-s model estimates the expected values of the beetles that can be captured by the PFTs installed in each circle, which are subsequently compared to the outdoor values to assess the fitness level (Anderson *et al*., 1983).

Results

Captured and estimated populations

In June, our surveys of the Sohwang coastal sand dunes revealed that *S. sulcatus* was dominant, with 383 individuals captured. This was followed by *S. aterrimus* with 13 and *S. terricola pacificus* with five captured individuals. In the August survey, 30 *S. sulcatus*, 20 *S. aterrimus*, and no *S. terricola pacificus* individuals were captured. Consequently, *S. sulcatus* was the most frequently recorded insect among the three species, whereas *S. terricola pacificus* was the least frequently recorded. In addition, the largest quantities of *S. sulcatus* and *S.* occurred in June and August, but *S. terricola pacificus* was only observed in June (Table 2). At the three different sites (A, B, and C), 188 and 30 *S. sulcatus* individuals were recaptured using TWs in June and August, respectively, while neither *S. aterrimus* nor *S. terricola pacificus* individuals were recaptured. In terms of different vegetation communities, the largest quantity of *S. sulcatus* was captured in *Vitex rotundifolia* trees. In contrast, the largest quantities of *S. aterrimus* and *S. terricola pacificus* were found in *Calystegia soldanella.* This demonstrated distinct differences in population density within various plant communities.

In terms of population, it was estimated that *S. sulcatus* dominated site B (36.6 individuals in a 10 m^2 area) with a higher density than the other two species. In contrast, *S. aterrimus* dominated site A in August, with a density of 2.9 individuals per 10 m^2. Reliability analysis of the estimate showed that *S. sulcatus* at site B in June had a significantly higher density (43.12 individuals per 10 m^2, χ^2: 0.005, 20.277) than at the other sites. In addition, *S. sulcatus* exhibited significantly higher densities at each site in August (χ^2: 0.050, 12.591). *S. aterrimus* was captured in June and August, but only the August result was statistically significant for this species. The number of *S. terricola pacificus* captured was insufficient for estimation purposes (Table 2).

Daily captured population

S. sulcatus was recorded in the highest numbers at all sites on the first day of both the June and August sur-

Table 2. Mark-release-recaptured estimated population of *Scarites* sp. in Sohwang coastal sand dune

Species name	June						August					
	Number of unmarked insects captured (number of recaptured)			Population density estimate (10 m^2) (G-value)			Number of unmarked insects captured (number of recaptured)			Population density estimate (10 m^2) (G-value)		
	Site			Site			Site			Site		
	A	B	C	A	B	C	A	B	C	A	B	C
S. sulcatus	40 (25)	242 (123)	101 (40)	6.1 (4.27)	36.6 (43.12*)	20.8 (4.23)	8 (1)	9 (1)	13 (2)	0.8 (14.23**)	1.4 (26.9**)	0.9 (31.44*)
S. aterrimus	12 (0)	-	1 (0)	2.3 (24.0*)	-	-	18 (0)	1 (0)	1 (0)	2.9 (30.8*)	-	-
S. terricola pacificus	3 (0)	1 (0)	1 (0)	-	-	-	1 (0)	-	-	-	-	-

n=7, *P<0.005, **P<0.05.

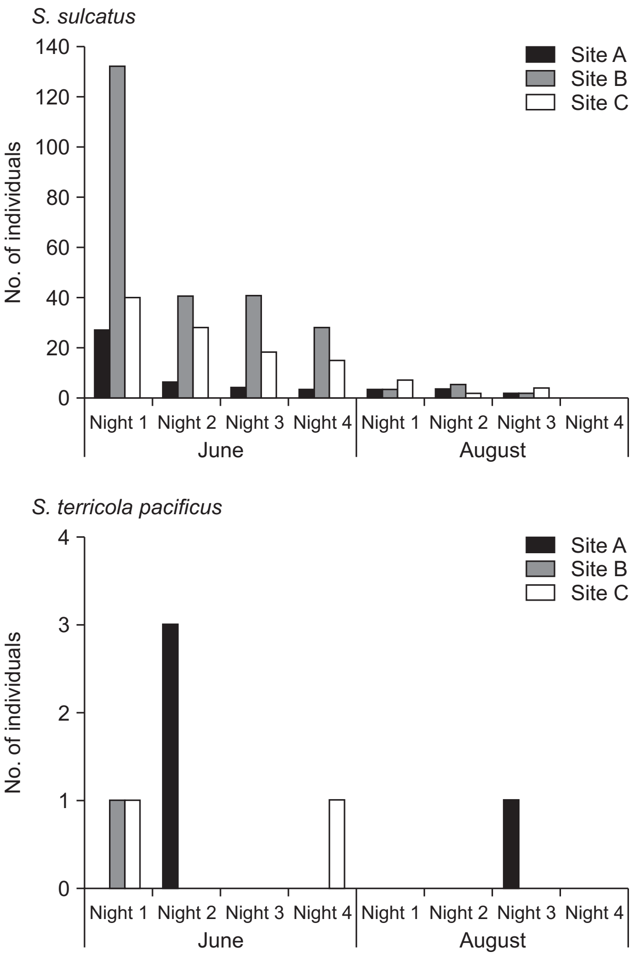

Fig. 2. Populations of three *Scarites* species captured at each site (A, B, C) on a daily basis.

veys, after which the captured population gradually decreased. *S. aterrimus* was captured in the highest amount on the third day, except at site B, where nothing was captured, with no bias in terms of the capture method over the specific period. *S. terricola pacificus* was captured in modest numbers and thus was captured opportunistically as opposed to at a specific time period (Fig. 2).

Spatial distribution

Concerning the spatial distribution of the three *Scarites* species, insects were captured in specific regional habitat areas between *S. sulcatus* and the other two *Scarites* species. The June and August surveys revealed that *S. sulcatus* was evenly distributed throughout the sandy beaches of the foreshore, embryo dunes, and dune crests at all three sites. In particular, several of these species were observed in the *Vitex rotundifolia* community, demonstrating their affinity for hiding places. However, in both the June and August surveys, *S. aterrimus* was recorded on the beach of the *Calystegia soldanella* community, whereas *S. terricola pacificus* was captured in the *Calystegia soldanella* region, a beach dominated by *Elymus mollis*, and embryo dunes in the June survey (Fig. 3).

Discussion

The difference between *S. aterrimus* and *S. terricola pacificus* habitats and *S. sulcatus* habitat on the Sohwang coastal sand dune in terms of the spatial distribution of each beetle species could be attributed to the tendency of *S. aterrimus* and *S. terricola pacificus* to avoid competition for food and predators by living in the vicinity of the beach. Moreover, surveys on insects inhabiting the coastal sand dunes of the Korean Peninsula demonstrated that *S. aterrimus* preferred beach topography over vegetation and was primarily found in beach areas as opposed to vegetation areas. This same holds true for *S. terricola pacificus* (Lee, 2011). Although additional research on the local landscape and vegetation is required, it appears that these two species are greatly affected by sand dune coverage, surrounding vegetation, and predators.

Spatial distribution analysis of all three species indicated that *S. aterrimus* and *S. terricola pacificus*, but not *S. sulcatus*, mainly inhabited the beach dominated by

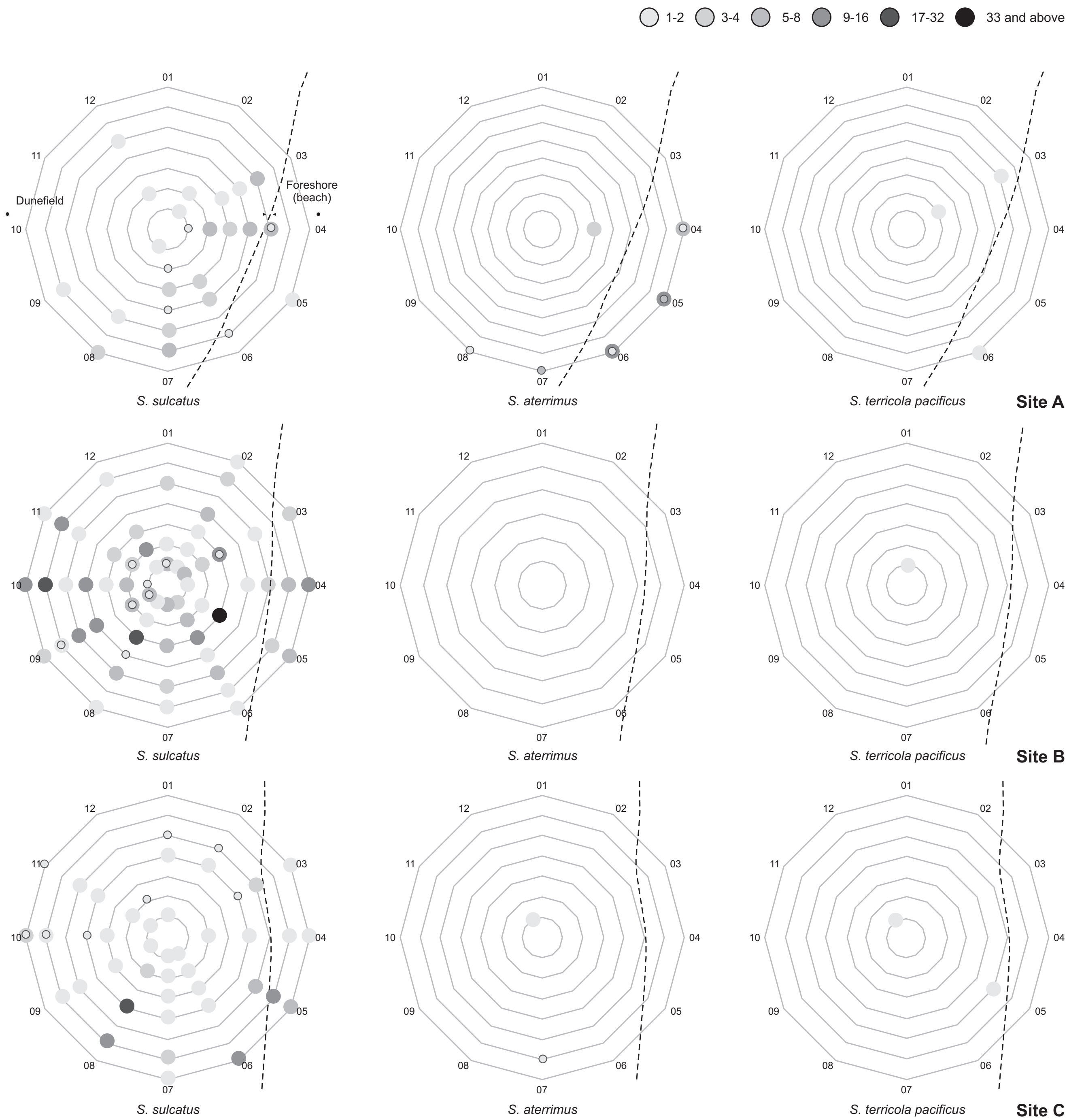

Fig. 3. Spatial distribution of the three *Scarites* species (non-border circle, population in June; border circle, population in August).

Calystegia soldanella. This area featured low vegetation coverage, a well-developed beach, and a variety of floating matter pushed from the ocean, providing excellent hiding places for insects. As such, vegetation coverage close to the habitat has a considerable effect on the activity and population density of beetles (Eyre *et al*., 2016), with beetle communities differing markedly depending on the vegetation type (Latty *et al*., 2006). It is also recognized that altitude above sea level, exposure to sunlight, and canopy density have considerable impacts on the community structure of beetles (Bergmann *et al*., 2012; Larochelle & Larivieve, 2003). This is also assumed to be

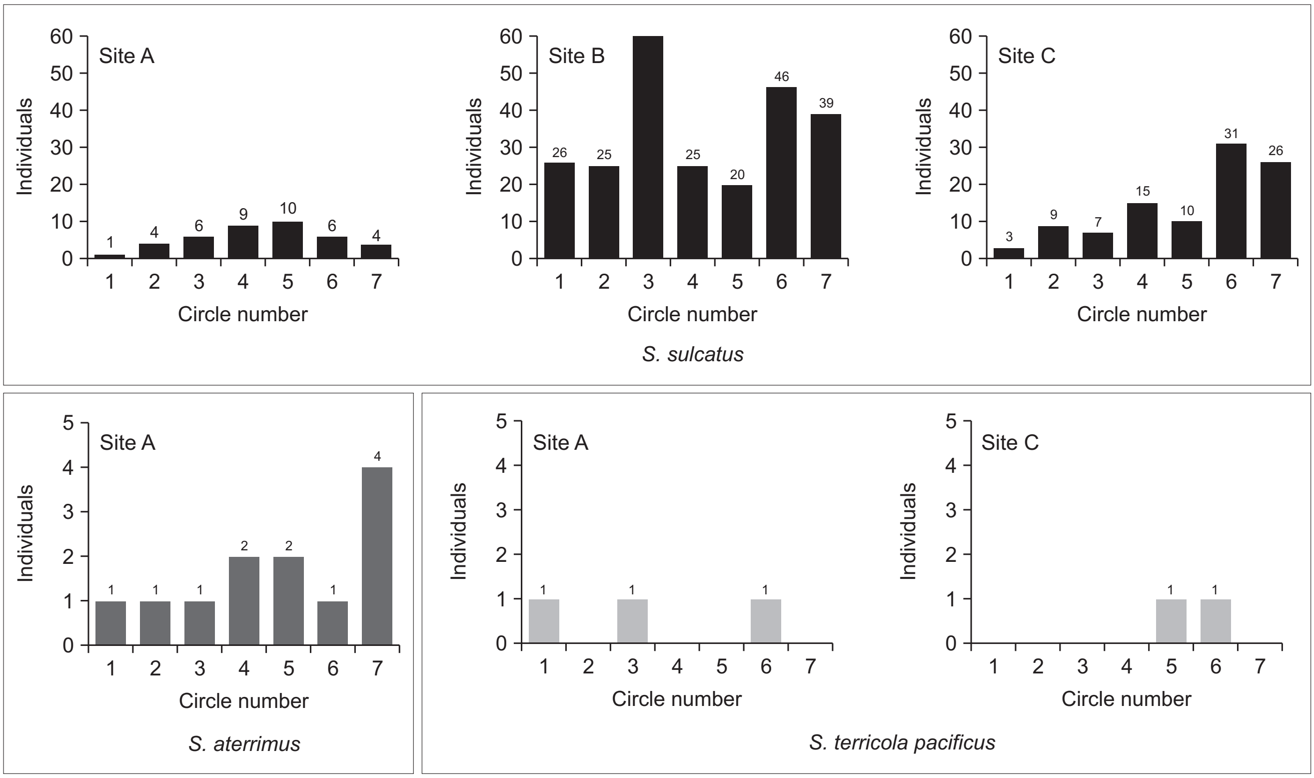

Fig. 4. Captured population of *Scarites* species on Sohwang coastal sand dune per each circle number from the center point.

associated with the comparatively small population of *S. sulcatus*, which is ecologically dominant in this area, as well as the relatively small population of *Eremias argus*, which is a prominent predator in this area. This is why abiotic factors (pathogens) and predators are the most causative factors of ground beetle mortality (Lövei & Sunderland, 1996).

In terms of monthly occurrences, *S. terricola pacificus* was solely observed in the June survey, whereas *S. sulcatus* and *S. aterrimus* were observed in both the June and August surveys. Years of monitoring have confirmed that *S. terricola pacificus* is primarily observed in May and June; in contrast, the other two species are recorded in June and August, indicating noticeable differences in the appearance periods of *S. terricola pacificus* and the other two species (ME, 2014).

A recent survey indicated that seasonal factors affected the emergence patterns among different *Scarites* species. Furthermore, it is likely that various species have distinct habitat preferences, allowing them to avoid competition for food and space. In particular, *S. terricola pacificus* had the smallest habitat, necessitating more precise beach-focused surveys. The estimated population was calculated using the TW mathematical model, which indicated that the number of captured individuals would likely increase as the target sites advanced from the center point to the outskirts. The exclusion of these edge effects was anticipated to result in more accurate population estimates per unit area. However, in this study, we demonstrated that there was something to be sought beyond the edge effect (Fig. 4). It is presumed that complex landforms of coastal sand dunes, characterized by sandy beaches, embryo dunes, and dune crests, have developed within a small area (Choi *et al*., 2011). Therefore, additional surveys and analyses are required to apply the recently estimated population sizes to all areas of the Sohwang sand dunes.

This study was based on vegetation types, estimated spatial distributions, and population sizes of three *Scarites* species recognized as emblematic carnivorous insects of sand dune ecosystems. Consequently, it is anticipated that the findings of this study will contribute to the estimation of the population density of insects on the Korean Peninsula and the development of assessment methods for conducting investigations.

Conflict of Interest

The authors declare that they have no competing interests.

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