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**A long-term ecological monitoring of subtidal macrozoobenthos around Dokdo waters, East Sea, Korea**

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**ABSTRACT**

Dokdo’s high marine biodiversity has received worldwide attention recently. A total of 578 macrozoobenthos are recorded since the 1960s, but ecology of Dokdo's fauna is unknown. We monitored Dokdo's subtidal macrozoobenthos for 5 years in 2013-17, in the present study. Five stations representing three subtidal habitats were monitored; 1) oceanic plateau, 2) coastal terrace, and 3) island wharf. In total, 13,664 individuals belonging to 141 taxa were recorded during the survey. The number of species and density varied greatly among stations without distinct year-round variation. Faunal compositions significantly differed in time and space, reflecting varied faunal adaptations in a harsh environment. Whilst, temporal stability in faunal assemblages was evidenced for some dominant or cosmopolitan taxa. High spatial heterogeneity reflects site-specific oceanographic conditions. Meantime, sea-surface temperature and wave action were associated with year-round faunal compositions. Overall, the Dokdo's macrozoobenthos significantly contribute to marine biodiversity of the East Sea.

*Keywords*:

Dokdo

East Sea

Macrofauna

Island ecology

Spatiotemporal variations

Biodiversity hotspot

Dokdo is a volcanic island complex in the East Sea, situated at the easternmost part of Korea. Dokdo is 217 km far away from mainland and 87 km away from Ulleung Island, with a limited public access. The Dokdo archipelago consists of two large islands (Dongdo and Seodo) with 89 small islets and emergent reefs resulting from seamount formation processes between the period from 4.6 and 2.5 million years ago (Kim et al., 2013; Sohn and Park, 1994). Dokdo is an oceanic, influenced by two major currents, the Tsushima Warm Current and the North Korea Cold Current (Chang et al., 2016). These unique geomorphological characteristics and oceanographic setting support high species diversity from various type of marine habitats such as rocky shores, marine plateaus, and seamounts (Ryu et al., 2012; Sohn and Park, 1994).

Dokdo has been relatively well-preserved island compared to other islands in Korea and reported as one of the well-known global biodiversity hotspots (Song et al., 2017). To date, many taxonomic studies supporting Dokdo’s unique and high biodiversity have long been documented since the 1960s. Inventories of various marine taxa have been established in Dokdo’s sea waters; polychaetes (Lee, 2000), crustaceans (Hong et al., 2006; Hong et al., 2008; Oh, 2001), molluscs (Son et al., 2004), nematodes (Rho et al., 2010), etc. More recently, Song et al. (2017) provided the most up to dated list of marine invertebrate taxa around Dokdo through taxonomic review and analysis of meta-data from the 60-year long published works. They reported a total 578 marine invertebrate species around Dokdo over the last half century, which is comparable to a total of 624 recorded species in the entire west coast of Korea (Park et al., 2014).

Although previous taxonomic studies revealed high diversity of macrozoobenthos species around Dokdo, their ecological studies have been limited to very few cases (Choi et al., 2002; Je et al., 1997; Kang et al., 2019). As benthic community structure is widely applicable to characterize various habitat conditions in marine environment, monitoring of macrozoobenthos is important for developing conservation strategy of marine creatures and/or resources in site-specific manner (Bussotti et al., 2006; Olsgard et al., 1997; Wilson and Jeffrey, 1994; Ysebaert and Herman, 2002). Macrozoobenthos is commonly used as biological indicator because: 1) they live long in bottom sediment, where exposure to contaminants in the most frequent and persistent; 2) they are sensitive to immediate environmental changes and respond water-sediment associated changes over time; and 3) they can usually be classified into diverse functional groups in marine ecosystem with high density ranging from tolerant to sensitive species (Alden III et al., 1997). Thus, to achieve an efficient long-term ecological monitoring, selections of type habitat and appropriate environmental parameters would be of critical importance.

The present work employed a systematic approach to obtain the most representative faunal community structure by the 5-year long monitoring of the three typical habitats of Dokdo; 1) oceanic plateau, 2) coastal terrace, and 3) island wharf. Our overall aim was to describe the long-term spatiotemporal distribution and its pattern for Dokdo’s subtidal macrozoobenthos assemblages. Specific objectives were to: 1) describe the patterns in the diversity (number of species), species abundance (density), and dominant species of macrozoobenthos, 2) to identify environmental variables determining the observed pattern and/or variability in faunal communities. As part of present study, a mini-review of macrozoobenthos in the East Sea encompassing Korean and Russian coastal and marine waters was performed, which will aid to understand marine benthic ecology of Dokdo and promote conservation strategy of the East Sea’s marine biodiversity in international perspectives.

Macrozoobenthos samples were collected at five rocky subtidal areas around Dokdo in 2013–17. Five fixed sampling stations widely cover the Dokdo waters in geographical manner; northern side (Keungajebawi, D1), western side (Hogdomgul, D2), central side between Seodo and Dongdo (Island Wharf, D3), southern side (Haenyeobawi, D4), and eastern side (Dongnimmunbawi, D5) of Dokdo (Table. S1). A total of 5 stations can fall into the 3 target habitats as follows; 1) oceanic plateau (D1 and D5), 2) coastal terrace (D2 and D4), and 3) island wharf (D3). Each ecological habitat indicates different (say typical) environmental conditions, i.e., depth, wave exposure, sediment load, occurrence of dominant microalgae, etc. For example, oceanic plateau is the most exposed side to wave action, coastal terrace shows the common intertidal zone, and island wharf is considered as the most sheltered area in Dokdo. Of note, D1–D2 are located in Seodo (west island) and D3–D5 are situated in Dongdo (east island).

Table 1 summarizes data statistics of the broad scale and station specific environmental information for each monitoring station. For example, sea-surface temperature, sea-20 m temperature, wind speed or direction, and ranked wave exposure collected from the Dokdo Research Centre of Korea Institute of Ocean Science and Technology (KIOST) were presented. The detailed environmental conditions for bottom sediment or rock type, amount of seaweed, etc. were also provided to understand the overall oceanographic setting and conditions.

All macrozoobenthos samples were collected by SCUBA diving using 1 m × 1 m quadrat sampling. Three replicates were randomly collected at each station in each year by scraped off the rocks. Samples were then immediately brought to the research vessel and preserved in 4% buffered formalin, and then transferred to the laboratory to further analyses. In laboratory, all macrozoobenthos samples were counted and identified to species level under a stereomicroscope (LEICA M205c) following the national list of species of Korea and the list of Dokdo species of Korea (National Institute of Biological Resources, 2015a, b).

Univariate and multivariate data analysis was performed using the software Primer 6.0.2 (Clarke and Gorley, 2006) with permutational analysis of variance (PERMANOVA) add-on. The data for abundance of each subtidal faunal composition in each replicate were standardised by their total abundance and square-root transformed. The means of the transformed abundance for each station and year were used to construct a Bray-Curtis similarity matrix; this was then subjected to group averaged hierarchical cluster analysis and non-metric multidimensional scaling (nMDS) ordination. Two-way PERMANOVA was used to test at which spatial (station) and temporal (year) scale differences diversity (viz., number of species), density, and species composition of subtidal macrozoobenthos occurred. Estimates of components of variation were calculated in a PERMANOVA test to identify variability of benthic composition among stations and years. Test of homogeneity of dispersion (PERMDISP) was performed to examine the PERMANOVA assumption on the homogeneity of multivariate dispersion, and to identify the nature of the effect of the factor of interest. When the PERMANOVA detected significant differences among the groups, the similarity percentages (SIMPER) were used to determine the species that typified those groups and the species that distinguished each group from each of the other groups.

In order to compare the potential species richness in Dokdo among stations and years, the species accumulation curve (SAC) was analysed using R 3.0 (R Core Team, 2018) with R vegan package (Oksanen et al, 2019). The SAC was constructed by plotting number of species against number of sampling effort according to Ugland et al. (2003). We used both observed species richness (*S*obs) and the second-order Jackknife estimator, *Jack2* (Burnham and Overton, 1979) as estimates of species richness around Dokdo. The *Jack2* is a non-parametric method and might provide better estimate of whole species richness by reducing a bias (Gotelli and Colwell, 2011). The *S*obs and*Jack2* were plotted against number of sampling effort in SAC to determine whether the sampling was adequate to estimate the true number of species around Dokdo. Relationships between multivariate structure of macrobenthic assemblages and normalised abiotic factors were compared by BIOENV method in BEST test using Spearman’s correlation between similarity matrices.

Two-way PERMANOVA test indicated that site-specific distribution characteristics of subtidal macrozoobenthos around Dokdo, in general (Fig. 2). First, the number of macrozoobenthos species around Dokdo significantly differed from each station (Pseudo-F = 8.51, df = 4, *p* < 0.001), but not by years; there was no interaction between stations and years (Fig. 2A). Similarly, the density of subtidal macrozoobenthos greatly varied among stations (Pseudo-F = 8.81, df = 4, *p* < 0.001), but not among years, with no interaction between stations and years occurring (Fig. 2B). The PERMDISP test indicated no significant dispersion difference in number of species and density among stations and years (Table 2). The number of species and total density were the greatest (82 taxa, total 5,840 individuals) in D1 (at Seodo), on average. However, D2 (at Seodo) showed the greatest number of species in 2013 (21 taxa) and 2015 (28 taxa) than those in D1. Other three stations of D3, D4, and D5, all of which are situated in Dongdo, showed comparable diversity with total of 38, 43, and 54 taxa from all years. However, it should be noted that faunal abundance at those three stations considerably varied, reflecting a close association of species density to type habitats (Fig. 1 & 2B). Overall, the lesser variations in number of species and density cross all years generally supported the high biodiversity of Dokdo’s macrozoobenthos.

Two-way PERMANOVA test based on faunal abundance data demonstrated that the species composition differed significantly among stations (Pseudo-F = 3.51, df = 4, p < 0.001) and years (Pseudo-F = 3.92, df = 2, p < 0.001), with interaction between stations and years (Pseudo-F = 1.53, df = 8, p < 0.001). Also, the ordination of samples with the nMDS technique based on faunal abundance data showed clear difference among stations and years (Fig. 3). Meantime, the estimates of component variation test in PERMANOVA indicated that variation in faunal assemblages among years was slightly greater than that among stations (Table 2). Finally, in the PERMDISP test, significant dispersion effect was detected among years (*p* < 0.05) and interaction between stations and years (*p* < 0.05), but not among stations. This significant dispersion effect could be due to heterogeneous variance rather than real factor effect (Table 2).

The top five abundant species, collectively accounting for 52% of total macrozoobenthos include *Chthamalus challengeri* (31%), *Balanus trigonus* (6%), *Corynactis viridis* (6%), *Cantharidus callichroa* (5%), *Balanus* sp. (5%) in order; whereas 125 species contributed individually to less than 1% to total density. Moreover, the SIMPER test showed that the species that contribute the similarity within the ecological habitat was similar but the species within a station was different at each station (Tables S2 and S3). Several macrozoobenthos species were dominant in particular stations across all years: *Megabalanus rosa* (D1), *Chthamalus* *challengeri* (D2), *Omphalius rusticus* (D3), *Balanus trigonus* (D4), and *Asterina pectinifera* (D5). However, the most widely distributed species across all stations were different in each year: *Chthamalus* *challengeri* (2013, 2017), *Strongylocentrotus nudus* (2014), *Balanus trigonus* (2015), and *Omphalius rusticus* (2016).

In total 13,664 individuals belonging to 141 taxa were identified from all stations for all years (2013–17). The absolute value of species richness estimated by *Jack2* (235 species) was higher than observed species richness (*S*obs, 141 species) across Dokdo waters (Table S4). However, both *S*obs and *Jack2* showed same species pattern with higher values in D1 and lower values in D3 (Tables S5–8). The SAC of both *S*obs and *Jack2* revealed its asymptote, while number of sampling is unlikely to collect observed every species in the stations and years, it was sufficient to estimate the total number of seen and unseen species. (Fig. 4 and Fig. S1).

In general, five years long macrozoobenthos data from Dokdo waters indicated typical patterns in time and space. The prevailing site-specific variations in diversity, species abundance, and species composition collectively explained the dynamic interactions between faunal assemblages and corresponding habitat conditions. For example, aggregation of dominant species causes small scale heterogeneity (Blome et al., 1999) and the distribution of sessile assemblages were related to physical gradients along the exterior-interior axis (Bussotti et al., 2006). The SIMPER test showed that the species that contribute the similarity within a station was significantly different at each station (Table S2) and the most dominant species across all stations were mainly sessile species (*M*. *rosa*, *B*. *trigonus*,and *C*. *challengeri*). Moreover, our result showed relatively low diversity and species abundance but high abundance of Echinoideaat D3 than other stations. Echinoidea is a well-known predator on subtidal rock-bed (Briscoe and Sebens, 1988; Simoncini and Miller, 2007). The prevalence of predator species might be an important factor to determine species diversity (Chesson, 2000) by creating highly grazed barren grounds (Byrnes et al., 2013; Hereu et al., 2008; Simoncini and Miller, 2007).

Several previous studies have investigated the spatial variation of macrobenthic assemblage differences around Dokdo (Choi et al., 2002; Kim et al., 2015; Ryu et al., 2012). However, those studies are limited to conduct a qualitative sampling (Kim et al., 2015; Ryu et al., 2012) or a quantitative sampling at different time periods (Choi et al., 2002). In our study, the nMDS technique based on the quantitative data showed clear difference in macrofaunal assemblages between D1 and D3 (Fig. 3A). This could be explained by the geological feature of the corresponding stations. Of note, D1 is located at outer exposed side of Dokdo (oceanic plateau) whereas D3 (Island wharf) is situated on the sheltered inner side of Dokdo. Relatively high anthropogenic activity near D3 would have resulted in lack of species diversity (viz., small number of species) and lesser species abundance at the very region (Fig. 2). The number of Dokdo visit has rapidly increased since Dokdo was open to the public in 2005 (Dokdo Administration Office, 2005), thus anthropogenic activities could be one reason for the reduced diversity in D3. Altogether, the spatial variation of Dokdo’s faunal assemblages could be attributable to the combined effect of oceanographic setting and human activities.

Despite of only one sampling time in a year, our results showed certain temporal variation in faunal assemblages around Dokdo (Fig. 3B). The dissimilarity of species assemblages among years could be explained by different species groups dominated by year(s) (Table S3). For instance, *C*. *challengeri* was the most abundant and widely distributed species in 2014 that contributed dissimilarity of species assemblages between other years, whereas *B*. *trigonus* seemed to influence the assemblage difference between 2016 and 2017 (Tables S2 and S3). The temporal variation of benthic species assemblages would reflect natural recruitment fluctuations; typically for rocky bottoms (Johnson, 2007) or some habitats having typical planktonic larvae (Hartnoll and Hawkins, 1985). Meantime, our environmental data indicated relatively higher sea water temperature during the period of 2013–15 (mean = 21.7 ± 0.95 oC) compared to the period of 2016–17 (mean = 20.05 ± 1.7 oC). Such temporal variation of broad scale environment around Dokdo could affect the diversity and species composition of macrozoobenthos around Dokdo (Table 1 and Fig. 3B) (Johnson, 2007).

Further, the BIOENV method in BEST test using similarity matrices derived from relative faunal abundance and abiotic data indicated their association. For example, faunal composition around Dokdo was significantly correlated with sea-surface temperature and wave action (R = 0.169, *p* < 0.001) across all stations and years. Therefore, scale of recruitment which determined by broad-scale environments such as current and sea-water temperature could influence such spatiotemporal variations.

Although the most dominant species across Dokdo were different among years, spatial heterogeneity of species assemblages indicated clear difference among stations. This pattern was confirmed by the distribution of the most dominant taxa (*M*. *rosa*, *B*.*trigonus*,and *O*.*rusticus*), which varied among stations but lesser varied over time. Moreover, our study showed that the diversity and relative abundance were not significantly different among years. The temporal persistence of organism that characterise the benthic assemblages were also observed incoralligenous assemblages in the north-western Mediterranean (Garrabou et al., 2002) and in the northern Adriatic Sea (Ponti et al., 2011). The environmental factors in island ecosystem could greatly change at local and geographical scale (Brito et al., 2005; Whittaker and Fernández-Palacios, 2007). Our study revealed that broad-scale abiotic factors could affect the temporal fluctuations of macrozoobenthos across Dokdo.

The first comprehensive review on Dokdo’s marine invertebrates, based on meta-data analysis from ~40 publications (sampled in 1958–2012), have recently reported a total of 578 macrozoobenthos species in Dokdo (Song et al., 2017). Although previous meta-data analysis was based on mainly taxonomic literatures, higher spatial variabilities of macrozoobenthos around Dokdo were identified over time. For example, the number of documented species in Keungajebawi (D1) were relatively high compared to that reported in other regions of Dokdo (Song et al., 2017). Our result also showed that the highest number of species were recorded in D1 than those in other stations. However, it should be noteworthy that total of 173 species were documented in D1 during the last half century (Song et al., 2017), whereas we found only 82 species from 5-year long survey (2013–17). Of note, the estimated asymptotic number of species (*Jack2*) was 132 (Table S6) which is somehow closer to the long-term documented number of species in D1 (Fig. 4A). But, in the other hand, this result might indicate that particular local diversity (i.e. D4 and D5) around Dokdo could be underestimated than its true total diversity (Fig 4A and 5A).

Overall, the Dokdo’s diversity is quite high compared to those around East Sea reported in the previous studies (Fig. 5B and 5C). Considering number of species reported in the present study alone, the data still represents high biodiversity of Dokdo’s marine lives with comparable diversity to the Russian coast. In terms of species distribution, faunal assemblage from Dokdo could be divided into three ecological group (Fig. 5C). The first group includes 41 species which might be regarded as ‘Dokdo fauna’. Those species more likely appeared around Dokdo but not recorded on the eastern coast of Korea (Table 3). Second group consists of 34 species, all of which were reported both in Korean coasts and Dokdo. The cosmopolitan distribution of selected species would represent faunal similarity across Korean coast and Dokdo. For example, *Ammothea hilgendorfi*, *Balanus improvisus*, and *Omphalius nigerrima* were widely distributed both along the eastern Korean waters and Dokdo (Yun and Song, 1997; Yun and Song, 1998). Finally, third group includes 20 species which generally reflect ‘East Sea fauna’, which are dominant taxa in the East Sea. For instance, *Strongylocentrotus intermedius* and *Crassostrea gigas* were commonly distributed in the northern East Sea (Kolpakov et al., 2018; Volvenko et al., 2018). The meta-data analysis of species distribution largely indicates that Dokdo’s faunal assemblages are likely more similar to those reported on the Korean coast, in aspects of species occurrence, distribution, and species composition (Table S9).

Dokdo has been relatively well-preserved island due to the difficulty of access and thus recognized as one of the world well-known biodiversity hotspots (Song et al., 2017). Our study clearly showed Dokdo’s faunal variability at multiple scales in time and space, although it is very small and remote oceanic island. In the present study, the possible effects of several abiotic factors interacting with faunal changes have been explained. However, further correlative and comprehensive studies would be necessary to better understand the ecology of Dokdo. In order to protect and manage this special island environment, natural species variability in relation to abiotic parameters across different spatial scales should be identified (Denny et al., 2004; Horner-Devine et al., 2004). Finally, the role and ecosystem services provided by the unique and remote island of Dokdo would be benefit towards blue economy and sustainability (Lee at al., 2020).

In conclusion, the present work is one of the first efforts to describe and analyse the long-term distributions of macrozoobenthos in Dokdo’s subtidal environment. Our study showed clear spatiotemporal differences in macrozoobenthos assemblages of the Dokdo’s marine waters. The diversity and species abundance were significantly different among stations but not among years. The overall diversity and species abundance from Keungajebawi (D1) were relatively high compared to other stations, while those from Island wharf (D3) was the lowest. Dokdo’s high biodiversity hotspot is confirmed in several aspects, such as temporal persistence of diversity, high species abundance of several dominant species, and wide distribution of Dokdo’s common taxa. Whilst, the spatial heterogeneity of macrozoobenthos observed across the stations could be due to the interaction between biological components and site-specific or habitat-dependent environmental conditions. Of note, among several environmental parameters, sea-surface temperature and wave action seemed to influence general temporal variations of faunal assemblages. Further systematic and comprehensive studies are needed to ensure science-based solid management implementation toward sustainability of world-valuable and dynamic ecosystem of Dokdo, East Sea, Korea.

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**Appendix A. Supplementary data**

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Table 1. Data statistics of the broad scale and station specific environment in Dokdo’s subtidal area during the monitoring period of five years (2013–17).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Broad scale environment | Year | | | | | | | | | | | | | |
|  | 2013 | | | 2014 | 2015 | | | | | 2016 | | 2017 | | |
| Sea-surface temperature | 23.8±0.75 | | | 20.2±1.59 | | | 21±0.51 | | | 20.7+1.72 | | 19.4+1.7 | | |
| Sea-20 m temperature | 20.4±2.41 | | | 16.2±1.80 | | | 21+1.07 | | | 15.9+1.84 | | 17.5+0.4 | | |
| Wind speed | 4.7±2.47 | | | 2.7±1.26 | | | n.d.\* | | | 4.6+2.1 | | 5.8+1.74 | | |
| Wind direction | East | | | East | | | East | | | East | | East | | |
| Station specific environment | Station | | | | | | | | | | | | | |
|  | D1 | D2 | | | | | | D3 | | | D4 | | | D5 |
| Sediment type | Shell gravel | | Gravel sand | | | Gravel | | | Sand | | | | Gravel sand | |
| Rock type | Slope | | Small rock, flat | | | Small rock, flat | | | Rock, flat | | | | Slope | |
| Amount of seaweed (ranked) | 4 | | 2 | | | 1 | | | 3 | | | | 5 | |
| Wave exposure (ranked) | 5 | | 2 | | | 1 | | | 3 | | | | 4 | |

\*n.d.: not detected

Table 2. Summary of the PERMANOVA and PERMDISP tests based on the set of macrozoobenthos assemblage data; number of species, density, and species composition. S: Station; Y: Year; df: degree of freedom; P-F: Pseudo-F; ECV: Estimate Components of Variation; Sqrt: square root of ECV; Bold values: P < 0.05.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Community structure | PERMANOVA | | | | | |  | PERMDISP | |
|  | Term | *df* | P-F | ECV | Sqrt | *P* |  | P-F | *P* |
| Number of species | Y | 4 | 0.68 | -2.08 | -1.44 | 0.6 |  | 0.79 | 0.6 |
| S | 4 | 8.51 | 49.24 | 7.01 | **0.001** |  | 0.46 | 0.8 |
| S × Y | 16 | 1.51 | 16.87 | 4.1 | 0.1 |  | 2.34 | 0.5 |
| Res | 50 |  | 98.31 | 9.91 |  |  |  |  |
| Density | Y | 4 | 2.04 | 20.6 | 4.53 | 0.06 |  | 1.66 | 0.4 |
| S | 4 | 8.81 | 154.19 | 12.41 | **0.001** |  | 0.72 | 0.7 |
| S × Y | 16 | 1.42 | 42.12 | 6.49 | 0.1 |  | 3.14 | 0.3 |
| Res | 50 |  | 295.96 | 17.2 |  |  |  |  |
| Species composition | Y | 4 | 3.92 | 546.42 | 23.38 | **0.001** |  | 4.7 | **0.006** |
| S | 4 | 3.51 | 470.6 | 21.69 | **0.001** |  | 2.32 | 0.105 |
| S × Y | 16 | 1.53 | 485.58 | 22.04 | **0.001** |  | 5.31 | **0.015** |
| Res | 50 |  | 2808.8 | 52.99 |  |  |  |  |

Table 3. Summary of previous and present studies relating to the macrozoobenthos around Dokdo and the East Sea; information on study year, study area, sampling site, habitat type, sampling effort (# of samples), sampling season, number of species (N), and density (D: ind. m-2) given.

| # | Year | Area | Site | Habitat type | # of  samples | Season | N | D | Reference |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 1980-1981 | Southern East Sea | Ulsan Bay | Subtidal | 5 | Sp, S, A, W | 127 | - | Yi et al., 1982 |
| 2 | 1995 | Onsan Bay, Kori | Intertidal | 16 | Sp, S, A, W | 71 | - | Yun and Song, 1998 |
| 3 | 1997 | Ulsan Bay Onsan Bay | Subtidal | 63 | W | 117 | 535 | Shin et al., 2001 |
| 4 | 2006 | Ulsan Bay | Subtidal | 9 | Sp, S, A, W | 199 | 4,578 | Yoon et al., 2009 |
| 5 | 2006 | Gijang | Subtidal | 18 | Sp, S, A, W | 157 | 552 | Kim et al., 2011 |
| 6 | 2007-2008 | Wolseong | Subtidal | 10 | Sp, S, A, W | 163 | 1,005 | Seo et al., 2009 |
| 7 | 2011-2012 | Gori | Subtidal | 11 | Sp, A, W | 369 | 1,712 | Yu et al., 2013 |
| 8 | 2012 | Pohang-Busan | Subtidal | 16 | S | 158 | 834 | Lee et al., 2014 |
| 9 | 1993-1994 | Northern East Sea | Gangneung | Subtidal | 14 | Sp, S, A, W | 163 | 1,168 | Choi et al., 2000 |
| 10 | 1997 | Gangneung, Namdaechon | Subtidal | 9 | A | 50 | 427 | Hong et al., 2004 |
| 11 | 1997 | Yangyang, Namdaechon | Subtidal | 11 | A | 17 | 380 | Hong et al., 2000 |
| 12 | 2005 | Hupo | Subtidal | 15 | Sp, S, A, W | 319 | 1,972 | Paik et al., 2007 |
| 13 | 2005-2007 | Uljin | Subtidal | 23 | Sp, S, A, W | 334 | 3,221 | Yu et al., 2011 |
| 14 | 2012-2013 | Uljin | Subtidal | 23 | S, W | 319 | 3,330 | Kwon et al., 2017 |
| 16 | 2013 | Uljin | Subtidal | 10 | Sp, S, A | 345 | 5,797 | Hwang et al., 2012 |
| 17 | 2015 | Russian Water | Subtidal | 430 | Sp, S | 211 | - | Kolpakov et al., 2018 |
| 18 | 1977-2014 |  | Russian Water | Subtidal | 13,387 | n.s. | 356 | - | Volvenko et al., 2018 |
| 19 | 1958 | Dokdo | Dokdo | Intertidal | 1 | W | 2 | - | Kim, 1960 |
| 20 | 1958 | Dokdo | Subtidal | 1 | n.s. | 3 | - | Rho and Kim, 1966 |
| 21 | 1976 | Dokdo | Intertidal | n.s. | n.s. | 16 | - | Kim, 1978 |
| 22 | 1981 | Dokdo | Intertidal, Subtidal | n.s. | n.s. | 42 | - | Kim and Choe, 1981 |
| 23 | 1981 | Dongdo, Seodo | Intertidal, Subtidal | 4 | A | 22 | - | Hong, 1981 |
| 24 | 1989 | Dongdo, Seodo | Subtidal | n.s. | S | 9 | - | Son and Hong, 1992 |
| 25 | 1992 | Dongdo, Seodo | Intertidal, Subtidal | 2 | S | 22 | - | Choe and Lee, 1994 |
| 26 | 1995 | Dongdo, Seodo | Intertidal, Subtidal | 2 | S | 33 | - | Kim et al., 1996 |
| 27 | 1995 | Dongdo, Seodo | Intertidal, Subtidal | 2 | S | 71 | - | Choe et al., 1996 |
| 28 | 1996 | Dongdo, Seodo | Intertidal, Subtidal | 2 | S | 157 | 792 | Je et al., 1997 |
| 29 | 1993-1999 | Dongdo, Seodo | Intertidal, Subtidal | 8 | Sp | 15 | - | Park and Song, 2000 |
| 30 | 1999 | Dokdo | Intertidal | 1 | S, W | 4 | 24 | Choi et al., 2002 |
| 31 | 1997-1999 | Dongdo, Seodo | Intertidal, Subtidal | 11 | A, Sp | 8 | 435 | Oh, 2001 |
| 32 | 2000 | Dongdo, Seodo | Subtidal | 5 | - | 13 | - | Park et al., 2002 |
| 33 | 1999-2000 | Dokdo | Subtidal | 5 | A, Sp | 15 | 629 | Choi et al., 2002 |
| 34 | 2004 | Dongdo, Seodo | Intertidal, Subtidal | 8 | Sp, W | 25 | - | Son et al., 2004 |
| 35 | 2002-2004 | Dongdo, Seodo | Intertidal, Subtidal | 8 | SP, A | 16 | - | Choi et al., 2006 |
| 36 | 1999-2004 | Dongdo, Seodo | Subtidal | 8 | Sp, W | 13 | - | Hong et al., 2006 |
| 37 | 2006-2008 | Dongdo, Seodo | Subtidal | 8 | SP, S | 31 | - | Hong et al., 2008 |
| 38 | 2007-2008 | Dongdo, Seodo | Intertidal, Subtidal | 9 | S, A, Sp | 97 | - | Ryu et al., 2012 |
| 39 | 2012 | Dongdo | Intertidal, Subtidal | 1 | S, A | 26 | - | Kang et al., 2013 |
| 40 | 2019 | Dokdo | Subtidal | 15 | A | 177 | 1,566 | Kang et al., 2019 |

n.s.: not specified.

**Figure captions**

**Fig. 1.** Map showing the study area and sampling stations around Dokdo, samples were collected from 5 fixed monitoring stations (D1–D5, for 5 years in 2013–17) encompassing three representative ecological habitats of oceanic plateau, coastal terrace, and island wharf. Each ecological habitat indicates different environmental conditions, i.e., in depth, wave exposure, sediment load, dominant microalgae, etc.

**Fig. 2.** Box plots of species diversity (A) and density (B) of subtidal macrozoobenthos species around Dokdo at each station and year. Each dot represents raw data of measurements. The values above a dashed line (A) indicates those over 700 individuals.

**Fig. 3.** Non-parametric multi-dimensional scaling (nMDS) ordination based on the average abundance of macrozoobenthos species with respect to the stations (A) and years (B) around Dokdo. The density of dominant taxa in each station and year are superimposed on the plot.

**Fig. 4.** Species accumulation curve obtained from Jackknife 2 estimator for each station, year and across Dokdo when the curve reaches an upper asymptote the station and year are consider to be fully sampled.

**Fig. 5.** Mini review on the occurrence and distribution of macrozoobenthos around Dokdo (A) and the East Sea (B and C). The overall diversity of each station in 2013−17 are compared with previous studies (1958−2012).