



SEASONAL ABUNDANCE OF EPIPHYTIC DINOFLAGELLATES AROUND COASTAL WATERS OF JEJU ISLAND, KOREA

Md. Mahfuzur Rahman Shah
Jeju Sea Grant Center, Jeju National University, Korea.

So-Jeong An
Department of Earth and Marine Sciences, College of Ocean Sciences, Jeju National University, Korea.

Joon-Baek Lee
*Department of Earth and Marine Sciences, College of Ocean Sciences, Jeju National University, Korea.,
jblee@jejunu.ac.kr*

Follow this and additional works at: <https://jmstt.ntou.edu.tw/journal>



Part of the [Aquaculture and Fisheries Commons](#)

Recommended Citation

Shah, Md. Mahfuzur Rahman; An, So-Jeong; and Lee, Joon-Baek (2013) "SEASONAL ABUNDANCE OF EPIPHYTIC DINOFLAGELLATES AROUND COASTAL WATERS OF JEJU ISLAND, KOREA," *Journal of Marine Science and Technology*. Vol. 21: Iss. 7, Article 20.

DOI: 10.6119/JMST-013-1220-5

Available at: <https://jmstt.ntou.edu.tw/journal/vol21/iss7/20>

This Research Article is brought to you for free and open access by Journal of Marine Science and Technology. It has been accepted for inclusion in Journal of Marine Science and Technology by an authorized editor of Journal of Marine Science and Technology.

SEASONAL ABUNDANCE OF EPIPHYTIC DINOFLAGELLATES AROUND COASTAL WATERS OF JEJU ISLAND, KOREA

Acknowledgements

This work was supported by the research grant of Jeju national University in 2012 to Md. M. R. Shah, and by Jeju Sea Grant in 2012, funded by the Ministry of Ocean and Fisheries (MOF) of the Republic of Korea.

SEASONAL ABUNDANCE OF EPIPHYTIC DINOFLAGELLATES AROUND COASTAL WATERS OF JEJU ISLAND, KOREA

Md. Mahfuzur Rahman Shah¹, So-Jeong An², and Joon-Baek Lee²

Key words: seasonal abundance, epiphytic dinoflagellates, climate change, Jeju Island.

were less preferred host by most of the dinoflagellates.

ABSTRACT

The seasonal abundance of epiphytic dinoflagellates in the intertidal zone of Jeju Island, Korea was quantitatively estimated by monthly collection of macroalgal samples (Rhodophyta, Phaeophyta, and Chlorophyta) from six sampling locations from July 2012 to June 2013. Ten epiphytic dinoflagellate taxa, including eight potentially toxic species *Amphidinium carterae*, *A. operculatum*, *Gambierdiscus* sp., *Ostreopsis ovata*, *Prorocentrum concavum*, *P. emarginatum*, *P. lima*, and *P. rhathymum*, were identified. Two *Amphidinium* and three *Prorocentrum* species are newly recorded in Korean coastal waters. A significant change in seasonal abundance was recorded with maximum (751.82 ± 223.12 cells g^{-1} wet weight of algae; cells g^{-1} hereafter) in June (summer), followed by October (autumn) (650.45 ± 225.02 cells g^{-1}) and September (598.02 ± 197.82 cells g^{-1}). *O. ovata* was the most abundant (338.21 ± 11 cells g^{-1}), reported in October and *Gambierdiscus* sp. was the least abundant, which was found only in September (6.92 ± 16.97 cells g^{-1}) and October (6.54 ± 6.54 cells g^{-1}) at Hamduk (St 2). Significantly, highest spatial abundance of total dinoflagellates for all sampling stations was found at Hamduk (St 2) (547.91 ± 315 cells g^{-1}), while it was lowest at Hwasun (St 5) (232.59 ± 144.93 cells g^{-1}). Abundance of all dinoflagellate species was significantly correlated with environmental parameters, with some exceptions. During summer and autumn, increasing abundance of dinoflagellate at all sampling stations compared to the other seasons emphasizes environmental and biological interactions of epiphytic dinoflagellate with host macroalgae. Generally, each of the epiphytic dinoflagellates did not show specific preference of macroalgae as host. However, Chlorophytes

I. INTRODUCTION

Species in the genera *Gambierdiscus*, *Ostreopsis*, *Coolia*, *Prorocentrum*, and *Amphidinium* are known to be epiphytic and/or benthic dinoflagellates [25, 48]. Most of the epiphytic dinoflagellates in these genera are known to be potentially toxic [13, 36] and harmful to human as well as to marine organisms, alerting scientists, aquaculture industry, and government [35]. The most well known human intoxication because of benthic epiphytic dinoflagellates is ciguatera fish poisoning [19]. Globally, one million people may be affected by ciguatera annually [22], with estimated economic impact of ciguatera in the United States to be \$21.19 million per year on average [4]. The genus *Gambierdiscus* is the main causative agent of ciguatera. In particular, *Prorocentrum lima*, *P. concavum*, *Ostreopsis siamensis*, and *O. ovata* have been implicated in ciguatera fish poisoning based on distribution, toxicity to mice and the presence of a fat soluble toxic fraction [39, 51]. These organisms from epiphytic communities associated with coral reefs, or rather with macroalgae attached to coral surfaces. These assemblages may vary in species composition and cell concentration between sites [49]. The mixed association of toxic dinoflagellates may contribute to the polymorphism of the clinical features of ciguatera [52].

The majority of the benthic epiphytic dinoflagellates are reported from tropical or subtropical regions of the Pacific Ocean, Indian Ocean, and the Caribbean, and found associated with seagrasses, green, brown, and red algae, as well as dead coral and sediment [2, 18]. However, some species also live in temperate regions [44]. The occurrence of epiphytic and benthic dinoflagellates in temperate waters has been reported as evidence of increasing water temperature [26, 27, 43]. Seasonal/annual and interannual dynamics of benthic and epiphytic dinoflagellate assemblages in reef zone have been studied in the Virgin Islands [8], on Singapore reefs [24], and in the NW Mediterranean [50].

Jeju Island belonging to the temperate region classified based on air temperature and coastline is mainly composed of rocky shore and sandy beaches with a few sand tidal flats.

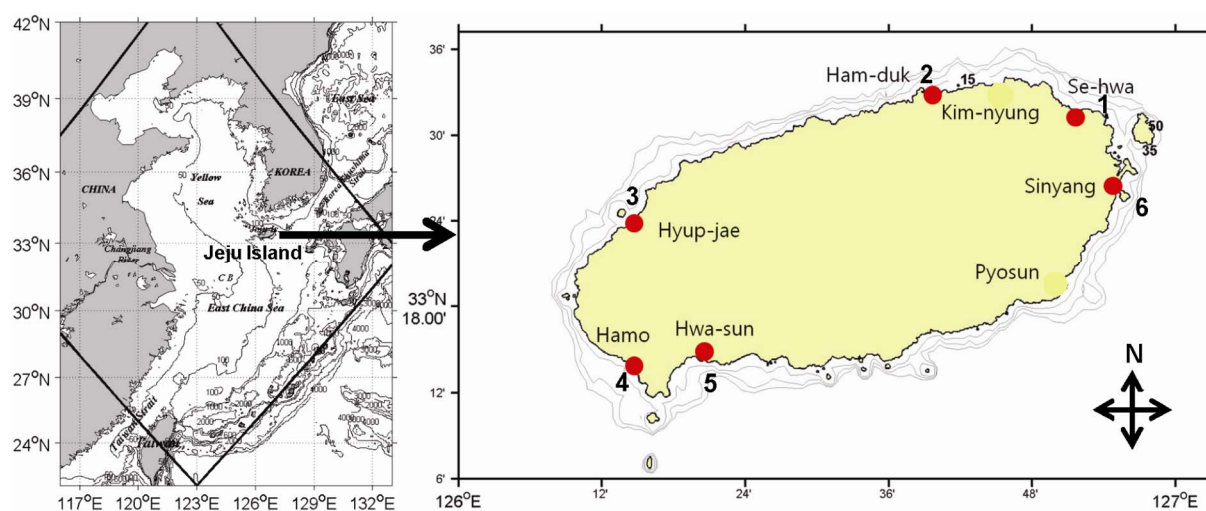
Paper submitted 11/04/13; revised 12/11/13; accepted 12/20/13. Author for correspondence: Joon-Baek Lee (e-mail: jblee@jejunu.ac.kr).

¹ Jeju Sea Grant Center, Jeju National University, Korea.

² Department of Earth and Marine Sciences, College of Ocean Sciences, Jeju National University, Korea.

Table 1. Summary of sampling stations in the intertidal zone along the coasts of Jeju Island, Korea.

Station	Locations	Latitude/ Longitude	Characteristics of sampling stations
1	SEHWA	33°31'29.86"N/126°51'40.50"E	Sandy beach with fine white sand and volcanic rocks
2	HAMDUK	33°32'32.94"N/126°40'12.27"E	White sandy beach with fine white sand
3	HYUPJAE	33°23'38.88"N/126°14'23.02"E	Large sandy beach with volcanic rocks
4	HAMO	33°12'39.86"N/126°15'38.23"E	Very small beach with coarse black and white sand with volcanic rocks
5	HWASUN	33°14'22.38"N/126°19'55.67"E	Small beach with coarse black and white sand with volcanic rocks
6	SINYANG	33°31'29.86"N/126°51'40.50"E	Sandy beach with fine white sand and volcanic rocks

**Fig. 1.** Map showing Jeju Island, Korea and locations of six sampling stations along the coasts of Jeju Island.

Previously, the dinoflagellates recorded from this Island were planktonic but potentially toxic benthic and epiphytic species have not been well documented. Information on existing diversity and distribution patterns and abundance of epiphytic dinoflagellates around Jeju Island is limited. To date, no toxic event caused by a marine benthic dinoflagellate has been reported from Jeju Island. Kim *et al.* [29] reported abundance of epiphytic dinoflagellate in autumn 2009. Jeong *et al.* [26, 27] and Lim *et al.* [33] reported the presence of benthic epiphytic dinoflagellates in the coastal waters of Jeju Island. However, in-depth information on diversity and seasonal abundance of benthic epiphytic dinoflagellates from coastal waters of Jeju Island is needed.

The aim of this study was to survey epiphytic dinoflagellate community present in intertidal zone of the coastal waters of Jeju Island. The objectives of the this study were: (1) to determine the species composition of epiphytic dinoflagellates, (2) to evaluate seasonal changes of benthic and epiphytic dinoflagellates, (3) to relate the presence and abundance of dinoflagellates from various macroalgal substrates, (4) to determine the physical-chemical variables and their relation to the abundance of dinoflagellates. The results of this study can be used to ascertain the potential threat that toxigenic epiphytic dinoflagellates pose to coastal food webs and human health.

II. MATERIALS AND METHODS

1. Study Sites and Sample Collection

This study was carried out from July 2012 to June 2013 in the intertidal zone along the coasts of Jeju Island, Korea. Monthly sampling was carried out at six stations (beaches) (Fig. 1). Total 247 samples of macroalgae including 30 macroalgal species (Rhodophyta, Phaeophyta, and Chlorophyta) were collected during the lowest low tide. A brief description of the characteristics, latitudes, and longitudes of the sampling stations is presented in Table 1. Hands picked macroalgae of ca. 20-100 g wet weight was placed into individual plastic Ziploc bags with ambient seawater. Samples were stored on ice cooler for transportation back to the laboratory.

In laboratory, each macroalgae was put in a plastic container with 200 mL of fresh filtered seawater were vigorously shaken to dislodge epiphytic dinoflagellate cells for 1 minute, and the material was passed through 200 and 100 μm mesh sieves to remove large particles and finally passed through a 20 μm mesh sieve. The material retained by the sieve was resuspended in sterile filtered seawater (25 mL) and fixed in 3.7% (final concentration) paraformaldehyde in filtered seawater. Wet weight of each macroalgal sample was determined using weighing balance. For quantitative analysis, 1 mL of preserved sample was counted triplicate using

Table 2. List of epiphytic dinoflagellates and abundance (cells g⁻¹ wet wt of algae) for each month during July 2012-June 2013 from Jeju Island, Korea.

Dinoflagellates	2012					
	Jul	Aug	Sep	Oct	Nov	Dec
<i>Amphidinium carterae</i> *#	14.38 ± 11.72 ^b	11.31 ± 6.39 ^b	20.63 ± 17.21 ^b	33.61 ± 26.61 ^{ab}	20.78 ± 14.72 ^b	12.03 ± 2.40 ^b
<i>A. operculatum</i> *#	19.56 ± 21.33 ^b	16.60 ± 5.91 ^b	39.64 ± 20.64 ^b	53.71 ± 29.25 ^{ab}	24.13 ± 15.43 ^b	19.58 ± 9.86 ^b
<i>Coolia malayensis</i>	48.52 ± 14.69 ^b	46.15 ± 17.66 ^{ab}	109.95 ± 43.82 ^a	104.85 ± 47.45 ^a	66.38 ± 48.13 ^{ab}	52.65 ± 9.27 ^b
<i>Gambierdiscus</i> sp.*	0 ± 0	0 ± 0	6.92 ± 16.97 ^a	6.54 ± 16.04 ^a	0 ± 0	0 ± 0
<i>Ostreopsis ovata</i> *	231.07 ± 87.87 ^{ab}	160.69 ± 81.69 ^b	311.03 ± 126.14 ^a	338.21 ± 119.54 ^a	196.61 ± 109.57 ^a	77.48 ± 46.43 ^b
<i>Prorocentrum concavum</i> *#	30.12 ± 18.05 ^{ab}	12.79 ± 11.62 ^b	38.51 ± 25.60 ^{ab}	28.78 ± 15.64 ^{ab}	17.69 ± 20.45 ^{ab}	17.24 ± 15.22 ^{ab}
<i>P. emarginatum</i> *#	6.40 ± 8.23 ^a	3.36 ± 4.30 ^a	9.75 ± 16.18 ^a	13.16 ± 17.98 ^a	2.77 ± 3.91 ^a	7.96 ± 13.18 ^a
<i>P. fukuyoi</i> #	4.37 ± 4.93 ^a	7.62 ± 7.23 ^a	17.93 ± 19.48 ^a	23.23 ± 15.24 ^a	16.42 ± 16.63 ^a	14.19 ± 12.10 ^a
<i>P. lima</i> *	12.71 ± 16.06 ^a	7.82 ± 11.21 ^a	24.09 ± 33.57 ^a	39.48 ± 48.91 ^a	8.76 ± 10.25 ^a	4.19 ± 6.67 ^a
<i>P. rhathymum</i> *	13.70 ± 22.55 ^a	12.56 ± 14.31 ^a	14.99 ± 14.74 ^a	10.36 ± 18.01 ^a	11.07 ± 15.02 ^a	9.7 ± 9.53 ^a
Total dinoflagellates	414.96 ± 137.86 ^b	273.48 ± 103.76 ^{bc}	598.02 ± 197.82 ^b	650.45 ± 225.02 ^{ab}	383.63 ± 153.75 ^{bc}	216.82 ± 81.67 ^{bc}
Dinoflagellates	2013					
	Jan	Feb	Mar	Apr	May	Jun
<i>Amphidinium carterae</i> *#	14.82 ± 3.99 ^b	16.77 ± 8.34 ^{ab}	19.78 ± 18.97 ^b	22.47 ± 14.32 ^{ab}	36.75 ± 10.47 ^{ab}	76.39 ± 37.21 ^a
<i>A. operculatum</i> *#	22.32 ± 7.13 ^b	27.45 ± 9.66 ^b	38.33 ± 9.52 ^b	35.28 ± 11.12 ^b	52.04 ± 17.50 ^{ab}	103.04 ± 37.60 ^a
<i>Coolia malayensis</i>	23.03 ± 10.42 ^b	35.34 ± 10.33 ^b	59.39 ± 21.12 ^{ab}	64.90 ± 28.57 ^{ab}	81.02 ± 19.09 ^{ab}	131.31 ± 77.43 ^a
<i>Gambierdiscus</i> sp.*	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
<i>Ostreopsis ovata</i> *	43.33 ± 20.33 ^c	60.91 ± 18.55 ^{bc}	95.71 ± 29.24 ^{bc}	123.52 ± 31.01 ^{ab}	172.79 ± 59.14 ^b	303.10 ± 64.83 ^a
<i>Prorocentrum concavum</i> *#	16.44 ± 9.69 ^{ab}	21.14 ± 7.81 ^{ab}	32.64 ± 20.40 ^{ab}	24.10 ± 14.51 ^{ab}	25.3 ± 7.25 ^{ab}	40.61 ± 28.98 ^a
<i>P. emarginatum</i> *#	1.43 ± 3.50 ^a	4.09 ± 4.77 ^a	10.76 ± 9.27 ^a	8.40 ± 5.30 ^a	7.38 ± 7.61 ^a	20.14 ± 21.04 ^a
<i>P. fukuyoi</i> #	18.45 ± 11.80 ^a	15.75 ± 13.79 ^a	6.17 ± 5.45 ^a	8.97 ± 6.60 ^a	5.63 ± 8.51 ^a	28.27 ± 15.50 ^a
<i>P. lima</i> *	11.26 ± 7.59 ^a	22.77 ± 18.47 ^a	12.30 ± 6.90 ^a	23.17 ± 19.51 ^a	33.87 ± 14.49 ^a	41.79 ± 24.57 ^a
<i>P. rhathymum</i> *	7.55 ± 13.05 ^a	11.014 ± 14.00 ^a	6.99 ± 7.49 ^a	5.70 ± 9.63 ^a	18.04 ± 17.32 ^a	30.02 ± 29.23 ^a
Total dinoflagellates	173.15 ± 72.25 ^c	203.03 ± 47.79 ^{bc}	266.67 ± 67.98 ^{bc}	317.02 ± 54.04 ^{bc}	424.63 ± 103.85 ^{bc}	751.82 ± 223.12 ^a

An ‘*’ denotes potentially toxic species. A ‘#’ denotes new record for Korean waters. Values are reported as averages ± standard deviation. The letters next to each dinoflagellate abundance value indicate that values are significantly different from the others within the same row, where ‘a’ is the highest value and ‘c’ is the lowest value.

Sedgwick-Rafter counting chamber under microscope (Axio-plan 2, Carl Zeiss, Oberkochen, Germany) at 20X and 40X magnifications. Cell density of epiphytic dinoflagellates expressed as cells g⁻¹ wet weight of macroalgae (cells g⁻¹ hereafter), following the methodology described by Delgado *et al.* [12] and Okolodkov *et al.* [40].

2. Identification of Dinoflagellates and Macroalgae

Freshly-collected living dinoflagellates were isolated by the micropipette-washing method, placed on slide glass covered with a cover slip, and the morphometric features were observed under transmitted light with bright field and phase-contrast at 400X magnification and photographed using a microscope (Axio-plan 2, Carl Zeiss) equipped with a digital camera (AxioCam ERc5s, Carl Zeiss). Both the dorsal and ventral sides of each dinoflagellate were examined. Cell size and some morphometric measurements were obtained from micrographs using Carl Zeiss ZEN Lite software. Thecal plate patterns of armored dinoflagellates were identified using Calcofluor White M2R [17]. The Calcofluor stained cells were examined using an epifluorescence (violet excitation at 430 nm, blue emission at 490 nm) microscope (Axio-plan 2, Carl Zeiss) equipped with a digital camera (AxioCam ICm1, Carl Zeiss). Unarmored dinoflagellates were identified

based on morphological features such as body contour and proportion, cingulum displacement, sulcus extension and direction on the epitheca, and presence and location of specific organelles. Dinoflagellates were identified using previously published schemes [3, 10, 14-16, 18, 21, 36, 38, 47]. Macroalgae were identified using appropriate keys [30, 31] and cataloged.

3. Physico-Chemical Parameters Analysis

Hydrological variables such as water temperature (°C) and salinity (psu) were estimated every month during sample collection in the water column of intertidal zone of all sampling stations with a temperature-salinity meter (YSI 35, Yellow Spring Instrument, Ohio, USA).

4. Statistical Analysis

Epiphytic dinoflagellate abundance data (each individual species and total number of dinoflagellate species) were tested for site and macroalgal host preference using one-way ANOVA with Tukey’s pair wise comparisons. Dinoflagellate abundance data were also tested for significant correlation (Pearson) with environmental variables (temperature, salinity). All statistical tests were conducted using Microsoft Excel and Graph Pad InStat ver.3 at an alpha level of 0.05.

III. RESULTS AND DISCUSSION

1. Epiphytic Dinoflagellate Species Composition

From the six study sites, ten species in five genera of epiphytic dinoflagellates were identified; of these, eight are potentially toxic species and four are first reported in Korean waters (Table 2). The number of species encountered in this study is comparable to values reported in other studies conducted around the world. For example, Faust [13] reported 16 species in sandy environments around Belize. Parsons and Preskitt [41] reported 26 benthic dinoflagellate species from Hawaiian coastal waters. Four of the species found in this study, have been reported previously in Jeju Island: *Coolia malayensis* [27], *Ostreopsis ovata* [28], *Prorocentrum rhathymum* [33], and *P. lima* [45]. *Amphidinium carterae*, *A. operculatum*, *P. concavum*, *P. emarginatum*, and *P. fukuyoi* are reported as present in Jeju coastal waters for the first time. Although *Gambierdiscus caribaeus* was reported from Jeju Island in previous study [26], *Gambierdiscus* sp. found in this study was not identified up to species level. Several of these dinoflagellates (e.g., *Gambierdiscus* sp., *P. concavum*, *P. emarginatum*, *P. rhathymum*, and *O. ovata*) have been reported from many other tropical and subtropical locations including Pacific Ocean [41], the Caribbean Sea [15], and in the Mediterranean Sea [2]. *P. lima* is a cosmopolitan species, found from boreal to tropical waters around the world [15, 41] and *P. rhathymum* commonly found in tropical and subtropical waters in the Atlantic and Pacific Ocean [15].

Eight of the encountered species in this study can be considered potentially toxic species [46], because they have been reported as toxic elsewhere [39, 52]. All species of *Prorocentrum* (except *P. fukuyoi*) in this study are reported as toxic (Table 2), known to produce okadaic acid and its derivatives, responsible of diarrhetic shellfish poisoning and may be involved in ciguatera fish poisoning [37].

2. Seasonal Abundance of Epiphytic Dinoflagellates

Epiphytic dinoflagellates were found during all the months of the annual sampling cycle (July 2012-June 2013) in the intertidal zone along the coasts of Jeju Island. The average abundance of total epiphytic dinoflagellates was significantly ($p < 0.05$) highest (751.82 ± 223.12 cells g^{-1}) and lowest (173.15 ± 72.25 cells g^{-1}) in June (summer) and January (winter), respectively (Table 2). The abundance pattern changed in August (late summer with rainfall), when we observed abrupt decline in the number of total cells during this month. A second peak of total average abundance (650.45 ± 225.02 cells g^{-1}) occurred in October (autumn) (Table 2). Similar seasonal pattern was reported by Delgado *et al.* [12] from northwestern coast of Cuba, where highest average abundance was in June 1999-2000 (1012 cells g^{-1}) and in 2000-2001 (1089 cells g^{-1}) and lowest mean concentration (21 cells g^{-1}) was in February. In 1999-2000, these authors observed abrupt decline in cells during August and September, and second peak of abundance (609 cells g^{-1}) in October.

In case of monthly variation of epiphytic dinoflagellates abundance in Jeju Island, *O. ovata* among the ten species was the most abundant species (338.21 ± 11 cells g^{-1}), which was reported in October (Table 2). The abundances of epiphytic dinoflagellate *Ostreopsis* sp. were quite lower than values reported in the previous studies: for example, Kim *et al.* [29]; about 9×10^3 cells g^{-1} , Parson and Preskitt [41]; 18×10^3 cells g^{-1} , Mangialajo *et al.* [35]; 2451×10^3 cells g^{-1} , Holmes *et al.* [24]; 3.3×10^3 cells g^{-1} , Aligizaki and Nikolaidis [1]; about 4.0×10^5 cells g^{-1} for *Ostreopsis ovata* + *O. siamensis*. *Gambierdiscus* sp. was the least abundant species, which was found only in September (average 6.92 ± 16.97 cells g^{-1}) and October (average 6.54 ± 6.54 cell g^{-1}) (Table 2). The abundance of *Gambierdiscus* sp. in the present study was extremely lower than these of Kim *et al.* [29] (about 5×10^3 cell g^{-1}); *G. toxicus* from the Gambier Islands, Pacific Ocean by Yasumoto *et al.* [51] (500×10^3 cells g^{-1}); *Gambierdiscus* sp. from Hawaii (average 127 cells g^{-1}) [41]; Tahiti, French Polynesia (10.88×10^3 cells g^{-1}) [10]. Similar to our study, low abundance of *Gambierdiscus*, *G. toxicus* was reported from Mauritius (0-4 cells g^{-1}) [25].

The average abundance of *A. carterae* and *A. operculatum* reached highest of 76.39 ± 37.21 cell g^{-1} and 103.04 ± 37.60 cells g^{-1} , respectively in June. The abundance of these species are also lower than Kim *et al.* [29], wherein the authors reported a maximum abundance of 0.41×10^3 cells g^{-1} for *Amphidinium* spp. from Jeju Island. Okolodkov *et al.* [40] reported abundance of 41172 cells g^{-1} from Gulf of Mexico, which is higher than our study. *Coolia malayensis* showed highest average abundance of 109.95 ± 43.82 cells g^{-1} in this study, whereas Kim *et al.* [29] reported higher abundance of 0.71×10^3 cells g^{-1} for *Coolia* spp. Calson and Tindoll [8] recorded 1200×10^3 cells g^{-1} for *Coolia monotis* from Virgin Island, Caribbean Sea. The average abundance of *Prorocentrum concavum* was also lower in our study (41.61 ± 28.98 cells g^{-1}) compared to the study by Delgado *et al.* [12] ($<10^3$ cell g^{-1}). Parson and Preskitt [41] estimated cell densities of 0-69 cells g^{-1} for *Prorocentrum emarginatum* and 3-224 cells g^{-1} for *Prorocentrum lima*, which are more similar to our findings (*P. emarginatum*: 20.14 ± 43.82 cells g^{-1} and *P. lima*: 41.79 ± 24.57 cells g^{-1}) but less than those reported by Delgado *et al.* [12] ($10^4 \sim 10^5$ cell g^{-1}) and Okolodkov *et al.* [40] (29756 cells g^{-1}) of *P. lima*. Parson and Preskitt [41] recorded *P. lima* + *P. concavum* densities averaged from 0 to 598 cells g^{-1} . In this study *Prorocentrum fukuyoi* and *Prorocentrum rhathymum* average cell abundance were 28.27 ± 5.50 cells g^{-1} , and 30.02 ± 29.23 cells g^{-1} (Table 2). Kim *et al.* [29] reported higher abundance of *Prorocentrum* spp. (0.30×10^3 cells g^{-1}) from Jeju Island than our study.

3. Spatial Abundance and Distribution of Epiphytic Dinoflagellates

Epiphytic dinoflagellates were found at all the stations during the sampling period. There was significant ($p < 0.05$) difference in the total cell numbers between sampling stations

Table 3. Abundance (cells g⁻¹ wet wt of algae) of epiphytic dinoflagellate species at each of the six sampling sites from Jeju Island during July 2012-June 2013.

Dinoflagellates	Sehwa (46)	Hamduk (51)	Hyupjae (47)	Hamo (45)	Hwasun (43)	Sinyang (45)
<i>Amphidinium carterae</i>	19.18 ± 16.49 ^a	27.83 ± 38.22 ^a	30.99 ± 16.98 ^a	15.06 ± 17.46 ^a	25.50 ± 26.05 ^a	31.29 ± 17.791 ^a
<i>A. operculatum</i>	35.19 ± 28.71 ^a	40.68 ± 40.89 ^a	32.77 ± 16.55 ^a	36.29 ± 25.76 ^a	35.97 ± 33.45 ^a	44.95 ± 26.78 ^a
<i>Coolia malayensis</i>	63.16 ± 42.32 ^a	97.50 ± 73.00 ^a	68.84 ± 34.85 ^a	68.53 ± 41.28 ^a	47.46 ± 26.41 ^a	66.25 ± 30.35 ^a
<i>Gambierdiscus</i> sp.	0 ± 0	7.351 ± 16.36	0 ± 0	0 ± 0	0 ± 0	0 ± 0
<i>Ostreopsis ovata</i>	215.09 ± 129.08 ^a	241.44 ± 150.21 ^a	191.99 ± 125.19 ^b	160.21 ± 92.81 ^b	81.00 ± 58.40 ^c	167.50 ± 99.52 ^b
<i>P. concavum</i>	31.34 ± 12.97 ^a	42.54 ± 24.03 ^a	28.27 ± 13.94 ^a	24.24 ± 14.19 ^a	12.60 ± 12.60 ^a	13.68 ± 12.37 ^a
<i>P. emarginatum</i>	9.62 ± 7.74 ^a	16.55 ± 18.08 ^a	5.21 ± 7.57 ^a	6.48 ± 8.41 ^a	5.96 ± 13.17 ^a	3.98 ± 6.58 ^a
<i>P. fukuyoi</i>	18.51 ± 12.52 ^a	21.94 ± 15.71 ^a	16.49 ± 11.57 ^a	7.34 ± 10.14 ^a	0.20 ± 0.72 ^b	19.01 ± 12.18 ^a
<i>P. lima</i>	35.64 ± 32.66 ^a	39.91 ± 25.32 ^a	16.79 ± 15.06 ^{ab}	10.80 ± 12.99 ^{ab}	6.44 ± 8.69 ^b	11.53 ± 17.50 ^{ab}
<i>P. rhathymum</i>	2.34 ± 5.06 ^b	7.22 ± 10.19 ^{ab}	25.19 ± 18.99 ^a	14.07 ± 13.39 ^a	25.44 ± 19.69 ^a	0.94 ± 3.26 ^c
Total Dinoflagellates	426.40 ± 222.01 ^a	547.91 ± 315.37 ^a	423.82 ± 176.98 ^a	348.01 ± 157.25 ^a	232.59 ± 144.93 ^b	358.10 ± 171.54 ^a

Values are reported as averages ± standard deviation. The numbers in parentheses next to each site represent the number of samples analyzed. The letters next to each dinoflagellate abundance value indicate that values are significantly different from the others within the same row, where 'a' is the highest value and 'c' is the lowest value.

(Table 3). Highest total abundance occurred at Hamduk (St 2) with mean value of 547.91 ± 315.37 cells g⁻¹. Lowest total abundance of epiphytic dinoflagellates was found at Hwasun (St 5), with mean concentrations of 232.59 ± 1441.93 cells g⁻¹ (Table 2). At Hamduk (St 2), all the epiphytic dinoflagellates showed highest mean abundance, except *Amphidinium carterae* and *A. operculatum* occurred at maximum mean cell abundance at Sinyang (St 6) (Table 3). Among all the sampling stations, comparatively lower abundance of epiphytic dinoflagellates at Hamo (St 4) and Hwasun (St 5) stations (more exposed coasts located at south-western part of Jeju Island) might be related with species interactions of dinoflagellates with physical and biological environment and also macroalgal abundance. This observation agrees well with Kim *et al.* [29], who also found lower abundance of epiphytic dinoflagellates near those areas. Shaking effect due to turbulent water at the open coast (physical-biological interaction) and/or diverse bi-species interaction among different macroalgae-epiphyte combinations may limit or support their success [7].

4. Dynamics of Water Temperature and Salinity, and Their Relation to Abundance of Dinoflagellates

The water temperature exhibited a predictable seasonal fluctuation with the range of 10.9°C to 26.3°C. Monthly average water temperature for all stations was highest (26.016 ± 0.33 °C) in July 2012 (summer) and lowest (12.98 ± 1.44 °C) in January 2013 (winter) (Fig. 2A). During the study period, salinity of the coastal seawaters in intertidal zone of Jeju Island ranged from 23.6 to 34.8 psu. For all the sampling stations, monthly average lowest salinity (26.33 ± 1.94 psu) was recorded in August 2012 (summer) and the highest salinity (33.91 ± 0.83 psu) was in April 2013 (spring) (Fig. 2B).

Total dinoflagellate abundance, *C. malayensis*, *O. ovata*, *Gambierdiscus* sp., *P. concavum*, *P. emarginatum*, *P. fukuyoi* and *P. rhathymum* abundance were significantly correlated

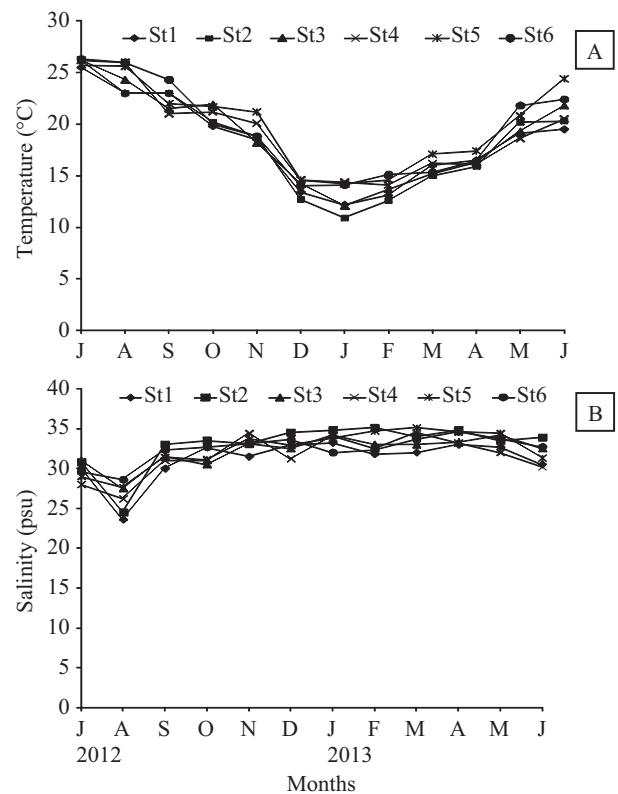


Fig. 2. Monthly variations in water temperature (A) and salinity (B) in the intertidal zone from July 2012 to June 2013 at different sampling stations of Jeju Island, Korea.

with water temperature and salinity (Table 4). *A. carterae* was the only dinoflagellate to be not significantly correlated with temperature and salinity. *A. operculatum* did not show significant correlation with the salinity and *P. lima* was not significantly correlated with temperature variation in this study. Lower abundance of epiphytic dinoflagellates during winter

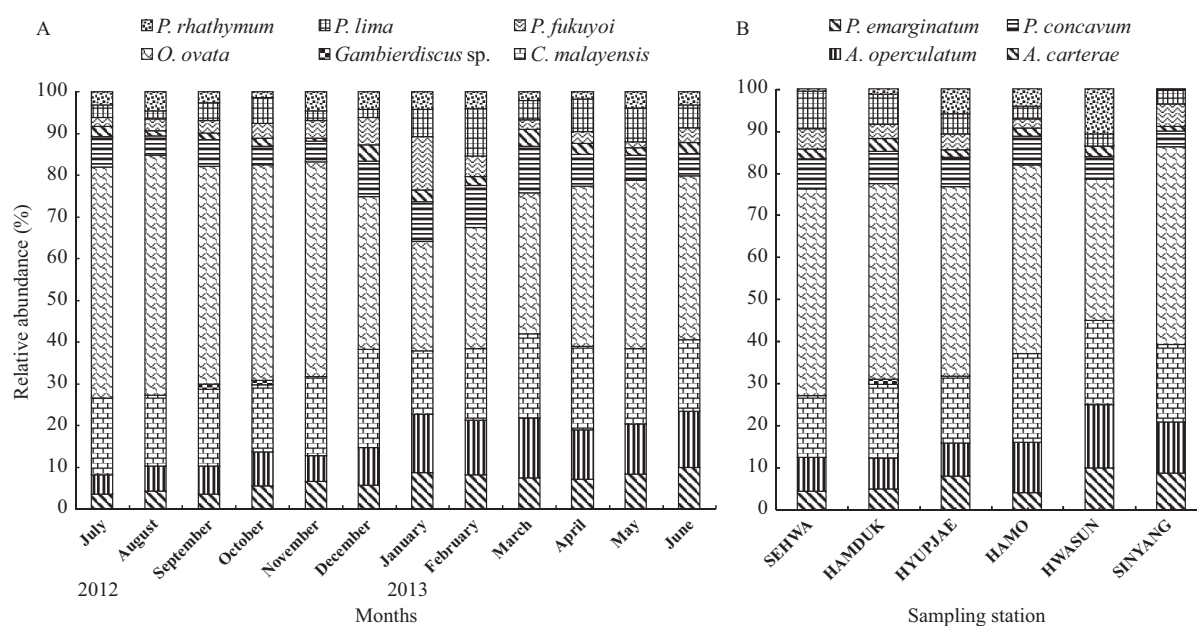


Fig. 3. A. Relative abundance of epiphytic dinoflagellate species by month from July 2012 to June 2013. B. Relative abundance of epiphytic dinoflagellates at each station from July 2012 to June 2013.

Table 4. Pearson correlation analysis results between epiphytic dinoflagellates abundance and water temperature and salinity parameters at all stations during July 2012-June 2013 from Jeju Island, Korea.

Dinoflagellates	Temperature (°C)	Salinity (psu)
<i>Amphidinium carterae</i>	ns	ns
<i>A. operculatum</i>	0.18 (0.01)*	ns
<i>Coolia malayensis</i>	0.43 (0.00)**	0.00 (0.00)**
<i>Gambierdiscus</i> sp.	0.29 (0.00)**	-0.09 (0.00)**
<i>Ostreopsis ovata</i>	0.75 (0.00)**	-0.33 (0.00)**
<i>P. concavum</i>	0.34 (0.03)*	0.12 (0.02)*
<i>P. emarginatum</i>	0.23 (0.00)**	0.08 (0.00)**
<i>P. fukuyoi</i>	-0.12 (0.05)*	0.17 (0.00)**
<i>P. lima</i>	ns	0.17 (0.00)**
<i>P. rathymum</i>	0.48 (0.01)*	-0.23 (0.00)**
Total average	0.59 (0.00)**	-0.14 (0.00)**

Non-significant results are denoted by 'ns' for each dinoflagellate species. The correlation coefficient and corresponding p -value (in parentheses) at $p < 0.05^*$ and $p < 0.001^{**}$ is given for significant results.

months might be due to lower temperature recorded in Jeju Island. Higher water temperatures could be a promoting factor for the growth of macroalgae and epiphytic dinoflagellates [12]. Lower abundance seems to be related to decreasing salinity due to rainfall in August, which agrees well with the observation in the northwestern coast of Cuba [12]. In September and October, the increase of epiphytic dinoflagellates in Jeju Island probably depended on several environmental factors acting at the same time [8].

Our results were found to be comparable to those observed in the Virgin Islands, where all seven toxic epiphytic dinoflagellate species were positively or negatively correlated with water temperature [8]. In east Tasmanian waters, a decrease in temperature was associated with a decline in dinoflagellate numbers through winter [42]. In contrast, in southwestern Puerto Rico, two dominant epiphytic dinoflagellate species were not strongly correlated with temperature [5]. In Queensland, Australia, periodicity in the *G. toxicus* abundance did not seem to be related directly to temperature, and complex substrate interactions and other unknown factors appear to be involved [20]. In the NW Mediterranean, no significant correlations were observed between epiphytic dinoflagellates and water temperature; however, the epiphytic dinoflagellate assemblage demonstrated a clear seasonality [50]. High harmful dinoflagellates concentrations in May and October were related to physicochemical conditions in northwestern coast of Cuba [12]. The mechanisms that trigger species abundance are unclear, but changes in the hydrodynamic regime may be involved [50].

5. Relative Abundance of Epiphytic Dinoflagellates

In this study, *Ostreopsis ovata* predominated in abundance and spatial-temporal distribution of epiphytic dinoflagellates and was perennially present. Highest (57.4%) and lowest (26.1%) relative abundance of *O. ovata* occurred in August 2012 and January 2013, respectively, when low densities on the whole epiphytic dinoflagellates occurred in all stations. The relative abundances of other species were <10%, except for *Coolia malayensis* and *Amphidinium operculatum* that reached a highest relative abundance (23.48% and 14.33%) in December and March 2013, respectively (Fig. 3A).

Considering the relative abundance of each dinoflagellate species in different stations, *O. ovata* was also the dominant species (33.6% to 49.1%) at all sampling stations followed by *C. malayensis* (14.5% to 21%). The remaining species were <10%, except for *A. operculatum*, which reached a maximum relative abundance of 15% at Hwasun (St 5) (Fig. 3B).

An association, consisting of *Ostreopsis siamensis*, *O. lenticularis*, *O. ovata*, *Prorocentrum lima*, *P. compressum* and *Coolia monotis*, has been recorded in northern New Zealand [9]. The dominant species, *O. siamensis*, accounted for 64% to 85% of the total epiphytic flora during summer [9] which is more or less similar to our findings for this study. Bomber *et al.* [6] reported *P. lima* species during the entire year in the Florida Keys, being more abundant from November to May. Heil *et al.* [23] reported *P. lima* species as the most abundant along Australian shores and associated with ciguatera. Delgado *et al.* [12] found *P. lima* as the dominant species (<50%) at all sampling stations in north-western coast of Cuba followed by *G. toxicus* (8 to 33%) and remaining species were lower than 8%. In this study, *P. lima* was never found as dominant species. Hurbungs *et al.* [25] reported *Amphidinium* sp. dominated (32.5%) over other species followed by *Prorocentrum* sp. (27.3%) and *C. monotis* (21.4%) in Mauritius.

6. Host Preference of Epiphytic Dinoflagellates

We found total 30 species of macroalgae belonging to 21 genera under Rhodophyta, Phaeophyta and Chlorophyta (Table 5). Various species of macroalgae (Rhodophyta, Phaeophyta, Chlorophyta, and Cyanophyta) have been reported as host for different numbers of epiphytic dinoflagellates [49].

Among the ten epiphytic dinoflagellates, *Amphidinium carterae* and *Ostreopsis ovata* were found on all the macroalgal samples. Abundance of *A. carterae* was highest (16.94 ± 17.71 cells g^{-1}) on Pheophyte (*Dictyopteris prolifera*). Kim *et al.* [29] observed *Amphidinium* spp. with seven macroalgal species (*Cladophora wrightiana*, *Sargassum* sp., *Dictyopteris divaricata*, *Chordaria flagelliformis*, *Padina arborescens*, and *Martensia* sp.) with maximum cell density on *Martensia* sp. (406 cells g^{-1}). From these seven macroalgal species, *Chordaria flagelliformis*, *Padina arborescens* were not found during this study.

O. ovata cell abundance was overall higher for most of the macroalgal host with the highest abundance (102.07 ± 17.71 cells g^{-1}) on Chlorophyte *Cladophora wrightiana*. *Amphidinium operculatum* cells were recorded from all the macroalgal samples with highest abundance (22.66 ± 17.71 cells g^{-1}) on Rhodophyte *Chondrus ocellatus* but it was only absent on *Jania adhaerens*. *O. ovata* were not found attached on *Codium fragile* by Kim *et al.* [29], which disagree with present study. The highest density (5.9×10^5 cells g^{-1}) detected for *Ostreopsis* sp. on *Halogetis scoparia* by the study of Vila *et al.* [50].

Coolia malayensis also preferred all macroalgae except one Chlorophyte *Codium fragile* which agreed with the observa-

tion by Kim *et al.* [29]. In this study, *C. malayensis* found on all macroalgae reported by Kim *et al.* [29], except *C. flagelliformis* and *P. arborescens*. *C. malayensis* highest cell density on *Hizikia fusiformis* (42.21 ± 33.15 cells g^{-1}) from this study differed with Kim *et al.* [29], who found highest cell density (710 cells g^{-1}) of *Coolia* spp. on Rhodophyte *Martensia* sp. Carlson and Tindol [8] found *C. monotis* density of 1.2×10^6 cells g^{-1} in Virgin Islands, which is very high compared to Jeju Island, Korea.

In our study, *Gambierdiscus* sp. was exceptionally absent on all macroalgae and only exclusively found attached on Rhodophyte *Gelidium amansii* with low abundance, whereas *Gambierdiscus* spp. were attached all the macroalgae, except *Codium fragile* and *Sargassum siliquastrum*, collected by Kim *et al.* [29]. *G. toxicus* was estimated to be 5.0×10^5 cells g^{-1} on Rhodophyte *Jania* in a Gambier Island reef [51]. Depending on the geographic region, *G. toxicus* has been shown to prefer different macroalgal host species and found with more than 50 algal genera [8, 11].

Generally, the species under the genus *Prorocentrum* were less abundant on Chlorophyte macroalgal species in this study. *P. concavum* was present on all the Rhodophytes, while it was absent on one Pheaeophyte (*Ecklonia cava*) and two Chlorophytes (*Codium fragile* and *Ulva pertusa*). Cell abundance of this epiphytic dinoflagellate was always below 15 cells g^{-1} . *P. emarginatum* never preferred any of the Chlorophytes and also absent on Rhodophyte, *Wrangelia tanegana* and Pheophytes, *Sargassum macrocarpum* and *S. siliquastrum*. *P. fukuyoi* abundance was highest (13.17 ± 11.35 cells g^{-1}) on Rhodophyte *Chondrus ocellatus* but cell abundance was lower for most of the macroalgal host. *P. lima* and *P. rhathymum* were found with maximum cell concentration (12.49 ± 8.42 and 22.04 ± 21.96 cells g^{-1}) on Pheophyte *Sargassum horneri* and *S. confusum*, respectively. Kim *et al.* [29] observed *Prorocentrum* spp. with eight macroalgal species (*U. pertusa*, *E. cava*, *Sargassum* sp., *D. divaricata*, *C. flagelliformis*, *P. arborescens*, *Martensia* sp., *Gelidium amansii*, *Corallina* sp.) with maximum density (304 cells g^{-1}) on *Martensia* sp. At Virgin Islands, *P. mexicanum* cell density was found at 1.5×10^6 cells g^{-1} [8].

Generally, no macroalgal species appeared to be an overall best or worst host for specific epiphytic dinoflagellates. Additionally, preferences were not consistent among the dinoflagellates. Significant differences in epiphytic densities between macroalgae were not observed in this study, which agrees with Lobel *et al.* [34] and Bomber *et al.* [7].

The availability of macroalgal substrates and water movement may affect the spatial distribution of epiphytic dinoflagellates. Beside these, environmental variables and nutrients from macroalgae could be important temporary factors [49]. Therefore, the temporal patterns should be interpreted with respect to the succession of host macroalgae [32]. In addition, macroalgal surface area and ash content appear to be regulating factors of epiphytic dinoflagellate population density [6].

Table 5. Average abundance (cells g⁻¹ wet wt of algae) of epiphytic dinoflagellates on each of the macroalgal species during July 2012-June 2013 from Jeju Island.

Algal host species	Total	AC	AO	CM	GM	OO	PC	PE	PF	PL	PR
Rhodophyta											
<i>Chondrus canaliculatus</i> (12)	121.03 ± 171.37	8.20 ± 9.41	14.57 ± 14.81	7.83 ± 10.69	0 ± 0	48.77 ± 42.17	5.19 ± 5.14	2.13 ± 4.81	4.11 ± 6.86	9.35 ± 13.04	1.1 ± 2.69
<i>Chondrus ocellatus</i> (5)	64.12 ± 60.37	4.78 ± 7.81	22.66 ± 30.82	26.81 ± 53.99	0 ± 0	35.16 ± 53.35	12.85 ± 12.57	1.67 ± 3.74	13.17 ± 11.35	11.32 ± 15.05	0 ± 0
<i>Coralina pilulifera</i> (7)	53.53 ± 86.44	2.82 ± 5.30	13.16 ± 10.93	7.24 ± 12.5	0 ± 0	40.33 ± 34.06	2.76 ± 3.99	0.74 ± 1.96	0 ± 0	0 ± 0	9.41 ± 9.82
<i>Galaxaura apiculata</i> (9)	94.46 ± 140.48	3.69 ± 1.51	4.60 ± 2.97	25.79 ± 18.33	0 ± 0	48.48 ± 49.57	11.47 ± 16.92	10.54 ± 11.42	0 ± 0	0.35 ± 0.5	0 ± 0
<i>Galaxaura falcata</i> (4)	46.05 ± 60.93	6.73 ± 3.89	14.65 ± 12.99	23.11 ± 25.09	0 ± 0	49.98 ± 69.71	6.16 ± 8.08	7.12 ± 7.25	0 ± 0	5.37 ± 6.78	1.99 ± 3.99
<i>Gelidium amansii</i> (24)	296.44 ± 432.66	8.05 ± 8.24	6.29 ± 8.78	21.24 ± 14.51	3.5 ± 11.6	61.16 ± 41.58	4.71 ± 4.85	3.39 ± 5.44	2.03 ± 4.89	9.95 ± 9.42	3.70 ± 11.82
<i>Gracilaria</i> sp. (9)	88.99 ± 99.73	10.45 ± 9.94	10.50 ± 13.06	15.68 ± 10.89	0 ± 0	37.78 ± 11.51	9.82 ± 3.52	2.76 ± 2.3	3.15 ± 4.68	0 ± 0	0 ± 0
<i>Gracilaria vermiculophylla</i> (2)	17.27 ± 31.31	3.82 ± 5.4	4.16 ± 5.88	14.13 ± 1.66	0 ± 0	51.77 ± 40.26	3.24 ± 4.58	3.24 ± 4.58	2.05 ± 2.89	0 ± 0	0 ± 0
<i>Grateloupia asiatica</i> (6)	60.29 ± 85.27	3.06 ± 3.80	12.82 ± 8.21	21.59 ± 13.59	0 ± 0	45.76 ± 21.93	7.82 ± 6.01	1.19 ± 3.21	0.81 ± 0.2	4.81 ± 0.89	2.59 ± 5.23
<i>Hypnea charoides</i> (7)	75.72 ± 108.85	4.26 ± 5.33	7.90 ± 5.22	28.07 ± 17.38	0 ± 0	48.28 ± 51.37	10.1 ± 5.82	0.81 ± 2.16	2.77 ± 1.58	5.95 ± 2.26	0 ± 0
<i>Jania adhaerens</i> (12)	157.55 ± 283.07	0.73 ± 1.97	0 ± 0	27.23 ± 33.06	0 ± 0	75.44 ± 48.27	13.74 ± 12.26	0.26 ± 0.90	4.42 ± 10.59	9.46 ± 11.19	0 ± 0
<i>Martensia</i> sp. (6)	87.49 ± 127.84	4.11 ± 6.50	21.9 ± 19.15	27.42 ± 11.55	0 ± 0	69.64 ± 68.63	3.41 ± 4.93	5.33 ± 5.17	4.89 ± 7.18	6.56 ± 8.55	2.53 ± 4.48
<i>Plocamium telfairiae</i> (25)	350.33 ± 22.35	4.95 ± 9.22	8.37 ± 9.45	23.71 ± 19.24	0 ± 0	74.58 ± 65.29	12.17 ± 8.90	2.33 ± 5.08	5.01 ± 2.64	11.22 ± 17.85	0 ± 0
<i>Pterocladia capillacea</i> (4)	51.85 ± 59.40	5.09 ± 5.88	12.99 ± 5.95	22.72 ± 29.78	0 ± 0	50.45 ± 40.0	11.08 ± 2.17	7.49 ± 14.98	9.65 ± 7.26	10.15 ± 11.54	0 ± 0
<i>Wrangelia tanegana</i> (11)	86.16 ± 109.29	9.38 ± 5.68	10.23 ± 4.14	9.95 ± 6.25	0 ± 0	33.46 ± 5.49	5.87 ± 5.26	0 ± 0	2.31 ± 2.11	7.10 ± 5.96	0 ± 0
Phaeophyta											
<i>Champia expansa</i> (3)	38.32 ± 47.12	16.66 ± 21.41	18.51 ± 20.0	30.13 ± 32.49	0 ± 0	47.61 ± 52.60	2.46 ± 3.74	3.87 ± 5.05	4.42 ± 6.70	4.05 ± 6.14	0 ± 0
<i>Colpomenia sinuosa</i> (3)	21.37 ± 28.75	2.48 ± 2.36	2.51 ± 2.36	11.1 ± 7.98	0 ± 0	32.20 ± 26.06	4.89 ± 4.38	8.27 ± 10.59	0 ± 0	8.14 ± 14.11	1.63 ± 2.82
<i>Dictyopteris prolifera</i> (4)	52.19 ± 62.96	16.94 ± 17.71	15.89 ± 10.64	37.66 ± 18.43	0 ± 0	43.17 ± 42.97	6.95 ± 12.47	7.75 ± 13.08	0 ± 0	0 ± 0	0.94 ± 1.89
<i>Dictyopteris divaricate</i> (3)	15.76 ± 19.36	3.58 ± 0.58	15.81 ± 10.20	14.84 ± 9.71	0 ± 0	12.36 ± 12.54	1.03 ± 1.79	1.48 ± 2.56	0 ± 0	3.43 ± 5.95	0 ± 0
<i>Ecklonia cava</i> (22)	60.29 ± 107.33	10.45 ± 13.47	13.03 ± 11.70	1.99 ± 8.39	0 ± 0	0.38 ± 1.17	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
<i>Hizikia fusiformis</i> (7)	98.78 ± 161.40	4.31 ± 5.99	0.73 ± 0	42.21 ± 33.15	0 ± 0	69.39 ± 38.96	9.68 ± 3.7	2.30 ± 2.60	3.2 ± 5.80	3.20 ± 5.56	6.52 ± 12.09
<i>Sargassum confusum</i> (5)	40.93 ± 42.37	1.02 ± 2.29	6.45 ± 5.52	18.41 ± 9.06	0 ± 0	19.47 ± 11.80	4.85 ± 3.20	4.57 ± 4.36	5.02 ± 5.66	0 ± 0	22.04 ± 21.96
<i>Sargassum horneri</i> (7)	91.39 ± 119.57	6.84 ± 6.41	14.74 ± 10.93	24.36 ± 14.5	0 ± 0	56.74 ± 58.26	7.92 ± 6.19	0.93 ± 2.47	5.65 ± 6.52	12.49 ± 8.42	0.85 ± 2.24
<i>Sargassum macrocarpum</i> (10)	112.40 ± 159.05	1.58 ± 3.48	9.26 ± 14.07	30.40 ± 34.52	0 ± 0	48.80 ± 36.88	10.51 ± 10.01	0 ± 0	4.66 ± 7.37	3.69 ± 4.88	4.52 ± 10.11
<i>Sargassum siliquastrum</i> (9)	78.66 ± 102.28	1.77 ± 3.55	4.66 ± 4.93	16.83 ± 8.71	0 ± 0	37.10 ± 24.41	11.57 ± 6.75	0 ± 0	3.94 ± 3.05	9.43 ± 3.25	2.52 ± 3.00
<i>Sargassum thunbergii</i> (22)	195.79 ± 215.46	7.61 ± 6.69	11.59 ± 8.72	23.03 ± 18.34	0 ± 0	25.37 ± 46.79	0.80 ± 2.72	0.29 ± 1.33	2.34 ± 4.5	0.69 ± 2.23	18.41 ± 16.66
Chlorophyta											
<i>Cladophora wrightiana</i> (4)	54.04 ± 125.76	10.09 ± 6.89	11.85 ± 5.92	5.50 ± 111.01	0 ± 0	102.07 ± 44.15	5.59 ± 11.18	0 ± 0	0 ± 0	0 ± 0	0 ± 0
<i>Codium fragile</i> (4)	21.57 ± 30.60	12.38 ± 8.51	12.79 ± 6.57	0 ± 0	0 ± 0	20.98 ± 34.82	0 ± 0	0 ± 0	0 ± 0	0 ± 0	7.76 ± 15.53
<i>Euteromorpha linza</i> (5)	50.29 ± 85.86	4.90 ± 2.63	8.71 ± 4.18	4.07 ± 9.10	0 ± 0	57.48 ± 16.31	4.05 ± 9.05	0 ± 0	10.73 ± 3.25	10.63 ± 11.91	0 ± 0
<i>Ulva pertusa</i> (26)	223.58 ± 415.59	10.0 ± 4.69	12.95 ± 8.63	3.25 ± 10.75	0 ± 0	52.07 ± 45.57	0 ± 0	0 ± 0	7.22 ± 8.52	0.44 ± 2.25	0.30 ± 1.57

AC = *A. carterae*, AO = *A. operculatum*, CM = *C. malayensis*, GM = *Gambierdiscus* sp., OO = *O. ovata*, PC = *P. concavum*, PE = *P. emarginatum*, PF = *P. fukuyoi*, PL = *P. lima* and PR = *P. rhathymum*. Values are reported as averages ± standard deviation. The numbers in parentheses next to each algal host species name represent the number of samples analyzed.

IV. CONCLUSION

The results of this study indicate that, (1) several potentially toxic dinoflagellate species are present in Jeju Island; (2) The epiphytic dinoflagellate assemblage demonstrated that they were being more abundant in September and October 2012 (autumn), and June 2013 (summer) than the other months; (3) The abundance of epiphytic dinoflagellates was appeared to be higher at Hamduk (St 2) and lower at Hamo (St 4) and Hwasun (St 5) in Jeju Island; (4) The population density of most of the epiphytic dinoflagellates was found to be significantly correlated with the variation of both water temperature and salinity, except *A. carterae*, *A. operculatum* and *P. lima*; (5) Epiphytic dinoflagellates did not show any significant preference for macrophyte species.

ACKNOWLEDGMENTS

This work was supported by the research grant of Jeju national University in 2012 to Md. M. R. Shah, and by Jeju Sea Grant in 2012, funded by the Ministry of Ocean and Fisheries (MOF) of the Republic of Korea.

REFERENCES

1. Aligizaki, K. and Nikolaidis, G., "The presence of the potentially toxic genera *Ostreopsis* and *Coolia* (Dinophyceae) in the North Aegean Sea, Greece," *Harmful Algae*, Vol. 5, pp. 717-730 (2006).
2. Aligizaki, K., Nikolaidis, G., and Fraga, S., "Is *Gambierdiscus* expanding to new areas?" *Harmful Algae News*, Vol. 36, pp. 6-7 (2008).
3. Al-Yamani, F. Y. and Saburova, M., *Illustrated Guide on the Flagellates of Kuwait's Intertidal Soft Sediments*, Kuwait Institute for Scientific Re-

- search, Safat, Kuwait (2010).
4. Anderson, D. M., Hoagland, P., Kaoru, Y., and White, A. W., *Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*, Woods Hole Oceanographic Institute Technical Report WHOI-2000-11, USA (2000).
 5. Ballantine, D. L., Bardales, A. T., Tosteson, T. R., and Durst, H. D., "Seasonal abundance of *Gambierdiscus toxicus* and *Ostreopsis* sp. in coastal waters of southwest Puerto Rico," *Proceeding of the 5th International Coral Reef Congress*, Tahiti, Vol. 4, pp. 417-422 (1985).
 6. Bomber, J. W., Norris, D. R., and Mitchell, L. E., "Benthic dinoflagellates associated with ciguatera from the Florida Keys. II. Temporal, spatial and substrate heterogeneity of *Prorocentrum lima*," in: Anderson, D. M., White, A. W., and Baden, D. G. (Eds.), *Toxic Dinoflagellates*, Elsevier, New York, pp. 45-50 (1985).
 7. Bomber, J. W., Rubio, M. G., and Norris, D. R., "Epiphytism of dinoflagellates associated with ciguatera: substrate specificity and nutrition," *Phycologia*, Vol. 28, pp. 360-368 (1989).
 8. Carlson, R. D. and Tindall, D. R., "Distribution and periodicity of toxic dinoflagellates in the Virgin Islands," in: Anderson, D. M., White, A. W., and Baden, D. G. (Eds.), *Toxic Dinoflagellates*, Elsevier, New York, pp. 171-176 (1985).
 9. Chang, F. H., Shimizu, Y., Hay, B., Stewart, R., Mackay, G., and Tasker, R., "Three recently recorded *Ostreopsis* spp. (Dinophyceae) in New Zealand: temporal and regional distribution in the upper North Island from 1995 to 1997," *New Zealand Marine Freshwater Research*, Vol. 34, pp. 29-39 (2000).
 10. Chinain, M., Faust, M. A., and Pauillac, S., "Morphology and molecular analyses of three toxic species of *Gambierdiscus* (Dinophyceae): *G. pacificus*, sp. nov., *G. australes*, sp. nov., and *G. polynesiensis*, sp. nov.," *Journal of Phycology*, Vol. 35 pp. 1282-1296 (1999).
 11. Cruz-Rivera, E. and Villareal, T. A., "Macroalgal palatability and the flux of ciguatera toxins through marine food webs," *Harmful Algae*, Vol. 5, pp. 497-525 (2006).
 12. Delgado, G., Lechuga-Devéze, C. H., Popowski, G., Troccoli, L., and Salinas, C. A., "Epiphytic dinoflagellates associated with ciguatera in the northwestern coast of Cuba," *Revista de Biología Tropical*, Vol. 54, pp. 299-310 (2006).
 13. Faust, M. A., "Observation of sand-dwelling toxic dinoflagellates (Dinophyceae) from widely differing sites, including two new species," *Journal of Phycology*, Vol. 31 pp. 996-1003 (1995).
 14. Faust, M. A., "Dinoflagellates in a mangrove ecosystem, Twin Cays, Belize," *Nova Hedwigia*, Vol. 112, pp. 445-458 (1996).
 15. Faust, M. A. and Gulledge, R. A., *Identifying Harmful Marine Dinoflagellates*, Smithsonian Institution Contributions, U.S. National Herbarium (2002).
 16. Faust, M. A., Larsen, J., and Moestrup, Ø., "Potentially toxic phytoplankton. 3. Genus *Prorocentrum* (Dinophyceae)," in: Lindley J. A. (Ed.), *ICES Identification Leaflets for Plankton*, Leaflet No. 184, International Council for the Exploration of the Sea, Denmark (1999).
 17. Fritz, L. and Triemer, R. E., "A rapid simple technique utilizing calcofluor white MR2 for the visualization of dinoflagellate thecal plates," *Journal of Phycology*, Vol. 21, pp. 662-664 (1985).
 18. Fukuyo, Y., "Taxonomical study on benthic dinoflagellates collected in coral reefs," *Bulletin of Japan Society of Science Fisheries*, Vol. 47, pp. 967-978 (1981).
 19. Gilbert, P. M., Seitzinger, S., Heil, C. A., Burkholder, J. M., Parrow, M. W., Codispoti, L. A., and Kelly, V., "The role of eutrophication in the global proliferation of harmful algal blooms," *Oceanography*, Vol. 18, pp. 198-209 (2005).
 20. Gillespie, N. C., Holmes, M. J., Burke, J. B., and Doley, J., "Distribution and periodicity of *Gambierdiscus toxicus* in Queensland, Australia," in: Anderson, D. M., White, A. W., and Baden, D. G. (Eds.), *Toxic Dinoflagellates*, Elsevier, New York, p 183-188 (1985).
 21. Hansen, G., Turquet, J., Quod, J. P., Ten-Hage, L., Lugomela, C., Kye-walyanga, M., Hurbungs, M., Wawiye, P., Ogongo, B., Tunje, S., and Rakotoarinjanahary, H., *Potentially Harmful Algae of the Western Indian Ocean: a Guide Based on a Preliminary Survey*, I.O.C., Manuals and Guides 41, Intergovernmental Oceanographic Commission of UNESCO (2001).
 22. HARRNESS, *Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*, Ramsdell, J. S., Anderson, D. M., and Gilbert, P. M. (Eds.), Ecological Society of America, Washington DC, 82 (2005).
 23. Heil, C. A., Bird, P., and Dennison, W. C., "Macroalgal habitat preference of ciguatera dinoflagellates at Heron Island, a Coral Cay in the south-eastern Great Barrier Reef, Australia," in: Reguera, B., Blanco, J., Fernández, M., and Wyatt, T. (Eds.), *Harmful Algae*, Xunta de Galicia and International Governmental Commission of UNESCO, Vigo, Spain, pp. 52-53 (1998).
 24. Holmes, M. J., Lee, F. C., Teo, S. L. M., and Khoo, H. W., "A survey of benthic dinoflagellates on Singapore Reefs," in: Reguera, B., Blanco, J., Fernandez, M. L., and Wyatt, T. (Eds.), *Harmful Algae*, Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, pp. 50-51 (1998).
 25. Hurbungs, M. D., Jayabalan, N., and Chineah, V., "Seasonal distribution of potentially toxic benthic dinoflagellates in the lagoon of Trou aux Biches, Mauritius," *Food and Agricultural Research Council, Réduit, Mauritius*, pp. 211-217 (2001).
 26. Jeong, H. J., Lim, A. S., Jang, S. H., Yih, W. H., Kang, N. S., Lee, S. Y., Yoo, Y. D., and Kim, H. S., "First report of the epiphytic dinoflagellate *Gambierdiscus caribaeus* in the temperate waters off Jeju Island, Korea: morphology and molecular characterization," *Journal of Eukaryotic Microbiology*, Vol. 59, pp. 637-650 (2012).
 27. Jeong, H. J., Yih, W. H., Kang, N. S., Lee, S. Y., Yoon, E. Y., Yoo, Y. D., Kim, H. S., and Kim, J. H., "First report of the epiphytic benthic dinoflagellates *Coolia canariensis* and *Coolia malayensis* in the waters off Jeju Island, Korea: morphology and rDNA Sequences," *Journal of Eukaryotic Microbiology*, Vol. 59, pp. 114-133 (2012).
 28. Kang, N. S., Jeong, H. J., Lee, S. Y., Lim, A. S., Lee, M. J., Kim, H. S., and Yih, W. H., "Morphology and molecular characterization of the epiphytic benthic dinoflagellate *Ostreopsis* cf. *ovata* in the temperate waters off Jeju Island, Korea," *Harmful Algae*, Vol. 27, pp. 98-112 (2013).
 29. Kim, H. S., Yih, W. H., Kim, J. H., Myung, G., and Jeong, H. J., "Abundance of epiphytic dinoflagellates from coastal waters off Jeju Island, Korea during autumn 2009," *Ocean Science Journal*, Vol. 46, pp. 205-209 (2011).
 30. Lee, Y. P. and Kang, S. Y., *A Catalogue of the Seaweeds in Korea*, Jeju National University Press, Jeju, Korea (2001).
 31. Lee, Y. P., *Marine Algae of Jeju*, Academy Press, Seoul, Korea (2008).
 32. Levasseur, M., Couture, J. I., Weise, A. M., Michaud, S., Elbrächter, M., Sauv e, G., and Bonneau, E., "Pelagic and epiphytic summer distributions of *Prorocentrum lima* and *P. mexicana* at two mussel farms in the Gulf of St. Lawrence, Canada," *Aquatic Microbial Ecology*, Vol. 30, pp. 283-293 (2003).
 33. Lim, A. S., Jeong, H. J., Jang, T. Y., Kang, N. S., Lee, S. Y., Yoo, Y. D., and Kim, H. S., "Morphology and molecular characterization of the epiphytic dinoflagellate *Prorocentrum* cf. *rhathymum* in temperate waters off Jeju Island, Korea," *Ocean Science Journal*, Vol. 48, pp. 1-17 (2013).
 34. Lobel, P. S., Anderson, D. M., and Durand-Clement, M., "Assessment of ciguatera dinoflagellate populations: sample variability and algal substrate selection," *Biological Bulletin*, Vol. 175, pp. 91-101 (1988).
 35. Mangialajo, L., Bertolotto, R., Cattaneo-Vietti, C., Chiantore, M., Grillo, C., Lemeo, R., Melchiorre, N., Moretto, P., Povero, P., and Ruggieri, N., "The toxic benthic dinoflagellate *Ostreopsis ovata*: Quantification of proliferation along the coastline of Genoa, Italy," *Marine Pollution Bulletin*, Vol. 56, pp. 1209-1214 (2008).
 36. Mohammad-Noor, N., Daugbjerg, N., Moestrup, Ø., and Anton, A., "Marine epibenthic dinoflagellates from Malaysia: A study of live cultures and preserved samples based on light and scanning electron microscopy," *Nordic Journal of Botany*, Vol. 24, pp. 629-690 (2007).
 37. Morton, S., Faust, M., Fairey, E., and Moeller, P., "Morphology and toxicology of *Prorocentrum arabianum* sp. nov., (Dinophyceae) a toxic

- planktonic dinoflagellate from the Gulf Oman, Arabian Sea," *Harmful Algae*, Vol. 1, pp. 393-400 (2002).
38. Murray, S., Flø Jørgensen, M., Daugbjerg, N., and Rhodes, L., "Amphidinium revisited. II. Resolving species boundaries in the *Amphidinium operculatum* species complex (Dinophyceae), including the descriptions of *Amphidinium trulla* sp. nov. and *Amphidinium gibbosum* comb. nov.," *Journal of Phycology*, Vol. 40, pp. 366-382 (2004).
 39. Nakajima, I., Oshima, Y., and Yasumoto, T. "Toxicity of benthic dinoflagellates in Okinawa," *Bulletin of Japan Society of Science Fisheries*, Vol. 47, pp. 1029-1033 (1981).
 40. Okolodkov, Y. B., Campos-Bautista, G., Gárate-Lizárraga, I., González-González, J. A. G., Hoppenrath, M., and Arenas, V., "Seasonal changes of benthic and epiphytic dinoflagellates in the Veracruz reef zone, Gulf of Mexico," *Aquatic Microbial Ecology*, Vol. 47, pp. 223-237 (2007).
 41. Parsons, M. L. and Preskitt, L. B., "A survey of epiphytic dinoflagellates from the coastal waters of the island of Hawaii," *Harmful Algae*, Vol. 6, pp. 658-669 (2007).
 42. Pearce, I., Marshall, J. A., and Hallegraeff, G. M., "Toxic epiphytic dinoflagellates from east coast Tasmania, Australia," in: Hallegraeff, G. M., Blackburn, S. I., Bolch, C. J., and Lewis, R. J. (Eds.), *Harmful Algal Blooms 2000*, Intergovernmental Oceanographic Commission of UNESCO, Hobart, Tasmania, pp. 54-57 (2001).
 43. Rhodes, L., "World-wide occurrence of the toxic dinoflagellate genus *Ostreopsis* Schmidt," *Toxicon*, Vol. 57, pp. 400-407 (2011).
 44. Selina, M. S. and Levchenko, E. V., "Species composition and morphology of dinoflagellates (Dinophyta) of epiphytic assemblages of Peter the Great Bay in the Sea of Japan," *Russian Journal of Marine Biology*, Vol. 37, pp. 23-32 (2011).
 45. Shim, J. H., *Illustrated Encyclopedia of Fauna and Flora of Korea, Vol. 34 Marine Phytoplankton*, Ministry of Education, Seoul (1994). (in Korean)
 46. Steidinger, K. A., "A re-evaluation of toxic dinoflagellate biology and ecology," in: Round, F. E. and Chapman, D. (Eds.), *Progress in Phycological Research*, New York, Elsevier, pp. 147-188 (1983).
 47. Steidinger, K. A. and Tangen, K., "Dinoflagellates," in: Tomas, C. R. (Ed.), *Identifying Marine Phytoplankton*, Academic Press, San Diego, pp. 387-570 (1996).
 48. Taylor, F. J. R., "A description of the benthic dinoflagellate associated with maitotoxin and ciguatoxin, including observations on Hawaiian material," in: Taylor, D. L. and Seliger, H. H. (Eds.), *Toxic Dinoflagellate Blooms*, Elsevier North Holland, New York, pp. 71-76 (1979).
 49. Tindall, D. R. and Morton, S. L., "Community dynamics and physiology of epiphytic/benthic dinoflagellates associated with Ciguatera," in: Anderson, D. A., Cembella, A. D., and Hallegraeff, G. M. (Eds.), *Physiological Ecology of Harmful Algal Blooms*, Springer-Verlag, Berlin, pp. 293-313 (1998).
 50. Vila, M., Camp, J., Garcés, E., Masó, M., and Delgado, M., "High resolution spatio-temporal detection of HABs in confined waters of the NW Mediterranean," *Journal of Plankton Research*, Vol. 23, pp. 497-514 (2001).
 51. Yasumoto, T., Oshima, Y., Murakami, Y., Nakajima, I., Bagnis, R., and Fukuyo, Y., "Toxicity of benthic dinoflagellates found in coral reef," *Bulletin Japan Society Science Fisheries*, Vol. 46, pp. 327-331 (1980).
 52. Yasumoto, T., Seino, N., Murakami, Y., and Murata, M., "Toxins produced by benthic dinoflagellates," *Biological Bulletin*, Vol. 172, pp. 128-131 (1987).