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Checklist and estimation of total number of phytoplankton species in Pari, Tidung, and Payung Islands, Indonesia

ARIEF RACHMAN♥
Research Center for Oceanography, Indonesian Institute of Sciences. Jl. Ancol Timur, Jakarta Utara 14430, Jakarta, Indonesia. Tel.: +62-21-6471-3850, Fax.: +62-21-6471-1948, ♥email: arief_rachman1987@yahoo.com

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Abstract. *Rachman A. 2020. Checklist and estimation of total number of phytoplankton species in Pari, Tidung, and Payung Islands, Indonesia. Biodiversitas 21: 2446-2458.* A checklist of phytoplankton species from an anthropogenically pressured ecosystem has become a necessity to study the marine ecosystem changes and to detect the presence of introduced species in the area. This study aimed to list and describe the phytoplankton community in the Tidung, Pari, and Payung Islands and to estimate the total number of phytoplankton species in those islands. Sampling was conducted in May 2019 in 10 sites, consisted of 5 sites around Pari Island, 1 site next to Payung Island, and 4 sites around Tidung Island. As many as 150 species of phytoplankton, consisted of 109 species of diatoms, 38 species of dinoflagellates, 3 species of cyanobacteria, were recorded in this study. However, up to 47 phytoplankton species were estimated to be missing from the current sampling effort. Three diatom species, *Chaetoceros curvisetus*, *Chaetoceros distans*, and *Chaetoceros affinis* were the most abundant and most common species in the studied areas. Dinoflagellates were found in low density and have limited distribution compared to diatoms. *Tripos trichoceros*, *Tripos fusus*, and *Tripos macroceros* were the three most common dinoflagellates in the studied islands. Several notable harmful species, such as *Pseudo-nitzschia* spp., *Alexandrium* sp., *Tripos furca*, *Cochlodinium* sp., *Dinophysis miles*, *Prorocentrum lima*, and *Noctiluca scintillans*, were present albeit with low cell density. However, concern on future blooms of those harmful species in the greater water regions (i.e. Seribu Island or Jakarta Bay) should be noted, as it might cause environmental damages, including a shift in species dominance and disappearance of some native phytoplankton species from the ecosystem in the future.

Keywords: Non-parametric species estimators, phytoplankton diversity, Seribu Island, species accumulation curve, species checklist

Abbreviations: HABs: Harmful Algal Blooms, SAC: Species Accumulation Curve, WoRMS: World Register of Marine Species

INTRODUCTION

Checklist of phytoplankton species is important for basic information in the studies of phytoplankton community in the marine ecosystem. This information is essential to detect changes in the community structure of phytoplankton assemblages which might be related to any possible ecological damages caused by the presence of environmental stress from anthropogenic activities, changes in water pH level, excessive nutrient loads that lead to eutrophication, excess of pollutant, and the presence of invasive species in the ecosystem (Mather et al. 2010; Häder and Gao 2015; Lee et al. 2015). Due to an increase in the alien species invasion in many marine ecosystems caused by anthropogenic activities, such as ballast water discharge and mariculture, good basic knowledge and information on diversity and richness of the native phytoplankton species are very important.

Diatoms (Phylum: Bacillariophyta) and dinoflagellates (Phylum: Miophyta) are two major groups of phytoplankton community which play great roles in the primary production and nutrient cycle of both marine and freshwater ecosystems (Lee et al. 2015). The diatoms group consists of more than 200 genera with over 8,000 known and recorded species, out of approximately over 100,000-200,000 diatoms species worldwide, which are the vital components of the marine ecosystem that contribute to up to 45% of total primary production (Yool and Tyrrell 2003; Guiry 2012; Lee et al. 2015). On the other hand, the dinoflagellates group consists of over 2,200 recorded and known species (Guiry 2012). Among them, some species produce harmful toxic substances that cause diseases, such as Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP) (Glibert et al. 2005). Thus, the high density of dinoflagellate that replaces the dominance of diatoms in marine ecosystems is often related to various ecological problems, such as hypoxia, fish kills, ocean discoloration, and diseases (Glibert et al. 2005).

Another major component of the marine ecosystem is from the phylum Cyanobacteria, which consists of over 3,000 recorded species out of approximately around 8,000 species that exist in the world (Guiry 2012; Nabout et al. 2013). Like diatoms and dinoflagellates, cyanobacteria also plays a great role in the ecosystem, mainly because of the N-fixation ability, phosphorus (P) storage, or iron (Fe) sequestration in some of its species (Paerl and Otten 2013). However, cyanobacterial blooms or CyanoHABs are a major environmental problem that threatens both marine and freshwater ecosystems in the world which causes ecological damages and diseases for humans and marine animals (Paerl and Otten 2013). Similar with some dinoflagellates and diatoms species, some cyanobacteria species also produce potent microalgal toxins, such as hepatotoxins, neurotoxins, dermatotoxins, cytotoxins, and endotoxins, which are harmful to human and animals (Codd et al. 2006).

This study focused on the phytoplankton community in Pari Island, Tidung Island, and Payung Island, which are part of the Seribu Islands, Jakarta, Indonesia. The Seribu Islands itself is a complex island chain consisted of more than 120 coral islands located in the northern part of the Jakarta Bay which extend about 80 km northward with a total area approximately 7,200 km^2 (Fauzi and Buchary 2002; Farhan and Lim 2011). About three-quarters of the northern islands of Seribu Island was protected in the Kepulauan Seribu Marine National Park (KSMNP) that covers 78 islands and with a total of 108,000 ha protected area (Fauzi and Buchary 2002). The Seribu Islands are home to many unique marine ecosystems, such as mangroves, sandy beaches, seaweed patches, coral reefs, and seagrass beds. Additionally, many important marine resources, such as reef-associated fish, economically valuable invertebrates, sea birds, and turtles, still existed in many parts of the island. However, due to overpopulation, the rapid development of settlements and tourism facilities, pollution, illegal unregulated and unreported fishing (IUUF), and marine debris (trash) from major rivers in Jakarta and Banten, the ecosystems of Seribu Island were under constant and increasing anthropogenic pressure which negatively affecting the water quality around the islands (Fauzi and Buchary 2002; Farhan and Lim 2011).

The degradation in water quality around the Seribu Island has caused many environmental problems, including CyanoHABs cases and an increasing number of toxic dinoflagellate species in the disturbed coral reefs and seagrass beds (Thoha 1991; Anggraeni et al. 2013; Widiarti and Pudjiarto 2015). Additionally, heavy national and international ship traffic in the Jakarta Bay has raised a concern on the possibilities of introduced and invasive phytoplankton species that were carried inside the ballast tanks of the ships (Thoha and Rachman 2018). Since phytoplankton is the foundation of the marine food web (Nybakken and Bertness 2003) and an important primary producer in the island ecosystems (Gove et al. 2016) like Seribu Island, changes in the species composition could cause a cascading effect that further degrade the marine ecosystems around the Seribu Island.

Diatoms, dinoflagellates, and cyanobacteria in the Pari Island and Tidung Island have been investigated in several studies (Thoha 1991; Anggraeni et al. 2013; Widiarti and Pudjiarto 2015; Rizqina et al. 2018). Their interaction with various environmental parameters (Rizqina et al. 2018), their usage as an indicator of water quality for aquaculture (Sutiknowati 2013), the potentially toxic and bloom-forming species (Anggraeni et al. 2013; Widiarti and Pudjiarto 2015) as well as the harmful algal bloom event itself (Thoha 1991), have been studied extensively. However, many of those studies were limited to genus level identification (Rizqina et al. 2018) or did not adequately describe the phytoplankton species assemblages in either Pari Island or Tidung Island due to their limited or very specific scope of the study (Thoha 1991; Anggraeni et al. 2013; Sutiknowati 2013; Widiarti and Pudjiarto 2015). Thus, information on the actual species composition, particularly of the group of Diatoms, Dinoflagellate, and Cyanobacteria have been rare. Therefore, this study aimed to describe the species composition of the phytoplankton community and also tried to estimate the total number of phytoplankton species in the islands of Tidung, Payung, and Pari. The checklist would be useful as a reference to study any changes in the marine ecosystem of the islands and to detect the presence of introduced or invasive phytoplankton species in the studied islands.

MATERIALS AND METHODS

Study period and area

Field sampling for this study was conducted on 2-4 May 2019. Samples were collected from a total of 10 sampling sites, consisted of 5 sites around the Pari Island, 1 site next to Payung Island, and 4 sites around the Tidung Island (Figure 1). Note that due to weather and time constraints, only one site was sampled around Payung Island.

Tidung Island is one of the main islands within the Seribu Island archipelago and consists of approximately 109 ha of human settlement, which directly influences the marine ecosystems around the island and might cause degradation in its environmental condition (Widiarti and Pudjiarto 2015). Tidung Island was also suffered from coastal abrasion resulting from the deforestation of mangroves that used to protect the coastline of the island (Farhan and Lim 2011). On the other hand, Pari Island is a ringing reef island located about 35 km northwest of Jakarta which has several unique marine ecosystems, such as seagrass bed, mangrove patches, and coral reefs, but has been impacted by anthropogenic activities, such as tourism, blast fishing, and domestic waste (Madduppa et al. 2012). Additionally, Pari Island is one of the most vulnerable island to oil pollutants in Seribu Island, with oil spills that have been recorded multiple times in the past 10 to 15 years (Nurfitri et al. 2018). Payung Island is a small island located in between the distance from Pari Island to Tidung Island which is currently a rising icon of eco-tourism site in Seribu Island. Therefore, the water surrounding the Payung Island is under increasing pressures from the anthropogenic activities on the island.

Phytoplankton species identification

The identification of phytoplankton species was carried out by fraction method following Arinardi (1997) and Legresley and Mcdermott (2010). Sedgewick Rafter Counting Chamber (SRCC) mounted on a Nikon Diaphot 3 phase-contrast inverted microscope was used to identify and count the number of cells for each phytoplankton species. Canon EOS 700D Digital Single-Lens Reflex (DSLR) camera mounted on the Nikon Diaphot 3 microscope was used to photographing the species. Fine details in some of the phytoplankton cell's morphological characters were observed after a fraction of the sample (5-15 mL) has undergone cleaning procedures with 5%

sodium hypochlorite (NaClO) solution following a modified cleaning method from Carr et al. (1986). Phytoplankton cells were identified to species level based on the description of the morphological characters, photographs, and illustrations in Davis (1955), Yamaji (1966), Shirota (1966), Tomas (1997), Praseno and Sugestiningsih (2000), Al-Kandari et al. (2009), Omura et al. (2012), and Al-Yamani and Saburova (2019a,b). Online taxonomic databases, such as Algaebase (Guiry and Guiry 2020) and WoRMS (WoRMS Editorial Board 2020), were used to determine the most recent taxonomic classification of each species and to correct the taxonomic name from the older publications. However, species that cannot be identified to species level will be written by its genus name and sp. for the genus consisted of just a single species, or spp. for the genus with a group of species that were difficult to identify, for example, *Pseudo-nitzschia*. Additionally, image and species database in the Plankton Laboratory, Research Center for Oceanography (RCO-LIPI), was also used as a reference in this study.

Data and image analysis

Species accumulation curve (SAC) and non-parametric estimators of species richness were used to estimate the total number of phytoplankton species, including the number of missing species from the data of this study. SAC is a method to describe the number of observed species as a function of effort, which is expressed as the number of sampling sites, sampling duration, sampling frequency, or the number of analyzed individuals (Colwell et al. 2004). In this study, the effort was defined as the number of sampling sites. The analysis to construct SAC and estimation of species richness was done using 'vegan' package (Oksanen et al. 2015) in R-Studio. Four different non-parametric estimators of species richness, which are Chao, Jackknife-1 (1st order), Jackknife-2 (2nd order), and Bootstrap, were used to estimate the total number of species in this study (Colwell and Coddington 1994; Colwell et al. 2004; Béguinot 2015). Image analysis on some phytoplankton species was done firstly by monochromatic image conversion, followed by image post-processing in Adobe Lightroom CC (ver 2015.10) to enhance the fine details and structures of the diatoms frustules or dinoflagellates theca. Calibrated profile for the DSLR and phase-contrast microscope in Carl Zeiss Axiovision SE64 Rel.4.9.1 was then used to add size scale in the final images and performing morphometric analysis.

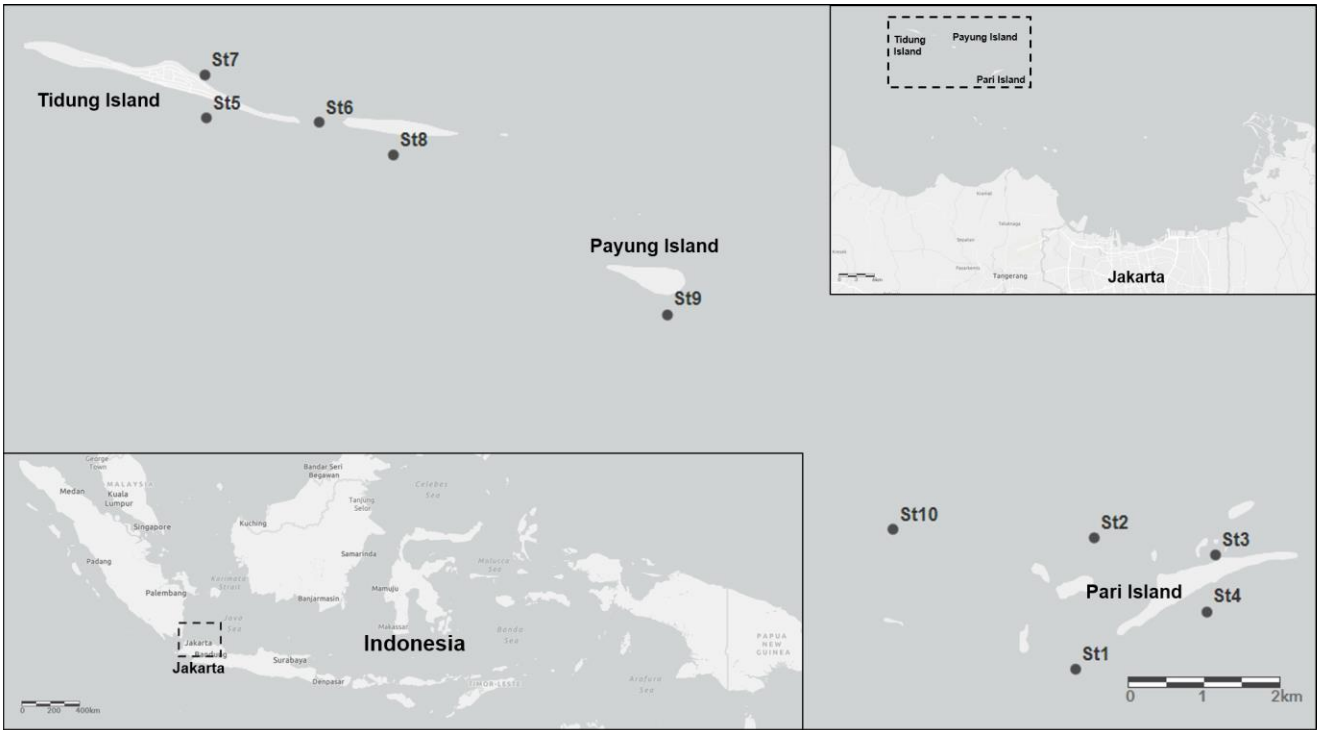

Figure 1. Sampling sites of this study which consist of 5 sites around Pari Island, 1 site around Payung Island, and 4 sites around Tidung Island, Jakarta, Indonesia

RESULTS AND DISCUSSION

Results

Checklist of phytoplankton species around the islands of Pari, Payung, and Tidung

In this study, a total of 150 phytoplankton species was identified and counted which consisted of 109 species of diatoms, 38 species of dinoflagellates, and 3 species of cyanobacteria. The list and abundance codes of all phytoplankton species in this study are listed in Table S1 (for diatoms group) and Table S2 (for dinoflagellates and cyanobacteria groups). Among all species found in this study, three diatom species of *Chaetoceros curvisetus*, *Chaetoceros distans*, and *Chaetoceros affinis* were the most abundant and most common species in the studied areas, with the density of 6.1×10^7 cells.m^{-3}, 2.91×10^7 cells.m^{-3}, and 2.16×10^7 cells.m^{-3}, respectively. Genus *Chaetoceros* was also the largest phytoplankton group, with 19 member species within the group (Table S1), followed by two dinoflagellate genera, *Tripos*, with 12 member species, and *Protoperidinium*, with 9 member species (Table S2). On the other hand, the most frequent phytoplankton species that were present in all sites (10 sites) of this study were *Trichodesmium erythraenum* (cyanobacteria), and diatoms of *Bacteriastrum furcatum*, *C. curvisetus*, *Cylindrotheca closterium*, *Proboscia alata*, *Pseudo-nitzschia* spp., *Rhizosolenia imbricata*, *Thalassionema nitzschioides*, and *Thalassionema nitzschioides var. parvum* (Table S1). Among the diatoms found in this study, *Pseudo-nitzschia* spp. was considered as harmful species. However, identification to species level was not conducted in this study. *Pseudo-nitzschia* spp. was found in all sites with maximum density of 1.95×10^7 cells.m^{-3}. Aside from *Pseudo-nitzschia* spp., *T. erythraenum*, a cyanobacteria species, was also common in the waters of Pari, Payung, and Tidung Islands, and was considered as harmful species.

The most frequently observed dinoflagellate in the studied islands belongs to *Tripos* genus, which was *Tripos trichoceros* (9 sites), *Tripos fusus* (8 sites), and *Trippos macroceros* (8 sites). In this study, no dinoflagellate species could be found in all 10 sites in the Pari, Payung, and Tidung island. Among dinoflagellates found in this study, some species were known as harmful or toxic species, which were *Alexandrium sp.*, *Tripos furca*, *Cochlodinium sp.*, *Dinophysis miles*, *Prorocentrum lima*, and *Noctiluca scintillans* (Table S2). However, their abundance was always lower than 10^5 cells.m^{-3} in this study. On the other hand, cyanobacteria *T. erythraeum* was common and abundant in most sites (Table S2). As a note, a freshwater cyanobacterium, *Spirulina* sp. was found in St3 of Pari Island (Table S2). In this case, the sample was collected in a sandy beach next to a small mangrove patch at the northern part of Pari Island (Figure 1), which received freshwater input from the land.

Notes on the two unknown diatom species

Two unidentified phytoplankton species were found in this study. Based on the cell's general morphological characters, it was determined that both belong to the diatoms group (Bacillariophyta), which was then coded as Unknown Diatom Species 1 (*Cocconeis* or *Surirella* shaped) and Unknown Diatom Species 2 (*Ephemera* or *Thalassiophysa* shaped). The code name for each of those unidentified species was given based on the similarity of their frustule characters with some known diatom species.

Unknown diatom species 1 (*Cocconeis* or *Surirella* shaped) (Figure 2.A) – The specimen was found only at St2 around Pari Island with distinct morphological characteristics, resembling some species within *Cocconeis* or *Surirella* genus. Cells are solitary. Frustule is elliptical with rounded apices, with a length of 90-110 μm, central width of 55-70 μm. One apex is wider than the other, with a width of 64-80 μm. Raphe is visible. Sternum is not present. Central nodule is either absent or blocked from view by the clump of organic material at the center of the frustule. Transapical striae are visible with a parallel pattern at the middle and radiate towards the axis. The width of striae is between 1.2 to 2.5 μm. At the wider valve's apex, the striate form a concentric pattern. Under light microscopy, the striae seem to be composed of a single row of pores (uniseriate) and form a parallel pattern of finer striae. However, higher magnification using electron microscopy is required to observe the characteristics of the valve's areolae.

Unknown diatom species 2 (*Ephemera* or *Thalassiophysa* shaped) (Figure 2.B) – The specimen was found only at St7 around Tidung Island with distinct morphological characteristics, closely resembling some species within *Ephemera* genus. However, some characters were also similar to species within genus *Thalassiophysa*, particularly, the *Thalassiophysa hyalina*. Cells are solitary. Frustule is broadly elliptical with truncated ends. Frustule has a length of 84-106 μm and central width of 52-61 μm. Raphe is visible but sternum is not visible. Organic materials in the uncleaned cells are present at the center of the cell. Fibulate raphe system, with keeled raphe that strongly bifurcates and curved into the ventral side near the center and formed strong central notch. Valve striation, with parallel striae pattern, is weakly visible under phase-contrast in water mounted specimen. Finer striae characteristic is not visible in light microscopy and might require electron microscopy to observe more detailed characteristics of the frustule.

Phytoplankton community and estimated number of species

In this study, the number of species found at each site varied between 39 to 73 species, with the highest number of species was found at St5 around Tidung Island and the lowest found at St3 around Pari Island (Figure 3.B). Similarly, the density of phytoplankton was also found at the highest at St5 and lowest at St3 (Figure 3.A). Despite its lowest cell density and number of species, St3 around Pari Island had the highest evenness index (Figure 3.C) and had a higher diversity index compared to most of the sites in Pari Island, Payung Island, and Tidung Island (Figure 3.D). Based on the evenness index (Figure 3.D), there was no over-domination of one or two phytoplankton species despite the obvious domination of diatom species in waters around the Pari, Payung, and Tidung Islands.

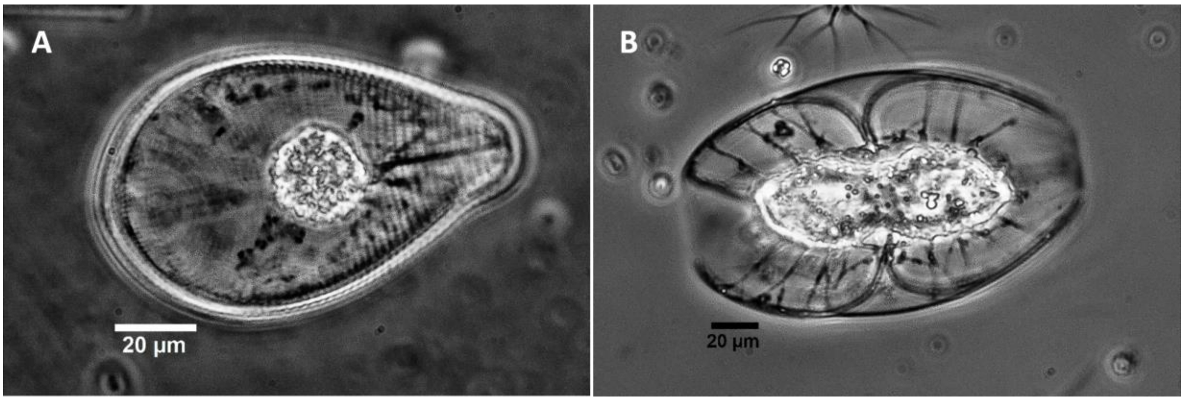

Figure 2. A) Unknown diatom species 1 (*Cocconeis* or *Surirella* shaped); B) Unknown diatom species 2 (*Ephemera* or *Amphora* shaped). Photographed using a phase-contrast inverted microscope at 400X magnification. Images were converted into the monochrome mode to improve the sharpness and clarity of some fine morphological characteristics.

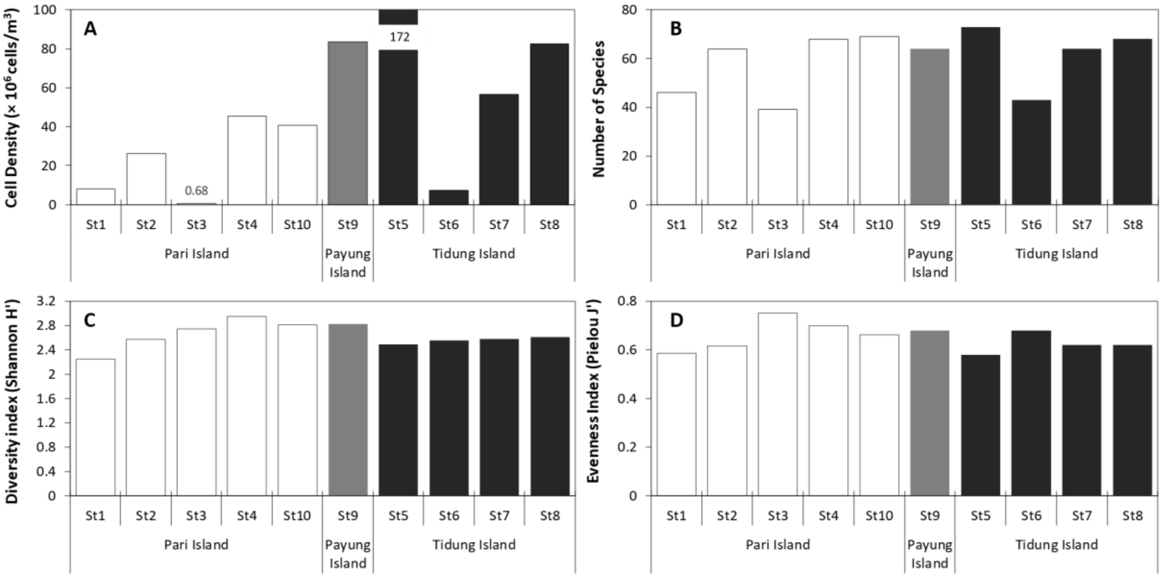

Figure 3. Phytoplankton community in the studied areas: A) Cell density; B) number of species; C) diversity index; D) evenness index

Table 3. Result of estimation for missing species using four different species estimators: Chao, Jackknife 1, Jackknife 2, and Bootstrap. In this analysis, a 999 permutation was used to randomize the site order.

Number of sites	Number of species (S)	Chao	Jack-knife 1	Jack-knife 2	Bootstrap
1	60	60	60	-	60
2	86	118	112	112	99
3	102	131	135	146	117
4	114	147	150	165	131
5	123	157	161	176	141
6	131	164	168	184	149
7	137	169	174	190	155
8	142	173	179	195	161
9	147	174	183	196	165
10	150	176	186	198	169
Estimated number of missing species		26	36	48	19

Four species estimators were used in the non-parametric estimation analysis of species richness, which results in the total estimated missing phytoplankton species in this study was between 19 to 48 species (Table 3). The species accumulation curve (SAC) in Figure 4 shows the differences in the estimated values and range of standard deviation between the species estimators used in this study. In this case, Jackknife 2 shows the highest estimated values between all the species estimators but has a considerably higher range of error (standard deviation) compared to the other species estimators. On the other hand, the bootstrapping method seems to have the narrowest error range in this analysis (Figure 4).

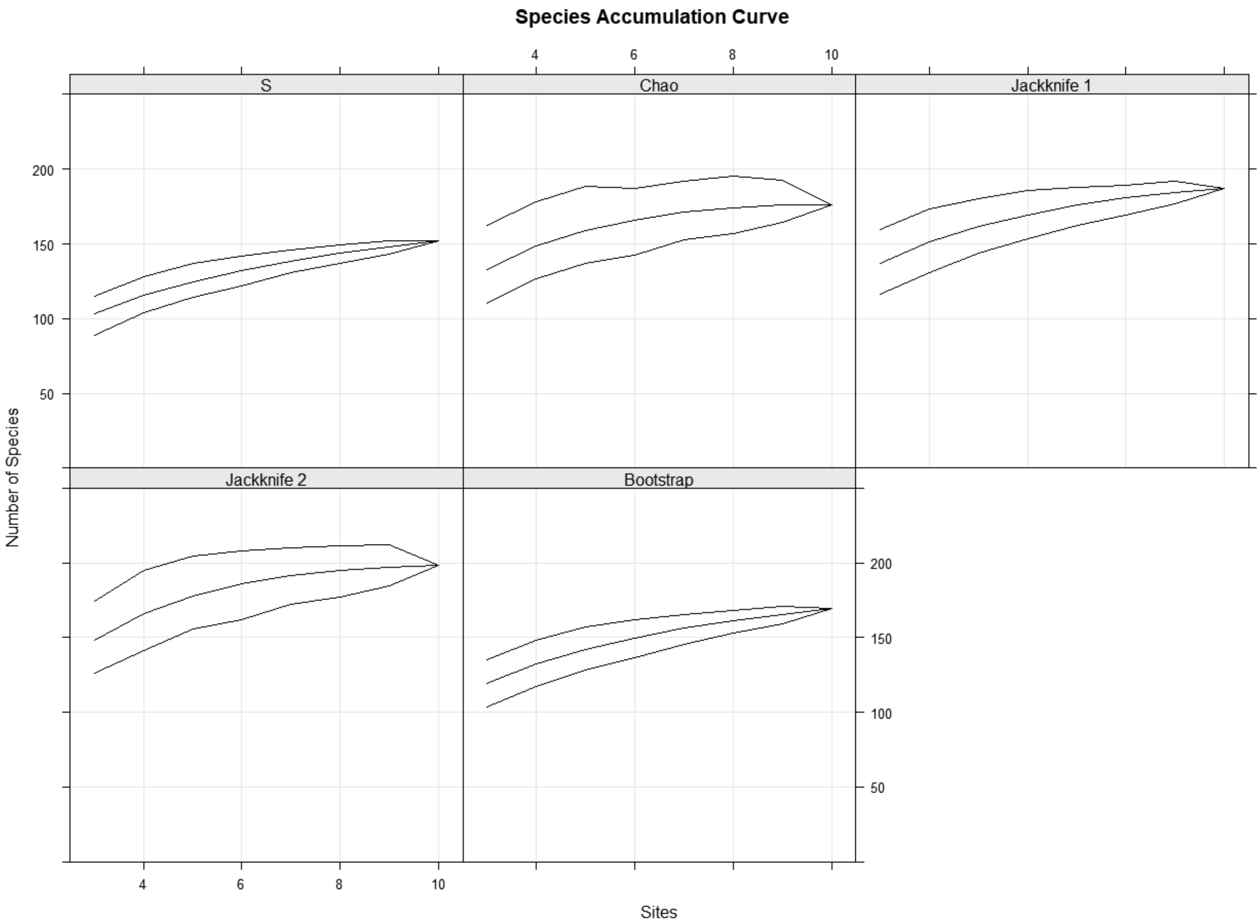

Figure 4. Species accumulation curve (SAC) from four different species estimators: Chao, Jackknife 1, Jackknife 2, and Bootstrap. S in this figure refers to the total number of phytoplankton species from the data. In this analysis, a 999 random permutation was used to assuring there was no selection bias

Discussion

Density and diversity of phytoplankton in Pari, Payung, and Tidung Islands

The dominance of diatoms among the phytoplankton community in all studied sites was expected mainly because the dominance of diatoms is typical for most marine coastal ecosystems (Oseji et al. 2018). High density and diversity of diatoms are considered as a normal condition in most coastal ecosystems, whereas domination of dinoflagellates indicates the presence of environmental anomalies or disturbances in the ecosystem. Changes in the domination of diatoms to dinoflagellates could happen due to various reasons, for example, anthropogenic activities on the coastline could change the temperature and nutrient ration in the water column, which favor the rapid growth of dinoflagellates (Xiao et al. 2018).

Tidung and Pari Islands have been reported to suffer from various type of anthropogenic stresses, degrading the coastal water quality and causing damages to its various coastal ecosystems, such as coral reefs and seagrass bed (Maduppa et al. 2012; Widiarty and Pudjiarto 2015; Rizqina et al. 2017). In this case, a higher average of phytoplankton cell density and lower species diversity, as well as lower evenness in Tidung Island might be related to its higher anthropogenic impacts from denser coastal population and higher domestic activities compared to those in Pari Island. Unfortunately, no environmental data was collected in this study, thus it was not possible to prove that assumption. However, the relationship between lower phytoplankton biodiversity in coastal areas with stronger anthropogenic pressures has been reported in some studies, such as in the study by Ninčević-Gladan (2015) in the coastal waters of the Adriatic Sea and Karthik et al (2012) in the Port Blair of South Andaman Island. Stronger anthropogenic activities in coastal ecosystems could increase environmental stresses to phytoplankton communities via changes in nutrient ratio, pH, or turbidity, which could reduce primary productivity and lowering species diversity (Häder and Gao 2015).

Anthropogenic activities are also highly related to coastal eutrophication. If it is combined with ocean warming, it could lead to the expansion of dead zones (anoxic waters) and increasing frequency of harmful algal blooms (HABs) events in the disturbed ecosystems (Xiao et al. 2018). Although phytoplankton cell density in some sites of this study was high (> 10^6 cells.m^{-3}), none of the sites in Pari, Tidung, or Payung island, experiencing a phytoplankton bloom. As a note, blooms of phytoplankton are considered when the total cell density of phytoplankton is higher than 10^9 cells.m^{-3} or 10^7 cells.L^{-1} (Spatharis and Tsirtsis 2010).

Species checklist and estimators as a tool to detect harmful and/or invasive species

It was estimated that the current sampling effort was sufficiently captured the general community structure of phytoplankton in Pari, Tidung, and Payung Island, which includes a list of common species within diatoms, dinoflagellates, and cyanobacteria groups. That statement was based on the graph of SAC from all four estimators used in this study, which showed an indication of reaching equilibrium at effort (sampling site) slightly beyond ten sites. However, several species were predicted to be missing from this study, with the estimated number varied between 19 to 48 phytoplankton species depend on the species estimator's formula. In this case, it was preferred to use the result from the analysis using the second-order Jackknife (Jackknife-2). Because it was generally known to provide a more accurate and produced less biased estimates of species richness (Colwell and Coddington 1994). Therefore, it is suggested that any future study dealing with phytoplankton community structure, or any future study that builds a phytoplankton species list in Pari, Tidung, and Payung Island, need to find and identify an additional 48 missing species according to the Jackknife-2 estimator.

In Jakarta Bay, at least 26 genera of phytoplankton were common in the water column which consists of 16 genera of diatoms and 10 genera of dinoflagellates (Adnan 1992). Among those genera, *Chaetoceros*, and *Skeletonema*, and *Thalassiosira* were the dominant genera in the ecosystem (Praseno et al. 2003; Sidabutar et al. 2016). This study listed 64 genera of phytoplankton, consisting of 45 genera of diatoms, 3 genera of cyanobacteria, and 16 genera of dinoflagellates. Additionally, this study further identified the genera into species level, which results in a total of 150 species of phytoplankton, which included two unidentified diatoms species. However, due to the limitation of light microscopy (LM), it is difficult to perform species-level identification with some genera, such as *Lyngbya*, *Pseudo-nitzschia*, *Nitzschia*, *Pleurosigma*, *Goniodoma*, and *Gonyaulax*. Thus, this gap might also contribute to the number of 'missing species' in the estimated species number of this study. Aside from the limitation in species-level identification, the true number of missing species in this study could be much higher than the estimated number, particularly due to the limited number of sampling sites and lack of repetition to represent different seasons in the Pari, Payung, and Tidung Islands. As a comparison, a study by Senming et al. (2015) in Lembeh Strait and Bangka Strait, North Celebes, initially identified 170 species of phytoplankton from 13 sites in the 2014 study. However, additional sampling efforts and further in-depth analysis by combining all data from 2012-2015, resulting in a total of over 400 species of phytoplankton (Senming et al. 2018). Therefore, a further study which deals with species checklist has to be carried out across different seasons, not only to find the missing species, but also to describe the natural shift in the phytoplankton community structure in the waters of Pari, Payung, and Tidung Island.

As mentioned earlier, a regular checklist of phytoplankton species is crucial to quickly determine the presence of new, and possibly, invasive species in the marine ecosystems (Mather et al. 2010; Lee et al. 2015). The species checklist was especially important and vital in coastal areas, which receive an increasing anthropogenic pressure, such as Jakarta Bay and Seribu Islands. Unfortunately, due to the lack of in-depth study of phytoplankton diversity in Pari, Tidung, and Payung Islands, it was not possible to determine which species in this study was new and non-native to the coastal waters of the islands. However, there are some species of concern in this study which are considered as bloom-forming and harmful species and have been known to cause ocean discoloration, mass fish mortality, or poisoning cases in Indonesia, such as recorded in the coastal area of Lampung, Ambon, Jakarta, Sorong, and Cirebon. Those species belongs to the genus of *Trichodesmium*, *Pseudo-nitzschia*, *Ceratium*, *Noctiluca*, *Gonyaulax*, *Dinophysis*, *Cochlodinium*, *Prorocentrum*, and *Alexandrium* (Praseno and Wiadnyana 1996; Wiadnyana et al. 1996; Praseno et al. 1999; Praseno and Sugestiningsih, 2000; Praseno et al. 2003; Likumahua 2015; Nurlina and Liambo 2018). Among those genera, species from genus *Trichodesmium*, the *T. erythraeum*, have been known to cause repeated blooms and ocean discoloration in Pari Island (Thoha 1991; Praseno et al. 1999). Other bloom-forming genera that often blooms in Jakarta Bay were *Chaetoceros* and *Skeletonema*, with blooms and dominance shift between seasons in the bay, while *Noctiluca scintillans* was the main contributor to the several cases of mass fish death event in the bay (Adnan 1992; Praseno et al. 1999; Praseno et al. 2003). Additionally, some other dinoflagellate species have recorded blooms in Jakarta Bay, such as *Prorocentrum minimum* and *Gonyaulax* sp. which also caused ocean discoloration and mass mortality of marine organisms (Adnan 1992; Praseno et al. 2003). On the other hand, *Cochlodinium* (*Margalefdinium*) *polykrikoides* was recently reported as the main cause of wide-area ocean discoloration, mass fish mortality, and economic loss of more than 60,000 USD from cage fisheries in Lampung Bay during the 2012-2013 blooms events (Muawanah et al. 2013; Thoha et al. 2019). The presence of *Cochlodinium* sp., a dinoflagellate which caused fish mortality cases in Lampung Bay, raises a concern of the possibility of whether or not it will cause a bloom in the ecosystem of the Seribu Island or Jakarta Bay. Furthermore, blooms of any non-native phytoplankton species in the Seribu Island or Jakarta Bay could change the species composition and might cause some native species to disappear from the ecosystem. Thus, a regular checklist of species like in this study is vital to monitor the existence of non-native and potentially invasive species. Information on the phytoplankton species checklist could also help in the management process to mitigate the anthropogenic impacts on the diversity of marine planktonic organisms in the ecosystem of Seribu Island.

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Table S1. List of species from the group of Chlorophyta, Cyanobacteria, and Diatomae from Pari Island, Payung Island, and Tidung Island, Jakarta, Indonesia

Phytoplankton	Pari Island				Payung Island		Tidung Island			
	St1	**St2**	**St3**	**St4**	**St10**	**St9**	**St5**	**St6**	**St7**	**St8**
Chlorophyta										
Spirulina										
Spirulina sp.	-	-	+	-	-	-	-	-	-	-
Cyanobacteria										
Lyngbya										
Lyngbya sp.	-	-	-	++	-	-	+++	++	-	-
Trichodesmium										
Trichodesmium eurythraenum	+++	+++	+	++++	+++	+++	++++	+	+++	+++
Diatomae										
Amphiphora										
Amphiphora sp.	-	-	+	-	-	-	-	-	-	-
Amphora										
Amphora laevis	-	-	++	-	-	-	-	-	++	-
Amphora sp.	-	-	++	-	-	-	-	-	-	-
Asterionellopsis										
Asterionellopsis glacialis	++	-	+	-	-	-	+++	++	++	-
Bacillaria										
Bacillaria paxilifera	-	-	+	-	-	-	-	-	+++	-
Bacteriastrum										
Bacteriastrum delicatulum	-	-	-	++++	++++	-	-	-	-	-
Bacteriastrum elongatum	-	+++	-	-	-	+++	+++	-	-	-
Bacteriastrum furcatum	+++	+++	+	++++	++++	++++	-	+++	++++	++++
Bacteriastrum hyalinum	+++	++++	-	+++	++++	++++	++++	+++	++++	++++
Bacteriastrum minus	-	++	-	+++	++	-	++++	++	-	++
Campylodiscus										
Campylodiscus ralfsii	-	-	-	-	-	-	-	-	+	-
Cerataulina										
Cerataulina bergonii	-	-	-	-	-	-	-	-	+++	-
Cerataulina dentata	-	-	-	+++	++	-	+++	-	-	++++
Cerataulina pelagica	++	-	-	+++	+++	+++	+++	++	-	+++
Chaetoceros										
Chaetoceros affinis	++++	++++	-	++++	++++	++++	++++	+++	++++	++++
Chaetoceros coarctatus	++	++	-	+++	-	++	+++	-	-	+++
Chaetoceros compressus	++	-	-	-	+++	+++	+++	-	+++	++
Chaetoceros contortus	-	++++	-	-	+++	-	-	+++	-	-
Chaetoceros curvisetus	++++	++++	+	++++	++++	++++	++++	++++	++++	++++
Chaetoceros decipiens	+++	++	-	++++	++++	++++	++++	+++	++++	++++
Chaetoceros denticulatus	-	++	-	-	-	-	-	-	++	-
Chaetoceros didymus	-	++	-	-	++	+++	+++	-	++	+++
Chaetoceros didymus var. protuberans	++	-	-	+++	-	+++	++	-	+++	+++
Chaetoceros distans	+++	++++	-	++++	++++	++++	++++	+++	++++	++++
Chaetoceros diversus	++	+++	-	+++	+++	++++	+++	++	++	+++
Chaetoceros eibenii	-	+++	-	-	++	+++	+++	-	-	++
Chaetoceros laciniosus	++	++	-	+++	+++	++++	++++	++	+++	+++
Chaetoceros lorenzianus	++	++++	-	++++	++++	++++	++++	+++	++++	++++
Chaetoceros paradoxus	+++	-	-	-	++++	++++	++++	-	-	+++
Chaetoceros pendulus	-	++	-	++	++	++	+++	+	++	++
Chaetoceros tenuissimus	-	+	-	+	+	++	-	-	-	++
Chaetoceros tortissimum	+++	++++	-	++++	-	++++	-	+++	++++	+++
Chaetoceros wighamii	-	-	-	-	+++	-	+++	+++	+++	+++
Climacodium										
Climacodium frauenfeldianum	-	-	-	-	++	-	-	-	-	-
Coscinodiscus										
Coscinodiscus centralis	-	-	-	-	-	-	+	-	-	-
Coscinodiscus concinnus	-	-	-	-	+	++	-	-	+	-
Coscinodiscus granii	-	-	+	-	-	-	-	-	-	-
Coscinodiscus oculus-iridis	-	-	-	++	+	+	++	-	-	+
Coscinodiscus radiatus	-	+	-	-	-	-	+	-	-	-
Coscinodiscus wailesii	-	-	+	-	-	-	-	-	-	+
Cylindrotheca										
Cylindrotheca closterium	++	++	+++	+++	+++	+++	++++	++	+++	+++
Dactyliosolen										

Dactyliosolen phuketensis	-	-	-	+++	+++	-	-	-	++	-
Diploneis										
Diploneis sp.	-	-	-	-	-	-	-	+	-	-
Diploneis sp2.	-	-	-	-	-	-	-	+	-	-
Ditylum										
Ditylum sol	-	-	-	++	++	++	++	+	+	-
Ethmodiscus										
Ethmodiscus sp.	-	-	-	-	-	-	++	-	-	-
Eucampia										
Eucampia cornuta	-	-	-	-	++	+	++	-	-	-
Eucampia zodiacus	-	-	-	++	++	-	++	-	-	-
Fragillariopsis										
Fragillariopsis doliolum	-	++	-	-	-	-	-	-	++	-
Grammatophora										
Grammatophora marina	-	-	++	-	-	-	-	-	-	-
Grammatophora sp.	-	++	-	-	-	-	++++	-	++	-
Guinardia										
Guinardia cylindrus	-	-	-	+++	-	+++	++++	-	-	-
Guinardia delicatula	-	++	-	++	+++	-	-	-	++	+++
Guinardia flaccida	-	-	++	++	++	++	+++	-	+++	+++
Gyrosigma										
Gyrosigma sp.	+	-	+	++	-	++	-	-	-	-
Haslea										
Haslea gigantea	-	++	-	-	-	-	-	-	-	-
Helicotheca										
Helicotheca tamesis	-	++	-	++	+++	+++	++	-	++	++
Hemiaulus										
Hemiaulus hauckii	-	-	-	++	-	+++	++	-	++	+
Hemiaulus indicus	-	-	-	+++	-	-	-	-	-	-
Hemiaulus membranaceus	-	-	-	++	-	-	++	-	-	++
Hemiaulus sinensis	-	++	+	++	++	++	-	-	++	-
Hemidiscus										
Hemidiscus cuneiformes	-	-	-	+	-	-	+	-	-	-
Lauderia										
Lauderia annulata	++	-	-	+++	+++	+++	++++	-	+++	+++
Leptocylindrus										
Leptocylindrus danicus	+	+++	-	+++	+++	+++	+++	++	-	++
Licmophora										
Licmophora abbreviata	-	++	+	-	-	-	-	-	++	-
Licmophora sp.	-	-	+	-	-	-	-	-	-	-
Lioloma										
Lioloma elongatum	-	+++	-	-	-	-	-	-	-	-
Lioloma pacificum	+	++	-	-	-	-	-	-	-	-
Meuniera										
Meuniera membranacea	-	-	-	+	-	-	-	-	++	-
Navicula										
Navicula directa	-	++	++	++	-	++	-	-	++	++
Navicula sp.	-	-	++	-	-	-	-	-	-	-
Nitzschia										
Nitzschia longissima	+	++	++	++	-	-	-	-	-	-
Nitzschia longissima var. reversa	-	++	++	-	+	-	-	++	+++	-
Nitzschia lorenziana	+	++	++	-	-	-	-	-	++	-
Nitzschia marina	-	-	-	-	-	-	-	+	-	-
Nitzschia sigma var. indica	+	++	-	-	-	-	-	-	-	-
Nitzschia sp.	-	-	-	-	-	-	-	+	-	-
Nitzschia sp2.	-	-	+	-	-	-	-	-	-	+
Odontella										
Odontella mobiliensis	-	-	-	+	-	+	-	-	+	+
Odontella sinensis	+	-	-	+++	++	++	++	-	++	++
Plagiogramma										
Plagiogramma interruptum	-	-	++	-	-	-	-	-	-	-
Pleurosigma										
Pleurosigma elongatum	+	-	-	-	-	+	-	-	-	-
Pleurosigma pelagicum	-	-	-	-	+	-	-	++	-	-
Pleurosigma sp.	-	-	++	-	-	-	-	+	-	-
Pleurosigma sp2.	-	-	+	-	-	-	-	-	-	-
Proboscia										

Proboscia alata	+	+++	+	+++	+++	+++	+++	++	+++	+++
Pseudo-nitzschia										
Pseudo-nitzschia sp.	+++	+++	++	++++	++++	++++	++++	++	++++	++++
Rhizosolenia										
Rhizosolenia bergonii	-	-	-	+	-	-	++	-	+	+
Rhizosolenia calcar-avis	+	+++	-	+++	++	+++	+++	-	++	+++
Rhizosolenia castracanei	-	-	-	++	-	-	-	-	+	+
Rhizosolenia cochlea	-	-	-	-	++	-	-	-	++	+
Rhizosolenia decipiens	+	+++	-	++	++	++	+++	-	++	++
Rhizosolenia hebetata	-	++	-	+++	-	++	+++	++	-	++
Rhizosolenia hebetata f. semispina	+	-	-	-	-	++	++	-	++	-
Rhizosolenia imbricata	+	++	+	+++	+	++	+++	+	+++	+++
Rhizosolenia robusta	-	-	-	++	+	++	++	-	+	-
Rhizosolenia setigera	-	+	-	+	++	++	+++	-	+	++
Skeletonema										
Skeletonema costatum	+++	++++	-	++++	+++	++++	++++	++	+++	++++
Thalassionema										
Thalassionema frauenfeldii	-	-	+	-	-	-	-	+	++	-
Thalassionema javanicum	+	++	-	-	-	-	-	-	-	-
Thalassionema nitzschioides	+++	+++	++	++++	++++	++++	-	+++	++++	++++
Thalassionema nitzschioides var. parva	++	+++	+	++++	+++	++++	-	++	+++	++++
Thalassiosira										
Thalassiosira sp.	+	+	+	-	+	+	-	++	++	+
Thalassiosira sp.2	-	-	-	-	+	-	-	-	-	-
Thalassiosira subtilis	-	-	-	+++	-	-	-	-	-	-
Thalassiothrix										
Thalassiothrix longissima	+	++	-	++	++	-	++	++	++	++
Triceratium										
Triceratium sp.	-	+	-	-	+	-	-	-	-	-
Unknown										
Unknown species	-	-	-	-	-	-	-	-	+	-
Unknown species 2	-	+	-	-	-	-	-	-	-	-

Note: '++++' ≥ 106 cells.m-3; '+++' = 104 – 105 cells.m-3, '++' = 102 – 104 cells.m-3, '+' = 1 - 102 cells.m-3, '-' = no cells

Table S2. List of species from the group of Dinoflagellate from Pari Island, Payung Island, and Tidung Island, Jakarta, Indonesia

Phytoplankton	**Pari Island**			**Payung Island**			**Tidung Island**			
	St1	**St2**	**St3**	**St4**	**St10**	**St9**	**St5**	**St6**	**St7**	**St8**
Dinoflagellate										
Alexandrium										
Alexandrium sp.	-	-	+	-	-	-	-	-	-	+
Amphisolenia										
Amphisolenia bidentata	-	+	-	-	+	-	-	-	-	-
Amphisolenia schauvislandii	-	+	-	-	-	-	-	-	-	+
Ceratium										
Ceratium breve	-	-	-	++	++	-	+	-	-	+
Ceratium candelabrum	-	-	-	-	-	-	-	-	-	+
Ceratium carriense	-	-	-	-	-	-	+	-	-	-
Ceratium declinatum	-	-	-	-	+	+	-	-	-	-
Ceratium furca	-	-	-	-	-	+	++	-	-	+
Ceratium fusus	+	++	-	++	++	++	++	-	++	++
Ceratium gibberum	-	+	-	-	-	-	-	-	-	-
Ceratium inflatum	+	-	-	-	-	-	-	-	-	+
Ceratium macroceros	+	+	-	-	++	++	++	+	++	++
Ceratium massiliense	-	-	-	-	+	-	-	-	-	+
Ceratium trichoceros	+	++	-	++	++	+	++	+	++	++
Ceratium tripos	-	+	-	+	++	-	++	-	-	-
Ceratocorys										
Ceratocorys armata	-	-	-	-	-	-	+	-	-	-
Cladopyxis										
Cladopyxis brachiolatum	-	+	-	-	+	-	+	-	-	-
Cochlodinium										
Cochlodinium sp.	-	-	-	-	-	-	-	-	++	-
Dinophysis										
Dinophysis miles	-	+	-	-	-	-	-	-	-	-
Goniodoma										
Goniodoma sp.	-	-	-	-	-	-	++	-	-	-
Gonyaulax										
Gonyaulax sp.	-	-	-	-	-	+	-	-	-	-
Noctiluca										
Noctiluca scintillans	-	-	-	+	-	-	+	-	+	+
Ornithocercus										
Ornithocercus sp.	-	-	-	-	-	+	-	-	-	-
Peridinium										
Peridinium quinquecorne	+	+	-	-	-	-	-	-	-	-
Prorocentrum										
Prorocentrum lima	-	+	+	+	-	-	-	-	-	-
Protoperidinium										
Protoperidinium balticum	-	-	+	+	+	+	+	+	-	+
Protoperidinium curtipes	-	-	-	-	+	-	-	-	-	-
Protoperidinium depressum	-	-	-	-	+	-	+	-	-	-
Protoperidinium divergens	+	-	-	++	-	+	+	+	-	+
Protoperidinium faltipes	-	-	-	-	+	-	-	-	-	-
Protoperidinium minutum	-	-	+	-	+	-	-	-	-	-
Protoperidinium oceanicum	+	-	-	-	+	-	+	+	-	+
Protoperidinium pentagonum	-	-	-	-	-	+	-	-	-	-
Protoperidinium rectum	-	-	-	-	-	+	+	-	-	+
Protoperidinium roseum	-	-	-	+	-	-	-	-	-	-
Protoperidinium sphaericum	-	+	+	-	-	-	-	-	-	-
Pyrophacus										
Pyrophacus horologium	-	-	-	+	-	+	-	-	-	-
Pyrophacus steinii	-	-	-	+	-	+	+	-	-	+

Note: '++++' ≥ 10^6 cells.m^{-3}; '+++' = 10^4 – 10^5 cells.m^{-3}, '++' = 10^2 – 10^4 cells.m^{-3}, '+' = 1 - 10^2 cells.m^{-3}, '-' = no cells