Interactive comment on “The effects of different environmental factors on biochemical composition of particulate organic matters in Gwangyang Bay, South Korea” by Jang Han Lee et al.

Anonymous Referee #1

Received and published: 16 September 2016

Review of Biogeosciences Discuss., doi:10.5194/bg-2016-347 The effects of different environmental factors on biochemical composition of particulate organic matter in Gwangyang Bay, South Korea written by Jang Han Lee, Dabin Lee, Jae Joong Kang, Hui Tae Joo, Jae Hyung Lee, Ho Won Lee, So Hyun Ahn and Sang Heon Lee In the submitted article the authors analyzed seasonal changes of the biochemical composition (proteins, lipids, carbohydrates) of the particulate organic matter and linked it to environmental factors in order to determine the major environmental factor influencing the changes of biochemical composition and the origin of particulate organic carbon.

In general, the paper has a scientific potential and some parts of the paper are fairly discussed (biochemical composition) and linked to the relevant literature. However, some parts of the sections Materials and methods, Results and Discussion are not clearly outlined or missed important information that complicate understanding of the text and question the purpose of applied experimental design. The conclusions are mostly repeating of the results so it should be also rewritten and the last paragraph omitted, it is too general and does not contain the conclusion of the paper. The major revision and resubmission is recommended.

➔We revised each section throughout the manuscript, deleted most of repeating results in conclusions and revised carefully our manuscript based on referee # 1 comments as below.

The experimental design was based on three different light intensity depths along three stations in bay and all results were pooled together on the monthly basis since no significant differences between vertical and spatial distributions were found. It was mentioned in the Material and methods that some statistical tests (ANOVA, t-test) were used, but it is not clear which test they used, where and which parameters they tested and how (there is 1 concentration per 1 depth at 1 station).

➔ We did ANOVA test for each depth from 3 stations based on an assumption of no spatial difference and another ANOVA test for a spatial difference by pooling of 3 light depths at one station and comparing each station based on an assumption of no difference in light depths. But, we found to realize that there are statistical errors by doing that. So, we deleted no significant differences between vertical and spatial distributions.

The authors used very often describing results the word significant but did not specified the name of test, F-value or t-value.

➔We revised our results.

Details and reference about determination and/or calculation of the 30% and 1% of the photon flux based on Secchi disc depths should be added.

➔We added details and reference for light depth determination in line 87-90, page 4-5.

It was only mentioned that the samples were incubated and later on in discussion it was written that the incubation time was too short?

➔Our main purpose of the PAR measurements was calculating hourly primary productivity executed for 4~5 hours as a parallel study. Therefore, the irradiance values measured in this study were not representative for our sampling periods. We mentioned this in the method section in line 92-97, page 5 and further discussed on the issue in line 370-379, page 16.

Further on, the light intensity and its impact (or no impact) on the biochemical composition is not discussed, particularly considering 10 times difference in light intensity between April 2012 and April 2013. These findings should be discussed with regard to a body of literature in which the influence of light was investigated and found.

➔We added the discussion on the light intensity impact on the biochemical compositions, especially 10 times difference in light intensity between April 2012 and April 2013 in line 370-379, page 16.

In the Table 1 there is irradiance expressed as ave±S.D.; I wonder if given average contains measurements from all stations on the day of sampling?

➔We measured irradiance one time per each cruise at every 30 seconds during the incubation hours for primary productivity executed for 4~5 hours during day time around local noon time. So, ave±S.D. values in Table 1 are averages from every 30 seconds for 4-5 hours a day each season. We described the details in line 95-97, page 5.

Details about particulate organic carbon and nitrogen analysis such as volume of filtered water and station where the sample was taken should be added (only one result per month was presented). This is very important since the origin of POM is not typical for the estuaries.

➔We measured POC, PON, and δ^{13}C of POM collected from surface at the 3 stations at every sampling time. They varied but did not show large differences in POC, PON, and δ^{13}C among the different stations. We described the sampling details in line 114-120, page 6.

It is very interesting that riverine terrestrially derived organic matter is not an important component of the particulate organic matter in the Gwangyang Bay system, which has a large river runoff. One would expect partly organic matter of a terrestrial origin and not such clear phytoplankton fingerprint since the water column is very turbid and euphotic layer very thin (3- 11 m). Also this peculiarity and these results should be discussed and compared with other estuaries like the authors did for biochemical composition.

➔We further discussed on the issue in line 300-310, page 13-14.

Nutrient limitation, the use of the ratios (lines 301-305): it is not clear why the authors use for the interpretation of phosphorus and nitrogen limitation only the ratios with dissolved silica (DSi) and not between these two components (N: P). If it was not a random error, the reference should be added for listed criteria. Anyway, in criteria b) for nitrogen limitation instead of DSi:DIP ratio >16 should stand < 16, if it was presumed that DSi and DIN appear in similar concentrations, though not always the case.

➔We revised them in line 335-338, page 15 based on Dortch and Whitledge (1992).

References: Listed but not cited in the text: Adolf and Harding, 2006; Choi and Noh, 1998; De Oliveira et al 1999; Julian and David, 1966; Kim et al., 2016 Cited in the text but not listed: Choi et al., 1998; Kim et al., 2014; Kwon et al, 2001; Marsh and Weinstein 1966; Paerl et al., 2006; Yun et al., 2014 Cited or listed with different year of publication: Pirt 1975 (cited in the text), listed in references as Pirt 1976 Some references are written in uppercase. To the references published in the same year a, b should be added

➔We revised the references.

In Tables 1 and 4 in April 2012 appears st. 1 which is not marked on the map (Fig.1)

➔We revised the map in Fig. 1.

Interactive comment on “The effects of different environmental factors on biochemical composition of particulate organic matters in Gwangyang Bay, South Korea” by Jang Han Lee et al.

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General Comments The manuscript presents the seasonal variation of biochemical composition of POM in Bay. The author shows the major controlling factor for them based on statistical analysis. Overall, I found the paper to be sound and believe that it contains valuable data in understanding the characteristics of POM and their contribution to coastal ecosystem as basic food source. I think that the paper is worthy of publication for BGS after minor revisions are made, while there are a few areas that need improvement.

Major comment and corrections

1. Page 12, Line 258-278: The author showed _13C value and carbon to nitrogen ratio in surface, in order to find the origin of POM. I think that the contribution of benthic microalgae to POM could be large and significant, since the study area is located in coastal area and extremely turbid condition related to freshwater input or tidal cycles or wind. Therefore, many amounts of benthic microalgae could be included to POM through the resuspension, especially during high river input. Indeed, Table 3 shows the lower 13C value in August.

➔We discussed on potential contributions of benthic microalgae on POM in line 300-302, page 13.

2. Pages 13-14, Line 301-304: For the criteria of their moral ratios among dissolved inorganic nutrients, I wonder could it be applied in coastal area. I think that the status of nutrient limitation in phytoplankton could be different between open oceans and coastal area.

➔Actually, the criteria of the moral ratios can be applied in coastal area based on several papers as we referred in our discussion (e.g., Roelke et al., 1999).

3. Page 15, Line 335-344: As the author discussed, I think that the composition of phytoplankton assemblages and species could be closely related to seasonal variation of biochemical composition. High nitrogen supply during river-input increased season could lead to different phytoplankton composition. For example, the large sized phytoplankton (such as diatom) could be thrived in that condition, since the large phytoplankton could grow best and dominate under eutrophic condition. According to Fernandez et al. (1994), the carbon allocation into different biochemical pools were different depending on dominant phytoplankton group. For example, the carbon allocation into lipids was higher under the dominance of flagellates, whereas the lower lipid synthesis was observed in the dominance of diatoms. Therefore, the seasonally different phytoplankton composition related to nutrient input could affect to the different biochemical composition in the region.

➔Yes, the seasonal compositions of phytoplankton could lead different biochemical compositions. We discussed on that issues in line 380-389, page 15-16.

4. In figure 3, the author shows positive relationship between river input and protein composition. However, I didn’t find the positive relationship between them, based on comparison with table 2 and figure 2. For example, the protein composition in August was lowest, although the rive input was considerably high. In addition, the protein composition from October in 2012 to April in 2013 was higher than that in August, even though the lower river inputs were recorded.

➔Actually, the river input data in Table 2 are monthly integrated river inputs to show monthly patterns of river input and rainfall. In Figure 3, river-inputs were integrated from 20 days prior to our sampling dates since phytoplankton productivity is recovered after 20 days after rainfall in Gwangyang Bay according to Min et al. (2011). We added this explanation in line 100-102, page 5 to make it clear.

Minor corrections

1. Pages 8-9, Line 175-186: The position of some sentences needs to be corrected. For example, the results about irradiance and chl-a are shown in Table 1 (it is explained in line 178-186). The results for rainfall and river-input are indicated in former position (in line 175-178), although they are shown in Table 2.

➔We rearranged the sentences in line 190-194, page 9.

2. Page 9, Line 195-197: The author found that there were no significant differences in spatial distribution of POM. However, the protein composition in station 2A (is closest to the River) might be higher than in station 4 and 5, since there is the large effect of river-input on the biochemical composition in this study.

➔We did ANOVA test for each depth from 3 stations based on an assumption of no spatial difference and another ANOVA test for a spatial difference by pooling of 3 light depths at one station and comparing each station based on an assumption of no difference in light depths. But, we found to realize that there are statistical errors by doing that. So, we deleted no significant differences between vertical and spatial distributions in our text. The station 2A (is closest to the River) might be the largest effect of river-input but different effects of river-input could be different depending on water circulation, tidal currents, winds, and etc as well as distance from the river in Gwangyang Bay. At this point, we can not determine how much effect at each station from river inputs but the station 2A could have more proteins than others if they have more influence from river inputs based on Table 1 and Fig. 3.

Interactive comment on “The effects of different environmental factors on biochemical composition of particulate organic matters in Gwangyang Bay, South Korea” by Jang Han Lee et al.

Anonymous Referee #2

Received and published: 30 January 2017

The manuscript, “The effects of different environmental factors on biochemical composition of particulate organic matter in Gwangyang Bay, South Korea” written by Lee et al., describes the seasonal changes of the biochemical composition such as proteins, lipids, and carbohydrates of the particulate organic matter and investigates the major environmental controlling factors for the changes of biochemical composition. This paper is very interesting to present seasonal biochemical composition of particulate organic matter responding to various environmental factors and the food quantity assessed in Gwangyang Bay since previous studies have focused mainly on different biochemical compositions as the authors mentioned that. The present study has scientific merits and originality in that: 1. the topic, “biochemical composition of particulate organic matter as indicators of food quality and quantity”, is very intriguing enough to draw much attention for understanding marine ecosystem especially here in Gwanyang Bay; 2. the study is one of few studies that employed seasonal biochemical composition of particulate organic matter responding to various environmental factors; 3. authors found that river-derived dissolved inorganic nitrogen loading is a major governing factor for determining the biochemical composition in a natural bay system which implies that man-made artificial dams could cause a serious disturbance in the ecosystem. Overall, I would recommend publication of this manuscript for Biogeosciences after some minor revisions. I hope to see authors undertake revisions in an appropriate manner because I really want to see the final version of this paper in print.

Some minor comments are listed below:
-. Be consistent with Gwangyang Bay or bay throughout the text.
➔We checked it throughout the text.
-. Be consistent with average or mean in the results.
➔ We checked it throughout the text.
-. (Section 2.1) What time did usually authors make samplings? I’m wondering if there is tidal influence and/or diurnal changes?
➔ There might be tidal influence (no diurnal changes) so that we sampled waters at high tide period before the noon to reduce the tidal effects. We added sampling times in line 88-89, page 4-5.
-. (line 76) indicate t (ton ?).
➔Yes, it is ton! We changed t into ton in line 78, page 4.
-. (lines 83-83) Describe hot to determine 3 light intensities from secchi disk
➔We described how to determine 3 light depths from secchi disk in line 89-91, page 5.
-. (line 157 in section2.5) Describe what Winberg (1971) is.
➔We described the Winberg equation in line 173, page 8.
-. (3. Results) Indicate statistics results in the result section.
➔We indicated statistics results.
-. (Section 4.1) The first sentence in 4.1 section is repeated as the result section of 3.1. Remove it.
➔We rephrased it.
-. (Table 6) No description for Table 6 is shown in the result section. Describe it in the result section before the discussion on that in the discussion section.

➔We changed Table 6 into Table 2 and described the result for the table.

-. (Section 4.4) The first sentence in 4.4 belongs to the result.

➔We removed the sentence.

-. (Table 7) Be consistent with the unit in Table 7 and the text.

➔We changed the unit in Table 7 in consistency of the text.

-. The conclusion section is needed to be revised since some parts in the conclusion repeat some results.

➔We removed the conclusion section because it is too general and does not contain the conclusion of the paper.

The effects of different environmental factors on biochemical composition of particulate organic matters in Gwangyang Bay, South Korea

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Abstract

Biochemical composition of particulate organic matter (POM) through phytoplankton photosynthesis is important to determine food quality for planktonic consumers as well as physiological conditions of phytoplankton. Major environmental factors controlling for the biochemical composition were seasonally investigated in Gwangyang Bay which has only natural conditions (e.g., no artificial dams) in South Korea. Water samples for the biochemical compositions were obtained from three different light depths (100%, 30%, and 1%) mainly at 3 sites in Gwangyang B~~b~~ay from April 2012 to April 2013. Different biochemical classes (carbohydrates [CHO], proteins [PRT], and lipids [LIP]) were extracted and then the concentrations were determined by the optical density measured with a spectrophotometer. The highest and lowest of PRT compositions among the three biochemical classes were in April 2012 (58.0%) and August 2012 (21.2%), whereas the highest and lowest LIP compositions were in August 2012 (49.0%) and April 2012 (24.8%), respectively. CHO composition was recorded high in January 2013 and maintained above 25% during the study period. The calorific contents of food material (FM) ranged from 1.0 Kcal m^{-3} to 6.1 Kcal m^{-3} (annual ~~mean~~average ± S.D. = 2.8 Kcal m^{-3} ± 1.1 Kcal m^{-3}). Based on Pearson's correlation coefficient analysis, a major governing factor for biochemical composition of POM was dissolved inorganic nitrogen loading from river-input in Gwangyang ~~b~~Bay. In conclusion, relatively larger amount of FM and higher calorific contents of POM found in this study compared to other regions reflected good nutritive conditions for sustaining productive shellfish and fish populations in Gwangyang ~~b~~Bay. Continuous observations are needed for monitoring marine ecosystem response to potential environmental perturbations in Gwangyang ~~b~~Bay.

Key words:

Particulate organic matter, biochemical composition, phytoplankton, nitrogen source

1. Introduction

Particulate organic matter (POM) mostly from phytoplankton photosynthesis in the euphotic layer is an important food source for planktonic consumers in water columns (Cauwet, 1978) and their biochemical contents reaching the benthic environments are largely utilized by benthic organisms (Nelson and Smith, 1986; Rice et al., 1994). Therefore, POM is an essential link between surface and benthic ecosystems (Graf, 1992). Previous studies showed that the biochemical composition of the POM such as protein (PRT), lipid (LIP) and carbohydrate (CHO) levels could provide useful information on the nutritional value which is potentially available to consumers (Mayzaud et al, 1989; Navarro et al., 1993; Navarro and Thompson, 1995). However, previous studies mainly focused on the occurrence in the different patterns of biochemical composition of POM. It is noteworthy to investigate how biochemical composition of POM responds to changes in various environmental factors, such as nutrients, light, temperature, and salinity and to assess food quantity for higher trophic levels.

The coastal areas represent one of the world's most vital aquatic resources, supporting and providing food resources and habitats for large numbers of fish and shellfish species (Kwak et al., 2012; Wetz and Yoskowitz, 2013; references therein). In Gwangyang B~~b~~ay, the southern coast of Korea (Fig. 1), coastal fisheries and shellfish farming have been prevalence. Over the past decades, the bay have become industrialized such as the construction of steel mill company, power plant and industrial complex and environmental disturbances have been predicted. Also, estuaries have a high short-term variability depending on many episodic events, such as freshwater inputs, tidal cycles (neap-spring), and wind (storms) (Cloern and Nichols, 1985). These anthropogenic forces and environmental changes drastically affect the estuarine habitat properties which can cause different biochemical compositions of POM. Unfortunately, little information is yet available on the biochemical composition of POM in the bay, South Korea. Hence, this study tested the question of the main environmental factors determining seasonal variation and of biochemical composition POM and assessed quantity of food material (FM) in the bay. Physical (temperature, salinity, irradiance, river-input and rainfall data), chemical (nutrients), and biological (chlorophyll-*a* [chl-*a*], particulate organic carbon [POC] and nitrogen [PON]) parameters were measured in order to both characterize the origin of POM and understand their effects on the biochemical composition of POM. The aims of this study were to: (1) investigate seasonal variation of biochemical composition of POM, (2) identify the origin of POM, and (3) determine a major governing environmental factor for biochemical composition of POM in Gwangyang Bay, Korea.

2. Materials and methods

2.1. Study site and sampling procedure

The study site was located in Gwangyang Bay (34.9 ° N, 127.8 ° E), the southern coast of Korea (Fig. 1). The total area of the bay is 230 km^2 at mean sea level (Kang et al., 2003). The bay is characterized by semidiurnal tides with a maximal range of about 4.8 m at spring tides (Korea Hydrographic and Oceanographic Administration). Freshwater flows into the bay from the Seomjin River at the northern part of the bay (mean flow 27 m^3 s^{-1} and annually 1.9 x 10^9 ton during the study period; the National Institute of Environmental Research) and seawater enters through the narrow southern channel (Yeosu Channel).

To obtain data for seasonal variation of POM in the euphotic depth, the field samplings were undertaken at 3 stations of the bay (St.1 or St. 2A, St. 4, and St. 5; see Fig. 1) on a seasonal basis April, June, August, and October in 2012 and January and April in 2013. St. 1 was changed to St. 2A after April 2012 because of logistic problems. Both stations have similar environmental conditions at a relatively close distance. Using a 5 L Niskin water sampler, water samples were collected at different depths of 3 light intensities (100%, 30%, and 1% of surface irradiances; hereafter 3 light depths) ~~which were determined by a secchi disk~~ and transferred to brown sample bottles which were previously washed with a solution of 0.1 N HCl. The water samplings were conducted at high tide periods before the noon. The different 3 light depths were determined by a secchi disk using vertical attenuation coefficient (K_d = 1.7/secchi depth) from Poole and Atkins (1929) which have been applied globally.

To obtain *in situ* physical parameters, water temperature and salinity were measured with YSI-30 (YSI incorporated) and photosynthetically active radiation (PAR) was measured onboard during the cruise. PAR was measured one time per each cruise at every 30 seconds during the incubation hours for primary productivity by a quantum sensor (LI-190SA, LI-COR) with a data logger (LI-1400, LI-COR) on deck. Since the main purpose of the PAR measurements was calculating hourly primary productivity executed for 4~5 hours during day time around local noon time, the irradiance values in this study might be not representative for our sampling periods. Rainfall and river--input data during the study period were obtained from the Korea Meteorological Administration (http://www.kma.go.kr/index.jsp) and the National Institute of Environmental Research (http://water.nier.go.kr/main/mainContent.do). For relationships between river-input and other factors, river-inputs were integrated from 20 days prior to our sampling dates since phytoplankton productivity is recovered after 20 days after rainfall in Gwangyang Bay according to Min et al. (2011).

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2.2. Chl-*a* and major inorganic nutrient analysis

In order to determine chl-*a* concentration, water samples from 3 light depths were filtered through 25 mm GF/F (Whatman, 0.7 μm) which were kept frozen immediately and returned to the laboratory at Pusan National University, Korea for a further analysis. The filters for chl-*a* concentration were extracted in 90% acetone in a fridge (4 ℃) for 24 h and centrifuged for 20 minutes at 4000 rpm. Using a fluorometer (Tuner Designs, 10-AU) which had been calibrated with commercially purified chl-*a* preparations, chl-*a* concentrations were measured and calculated (Parsons et al., 1984). Water samples for inorganic nutrient concentrations from surface and bottom waters were obtained from Niskin bottles. The samples were kept frozen (-70 ℃) and sent for analysis to the laboratory in the East Sea Fisheries Research Institute (QUAATRO, Seal Analytical).

2.3. Particulate organic carbon and nitrogen analysis

The water samples (300 ml) for POC, PON, and $\delta^{13}C$ of POM were collected from surface at the 3 stations at every sampling time. The water samples were filtered through pre-combusted (450 ℃, 4 h) 25 mm GF/F (Whatman, 0.7 µm) using a low vacuum pressure less than 5 in. Hg. The filters for POC, PON, and $\delta^{13}C$ values were preserved frozen (-20 ℃) for further analysis at home laboratory. For stable isotope analysis, the preserved filters were acidified by concentrated hydrochloric acid fumes overnight to remove carbonate (Hama et al., 1983)~~and~~ and the abundances of ^{13}C and ^{15}N and the total amounts of POC and PON were determined using a Thermo Finnigan Delta + XP mass spectrometer at the stable isotope laboratory of the University of Alaska Fairbanks, USA.

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2.4. Biochemical composition analysis

The water samples for the biochemical composition (carbohydrates, proteins, and lipids) of POM were collected from 3 light depths. The water samples were filtered through 47 mm GF/F (Whatman, 0.7 µm pore), which were immediately frozen at -70 ℃ and preserved for biochemical composition analysis at the home laboratory.

Protein analysis

Protein (PRT) concentrations were assessed according to a modified method of Lowry at el. (1951). The filters for PRT analysis were transferred into 12 mL centrifuge tubes with 1 mL DH_2O, respectively. The filters were grounded (using a glass rod) in the tubes with a 5 ml alkaline copper solution (a mixture of 2% Na_2CO_3 in 0.1 N NaOH with 0.5% $CuSO_4{\cdot}5H_2O$ in 1 % sodium or potassium tartrate; 50:1, v/v). The solutions for PRT concentrations were mixed well (using a vortex) and allowed to stand for 10 min at room temperature in the hood. After 10 min, 0.5 mL of diluted Folin-Ciocalteu phenol reagent (1:1, v/v) was added into the solution, mixed occasionally with a vortex mixer, and allowed to sit for 1 h 30 min. The solutions with a blue color were centrifuged at 3,000 rpm for 10 min. Absorbance of the supernatant was measured at 750 nm. Bovine Serum Albumin (2 mg mL^{-1}, SIGMA) was used as a standard for the PRT concentration.

Lipid analysis

Lipid (LIP) concentrations were extracted according to a column method modified from Bligh and Dyer (1959), and Marsh and Weinstein (1966). The filters for LIP analysis were transferred into 16 mL glass tubes with 3 mL of chloroform-methanol (1:2, v/v). The filters in the tubes were grounded, and then the mixtures were mixed using a vortex mixer. For LIP extraction, glass tubes with samples were stored in the fridge (4 ℃) to prevent the solvents from evaporating. After 1 h, the solvents were centrifuged at 2,000 rpm for 10 min and the supernatants were collected and stored in new tubes. This extraction procedure was performed once again immediately. When the extractions were completed, 4 mL of DH_2O was added to the solution in the new tubes, and the solution was homogenized using a vortex mixer. After mixing, the tubes were centrifuged at 2,000 rpm for 10 min, and the solvents were separated into two phases (the chloroform phase for lipids and methanol + DH_2O phase). The methanol + DH_2O phase was removed from the solvent using a Pasteur pipette. The chloroform phase was placed in a dry oven at 40 ℃ for 48 h. After it totally dried for carbonization analysis (Marsh and Weinstein 1966), 2 mL of H_2SO_4 was added to the tubes and they were placed in a heating block at 200 ℃ for 15 min. After this heating procedure, the tubes were quickly placed in a water bath at room temperature; 3 ml of DH_2O was added to the tubes and the solvents were homogenized (with a vortex mixer) and stood for 10 min or until all bubbles had disappeared. Absorbance of the supernatant was measured at 375 nm. Tripalmitin solutions were used as a standard for the LIP concentration.

Carbohydrate analysis

Carbohydrate (CHO) concentrations were measured according to Dubois et al. (1956). The

POM samples for carbohydrate analysis were transferred individually into 15 mL polypropylene (PP) tubes. After 1 mL of DH_2O was added to the PP tubes, the samples were grounded using a glass rod. One ml of 5 % phenol for CHO extraction was added additionally, and the solutions were allowed to stand for 40 min at room temperature in the hood. After the extraction, 5 mL of sulfuric acid (H_2SO_4) was added to the solutions, mixed using a vortex mixer, and allowed to stand for 10 min. The solutions with an orange-yellow color were centrifuged at 3,500 rpm for 10 min. Absorbance of the supernatant was measured at 490 nm using UV spectrophotometer (Labomed, Germany). D (+) - glucose solutions (1 mg mL^{-1}, SIGMA) were used as a standard for the CHO concentration.

2.5. Statistical analyses and calorific value calculation

Statistical tests were carried out using the statistic software "SPSS" (*t*-test, ANOVA and Pearson's Correlation Coefficient). The level of significance was set at $p < 0.05$. The calorific value (Kcal g^{-1}) of the food material (FM) (FM was defined by Danovaro et al. (2000); PRT + LIP + CHO concentrations; hereafter FM) and the calorific content of FM (Kcal m^{-3} = Kcal g^{-1} × g FM m^{-3}) were calculated using the Winberg (1971) equation (Kcal g^{-1} = 0.055% Proteins + 0.041% Carbohydrates + 0.095% Lipids).

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3. Results

3.1. Seasonal distribution and variation of environmental factors and chl-*a* concentrations

The values of environmental factors were summarized in Table 1. The temperature ranged from 5.5 ℃ to 26.1 ℃~~. The temperature increased from April to August (the highest temperature in August 2012 at St. 4: 26.1 ℃) and decreased from August to January (the lowest temperature in January 2013 at St. 2A: 5.5 ℃). T~~and the salinity ranged from 14.5 ‰ to 32.9 ‰ during our sampling period.~~.~~ ~~Generally, the salinity increased from St. 1 or St. 2A to St. 5.~~ Relatively lower salinity, which is mainly affected by fresh water input from the Seomjin River, was observed at St. 2A. The annual average euphotic depth was 6.5 ± 3.4 m, ranging from 2 m to 12 m.

The highest nutrient concentrations were measured in April 2012, when the concentrations of NO_2 + NO_3, SiO_2, NH_4, and PO_4 were above 5.0 µM, 2.0 µM, and 0.2 µM, respectively, except at 1% light depth at St. 4. All inorganic nutrients except SiO_2 were nearly depleted in August 2012 (Table 1). During the rest of our study period, NO_2 + NO_3 and SiO_2 concentrations were observed with similar decreasing patterns from St.1 or St. 2A to St. 5. NH_4 concentrations averaged from October 2012 to April 2013 were 1.1 µM ± 0.4 µM, ranging from 0.5 µM to 1.9 µM. PO_4 concentrations (average ± S.D. = 0.1 ± 0.1 µM) ranged from 0 to 0.4 µM ~~throughout the water columns at all stations except at St. 2A in April 2012~~ during the study period. For determining the nutrient conditions, nutrient concentrations and their molar ratios in this study were summarized in Table 2. The ranges of the molar ratios from April, 2012 to April, 2013 were 9.8-69.5, 15.5-173.4, and 0.6-42.7 for DIN:DIP, DSi:DIP and DSi:DIN, respectively (Table 2).

Surface irradiance averaged from each measurement for 4-5 hours ranged from 167.9 ± 133.5 to 1593.3 ± 414.5 µmols m^{-2} s^{-1} (average ± S.D.) from April 2012 to April 2013. The highest and lowest irradiance were recorded in April 2013 and April 2012, respectively. Chl-*a* concentrations in the euphotic depth ranged from 0.8 µg L^{-1} to 14.2 µg L^{-1} during the study period (annual ~~mean~~average ± S.D. = 3.4 µg L^{-1} ± 2.8 µg L^{-1}; Table 1).

Monthly rainfall and river-input in the study location ranged from 15.6 mm to 559.0 mm (annual ~~mean~~average ± S.D. = 151.0 mm ± 155.5 mm) and 42.3 to 447.2 x 10^6 t (annual ~~mean~~average = 144.4 x 10^6 t), respectively (Table ~~2~~3). Rainfall and river-input were recorded as high during summer and low during winter ~~(Table 2)~~. ~~Average~~

~~irradiance during our incubation hour ranged from 167.9 ± 133.5 to 1593.3 ± 414.5 µmols m^{-2} s^{-1} (average ± S.D.) from April 2012 to April 2013. The highest and lowest irradiance were recorded in April 2013 and April 2012, respectively.~~

~~Chl-*a* concentrations in the euphotic depth ranged from 0.8 µg L^{-1} to 14.2 µg L^{-1} during the~~

~~study period (annual mean ± S.D. = 3.4 μg L^{-1} ± 2.8 μg L^{-1}; Table 1). There were no significant differences of chl *a* concentrations among 3 light depths and spatial distribution. However, there was seasonal variation of chl a concentrations during study period. Chl *a* concentrations were increased from April to August and decreased from August to October in 2012 and increased slightly again in January and April 2013.~~

3.2. δ^{13}C values and carbon to nitrogen ratios of POM

δ^{13}C values of sea surface POM ranged from - 23.1 ‰ to - 16.5 ‰ and the annual average δ^{13}C value was -20.9 ‰ (S.D. = ± 3.2 ‰). The annual average carbon to nitrogen (C:N) ratio of POM was 7.0 ± 0.4 (average ± S.D.), ranging from 6.8 to 7.7 (Table ~~3~~4).

3.3. Seasonal variation of biochemical composition

The contents of CHO, PRT, and LIP of POM in the water column ~~ranged from~~were 14.2~~ μg L^{-1} to -~~-412.3 μg L^{-1} (129.5 ± 87.2 μgL^{-1}), ~~from ~~22.8~~ μg L^{-1} to -~~-382.4 μg L^{-1} (155.0 ± 73.3 μgL^{-1}), and ~~from ~~21.4~~ μg L^{-1} to -~~-401.4 μg L^{-1} (154.9 ± 78.9μgL^{-1}), respectively (Table 4). The FM contents of POM ranged from 170.9 μg L^{-1} to 915.7 μg L^{-1} (435.5 ± 175.5 μgL^{-1}).~~ Since there were no significant differences in biochemical concentrations of POM and FM among 3 light depths and spatial distributions,~~ On monthly basis, we averaged each biochemical compound and FM from every depths and stations (Fig. 2)~~ on monthly basis~~. The biochemical compositions varied seasonally. The CHO and LIP concentrations increased from April to August and decreased from August to October in 2012. In contrast, the PRT concentrations decreased from April to October in 2012 and increased from October in 2012 to April in 2013. The seasonal pattern of FM concentrations was similar to the pattern of chl-*a* concentrations (r = -0.36, *p* < 0.05, Pearson's Correlation Coefficient).~~.~~

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In order to estimate the biochemical composition as food quality, we obtained relative contributions of each biochemical concentration of POM to FM, based on percentage basis. The biochemical composition of each class (CHO, PRT and LIP) ~~ranged from~~were 8.3~~% to -~~-59.1%,~~ from~~

6.8~~% to ~~-74.9% and~~ from~~ 9.4~~% to ~~-68.3%, respectively (annual ~~mean~~average ± S.D. of CHO, PRT, and LIP composition = 26.4 ± 9.4%, 37.8 ± 16.1%, and 35.7 ± 13.9%, respectively; Table ~~4~~5). ~~We found the seasonal variation of biochemical composition based on monthly basis of biochemical composition (Fig. 2). To illustrate these variations of biochemical composition of POM, the highest and lowest PRT compositions were in April 2012 and August 2012. In contrast to PRT compositions, the highest and lowest LIP compositions were in August 2012 and April 2012. CHO composition was recorded high in January 2013, but to compare CHO composition to PRT and LIP composition, CHO composition was not strong varied during the study period.~~

3.4. Seasonal variations of the calorific values and contents of FM

The calorific values and contents of FM ~~ranged from ~~were 5.4~~ Kcal g^{-1} to ~~-7.9 Kcal g^{-1} (annual ~~mean~~average ± S.D. = 6.6 Kcal g^{-1} ± 0.6 Kcal g^{-1}) and 1.0~~ Kcal m^{-3} to ~~-6.1 Kcal m^{-3} (annual ~~mean~~average ± S.D. = 2.8 Kcal m^{-3} ± 1.1 Kcal m^{-3}), respectively (Table ~~4~~5). The calorific values ~~of FM ~~had no apparent seasonal pattern, whereas the calorific contents~~ of FM ~~ had a seasonal pattern similar to the seasonal variation of FM concentrations.

3.5. Relationship between biochemical pools and environmental conditions

Relationships between biochemical pools and environmental conditions were performed using Pearson's correlation matrix (Table 6). Based on the results, we found a significant, positive relationships between PRT composition and river-input (r = 0.84, $p < 0.01$, ~~Table 5,~~ Fig. 3) and PRT composition and dissolved nitrogen concentrations (NH_4 : r = 0.69, $p < 0.01$; NO_2+NO_3 : r = 0.54, $p < 0.01$~~, Table 5~~). Lipid composition had an inverse relationships with river-input (r = -0.63, $p < 0.01$) and dissolved nitrogen concentrations (NH_4 : r = -0.59, $p < 0.01$; NO_2+NO_3 : r = -0.53, $p < 0.01$). These relationships led to a significant reverse relationship between PRT composition and LIP composition (r = -0.81, $p < 0.01$, Fig. 4). PRT composition was negatively correlated with temperature (r = -0.52, $p < 0.01$), whereas LIP composition was positively correlated with temperature (r = 0.72, p

< 0.01).~~ There were no significant relationships between PRT composition and irradiance and LIP composition and irradiance.~~

4. Discussion and conclusion

4. 1. Environmental conditions and chl–*a* concentration

The annual average chl-*a* concentration during the research period ~~was 3.4 µg L^{-1} (S.D.= ±2.8 µg L^{-1}) with a range from 0.8 to 14.2 µg L^{-1} which~~ is in a similar range of chl-*a* concentrations reported previously in Gwangyang B~~b~~ay, although it varied across different seasons and sampling depths (Cho et al., 1994; ~~–~~Choi and Noh~~et al.~~, 1998; Lee et al., 2001a; Kwon et al., ~~2001~~2002; Jang et al., 2005; Yang et al., 2005; Beak et al., 2011; Min et al., 2011; Beak et al., 2015). Previous studies reported that chl-*a* concentration was influenced mainly by salinity, temperature, and nutrients (nitrate and phosphate) depending on freshwater input from the Seomjin River. Our results in this study were similar to former studies (r = 0.34 and -0.41, $p < 0.05$, n = 48 and 28 for salinity and NH$_4$, respectively). However, high chl-*a* concentrations were previously recorded in spring and fall, whereas the highest concentrations were observed in summer (August 2012) from this study. In fact, Baek et al. (2015) reported that high chl-*a* concentrations were found in summer similarly, although there was difference between environmental factors and chl-*a* concentrations as compared with our results. The high levels of chl-*a* were observed with high nutrient concentrations and low salinity levels in the surface water by Baek et al. (2015), whereas the high values existed with low nutrient concentrations and high salinity levels in our results.

Despite this dissimilarity of environmental factors with high chl-*a* concentrations, we also found the highest chl-*a* concentrations observed in summer. According to Shaha and Cho (2009), there is a tendency with increasing precipitation and river-input in Gwangyang Bay during summer. This trend could increase loading nutrients from freshwater for maintaining phytoplankton growth in summer. In addition, a strong light intensity during summer could be favorable for phytoplankton growth since our study area was extremely turbid conditions during almost all seasons due to freshwater discharge and a strong spring-neap tidal oscillation. As a result, the combination of these factors is believed to enhance chl-*a* concentration and primary production of phytoplankton during summer in Gwangyang Bay.

4. 2. POM characterization

In general, POM consists of a mixture of living as well as detritus materials (phytoplankton, bacteria, zooplankton, fecal pellets, terrestrial matters, etc.) originating from freshwater and estuarine and marine environments. POM samples can be characterized or determined for source of the major contributor(s). The C:N ratio generally ranges between 6 and 10 for phytoplankton, whereas the ratios are between 3 and 6 for zooplankton and bacteria (Savoye et al, 2003; references therein). For terrestrial organic matters, the C:N ratios are normally over 12 (Savoye et al, 2003; references therein). Therefore, it is useful to classify phytoplankton from heterotrophs and terrestrial materials (Lobbes et al., 2000; Savoye et al., 2003; Lee and Whitledge, 2005). In this study, the ~~mean~~average C:N ratios of POM was 7.0 (S.D. = ± 0.4), which indicates that this POM is mainly phytoplankton (Table ~~3~~4). However, the original C:N ratio ~~must~~can be ~~used with caution~~changed ~~because of its variation in~~ caused by ~~the process of POM degradation~~biochemical alterations ~~(Savoye et al, 2003)~~. For example, PON is preferentially degraded compared to POC of phytoplankton, which causes an increase of the C:N ratio (Thornton and McManus, 1994; Savoye et al, 2003). In contrast, ~~T~~terrestrial organic matters ~~(~~with high C:N ratio~~s)~~ colonized by bacteria ~~(~~with low C:N ratio~~s)~~ could lower~~s~~ their initial high C:N ratio (Savoye et al, 2003; references therein). Therefore, similar C:N ratios of POM could be produced by degraded phytoplankton and bacteria-colonized terrestrial organic matters (Lancelot and Billen 1985; Savoye et al, 2003). In addition to C:N ratios, $\delta^{13}C$ of POM can be alternatively used for determining their origin. Kang et al. (2003) reported that the ~~mean~~average $\delta^{13}C$ signature of phytoplankton in Gwangyang Bay was -20.8 ‰ (S.D. = ± 1.1 ‰). In this study, our ~~mean~~average $\delta^{13}C$ signature of POM was -20.9 ‰ (S.D. = ± 3.2‰), which also indicates that POM was mostly phytoplankton during the study periods (Table ~~3~~4). However, some large contributions of benthic microalgae were seasonally found in our samples with relatively higher δ^{13}C values on August and October 2012 (Table ~~3~~4). According to Kang et al. (2003), the ~~mean~~average δ^{13}C value of benthic microalgae is approximately -14.1 ‰ in Gwangyang Bay. Based on our C:N ratio and δ^{13}C value in this study, we confirmed that our POM samples were primarily comprised of phytoplankton (seasonally benthic microalgae) in Gwangyang Bay. This is interesting that river-derived terrestrial organic matters were not important component of the POM in Gwangyang Bay with a large river runoff. Indeed, several previous studies reported a small fraction of terrestrial particulate matter in the same bay as well as in the southeastern coastal bays in Korea (Kang et al., 1993; Lee et al., 2001b; Kwon et al., 2002). Currently, we do not have solid mechanisms for the low contribution of terrestrial organic matters. A further investigation is needed for this paradoxical process.

4. 3. Environmental conditions and biochemical pools

Biochemical pools of POM originating from phytoplankton are influenced by various environmental factors, such as temperature, salinity, nutrients, and light conditions (Morris et al., 1974; Smith and Morris, 1980; Rivkin and Voytek, 1987; Boëchat and Giani, 2008; Cuhel and Lean, 1987; Mock and Kroon, 2002; Khotimchenko and Yakoleva, 2005; Ventura et al., 2008; Sterner et al. 1997). In this study, significant relationships were found between environmental conditions and biochemical pools, especially PRT and LIP (Table 5). Temperature was positively and negatively correlated with LIP and PRT. Previous studies reported that higher temperature stress mainly affects nitrogen metabolism (Kakinuma et al., 2006) which is related to significant decrease of PRT with increases of LIP and CHO content (Tomaselli et al., 1988; Oliveira et al., 1999). In a high temperature-stressed condition of phytoplankton, the decrease in PRT content is related to breakdown of protein structure and interference with enzyme regulators (Pirt, 1975), whereas LIP is predominant because LIP is more closely associated with cell structure such as thickened cell walls (Smith et al., 1989; Kakinuma et al., 2001, 2006). Our results are in agreement with other works, as described above.

The relationships between nutrients and biochemical pools could be explained by nutrient limitation and the characteristics of each biochemical compound. A combination of nutrient concentrations and ratios can be used to assess nutrient limitation (Dortch and Whitledge, 1992; Justić et al., 1995). Dortch and Whitledge (1992) suggested that nutrient limitations are existed in the Mississippi river plume and Gulf of Mexico, if the dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), and dissolved silicon (DSi) concentrations in water column are less than 0.2, 1.0 and 2.0 μM, respectively, depending on the half-saturation constant (K_s) that the threshold value is required for the uptake and growth of phytoplankton (Eppley et al., 1969; Fisher et al 1988).~~.~~ In addition, molar ratios of the DIN:DIP~~ and~~, DSi:DIN and DSi:DIP ~~–~~can be indicators of nutritional status and the physiological behavior of phytoplankton (Redfield et al., 1963; Goldman et al., 1979; Elrifi and Turpin, 1985; Dorch and Whiteledge 1992; Roelke et al. 1999). According to Dortch and Whitledge (1992), the following criteria of their molar ratios were (a) DIN:DIP ratio < 10 and DSi:DIN ratio > 1 for nitrogen (N) limitation; (b) DIN:DIP ratio > 30 and DSi:DIP ratio > 3 for phosphorus (P) limitation; (c) DSi:DIN ratio < 1 and DSi:DIP ratio < 3 for silicate (Si) limitation. In this study, nutrient limitation conditions were observed by absolute nutrient concentrations or/and their molar ratios depending on seasons (Table ~~6~~2). Previous studies of biochemical composition in relation to nutrient limitation reported that PRT production of phytoplankton was enhanced under abundant N conditions (Fabiano et al., 1993; Lee et al., 2009). In contrast, LIP production and storage were dominant (Shifrin and Chisholm, 1981; Harrison et al., 1990) and PRT contents decreased (Kilham et al., 1997; Lynn et al., 2000; Heraud at al., 2005) under N-depleted conditions. High LIP contents have also been detected in phytoplankton under P or/and Si limitation (Lombardi and Wangersky, 1991; Lynn et al. 2000; Heraud et al., 2005; Sigee et al., 2007). Under N or P-limited conditions, triglyceride content (energy storage) increases and shifts from PRT to LIP metabolism since proteins are nitrogenous compounds whereas LIP and CHO are non-nitrogenous substrates (Lombardi and Wangersky, 1991; Smith et al., 1997; Takagi et al., 2000). In our study, Si and P concentrations may not significantly impact on biochemical composition of phytoplankton. Si concentrations were almost above 2.0 µM except in April 2013 during the study period. P limitation was observed based on the absolute concentration and molar ratios during study period. However, under P limitation, phytoplankton can relocate the cellular P pool to maintain their P requirements for the maximum growth rate (Cembella et al., 1984; Ji and Sherrell, 2008). In this respect, we suggest that DIN could be significantly impact on biochemical composition of phytoplankton in our study area. DIN was initially believed to be the most important limiting factor for phytoplankton growth in marine ecosystems (Ryther and Dunstan, 1971; Howarth, 1988). In fact, DIN was strongly positively correlated with PRT composition, whereas it was negatively correlated with LIP composition. The most of DIN loading came from freshwater input of the Seomjin River (Table ~~5~~6, river-input vs NH_4 and NO_2+NO_3; $r = 0.91$ and 0.55, $p < 0.01$, respectively) influences on PRT and LIP synthesis and subsequently macromolecular composition of phytoplankton. As a result, the amount of river-input was also strongly correlated with PRT composition (Table ~~5~~6 and Fig. 3). Therefore, DIN is an important controlling factor for biochemical composition, especially PRT and LIP composition of phytoplankton in Gwangyang ~~b~~Bay.

Although irradiance is also known for an important governing factor for biochemical composition, irradiance was not ~~significantly~~ statistically correlated with biochemical pools in this study (Table ~~5~~6). We measured ~~irradiance~~ PAR during our short incubation time (4~5h) for phytoplankton productivity as a parallel study. Since ~~T~~this short time of measured irradiance can be largely variable by a local weather, it might be not enough to reflect and detect the change of biochemical composition in phytoplankton with irradiance. The irradiance between April 2012 and April 2013 was largely different (approximately 10 times lower in April 2012 than in April 2012; Table 1). Increasing synthesis of proteins is found as light intensity decrease because a relatively lower irradiance saturation level is required for protein synthesis than that of other biochemical components (Lee et al., 2009; Suárez and Marañón, 2003; Morris et al., 1974, 1978). Consistently, the protein compositions were significantly higher in April 2012 than in April 2013 (*t*-test, $p < 0.01$; Fig.

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2) in this study. The proteins accounted approximately 62 % and 37 % of biochemical compositions in April 2012 and April 2013, respectively. However, the main reason for no consistent relationships between irradiance and biochemical components along seasons might be the PAR measurements as discussed previously in this study.

The structure and composition of phytoplankton assemblages and species could have a significant influence on the seasonal variation of biochemical composition. Although we did not conduct a study of phytoplankton community structure, there is seasonal succession of phytoplankton community structure in the bay. Previous studies showed that the dominant phytoplankton community was diatoms and dominant diatom species were *Skeletonema spp.* during summer and winter in Gwangyang B~~b~~ay (Choi et al., 1998; Baek et al., 2015). Kim et al. (2009) also reported that diatom and dinoflagellate communities have experienced a considerable change because of increased nutrient loadings from both domestic sewage and industrial pollution during summer. Therefore, the seasonal change of phytoplankton species composition and community structure could lead to determining different biochemical pools on seasonal basis.

However, other studies in different regions reported that environmental conditions, such as temperature, nutrients and irradiance are more important controlling factors in biochemical composition than variation of phytoplankton community and species composition (Lindqvist and Lingnell, 1997; Suárez and Marañón, 2003). In this study, we also concluded that DIN from river-input was a primary governing factor for the seasonal variation of biochemical composition of phytoplankton in Gwangyang Bay as discussed above.

4.4. Total FM and energy content of POM in a global context

~~The annual average of FM was 434.5 µg L^{-1} (S.D. = ± 175.5 µg L^{-1}) in this study.~~ Since there were no comparable data available in South Korea, we compared our results with other regions (Table 7), although they were conducted in different seasons and sampling depths. PRT contents in this study were as high as in the Ross Sea (Fabiano and Puscceddue, 1998; Fabiano et al., 1999a), the Amundsen Sea (Kim et al., ~~2015~~2016) and the Humboldt Current System (Isla et al., 2010). A similar range of LIP contents was observed in Bedford Basin (Mayzaud et al., 1989), Yaldad Bay (Navarro et al., 1993) and the Humboldt Current System (Isla et al., 2010). CHO contents were comparatively higher in this study than other studies except Bedford Basin (Mayzaud et al., 1989) and Yaldad Bay (Navarro et al., 1993). One of the highlights is that the calorific contents of FM in this study were generally higher than those of other areas except several regions. The FM values were comparatively higher than other regions such as the northern Chu~~c~~kchi Sea (Kim et al., ~~2014~~2015; Yun et al., ~~2014~~2015), Ross Sea (Fabiano et al., 1996; Fabiano and Pusceddu, 1998; Fabiano et al., 1999a; Pusceddu et al., 1999), Amundsen Sea (Kim et al., ~~2015~~2016) and the northern part of the East/Japan Sea (Kang et al., unpublished) or similar to the Humboldt Current System which is known as an important spawning sites for pelagic fishes and the highest abundance of anchovy eggs (Isla et al., 2010). Actually, the southern coastal sea (including our study area) in Korea represents calm seas, an indented coastline, and numerous bays, which have high diversities of habitat for fishes and shellfishes (Kwak et al., 2012) and give a favorable condition for mariculture (Kwon et al., 2004). The high quantity of FM and the calorific contents of POM found in this study reflected good nutritive conditions of primary food materials mainly provided by phytoplankton for the maintenance of productive shellfish and fish populations in Gwangyang B~~b~~ay.

~~5. Summary and Conclusion~~

~~This study is the first report that was investigated the biochemical composition of POM on seasonal basis in Gwangyang Bay, South Korea and we determined major controlling factors for biochemical composition which is influenced by various environmental factors (Morris et al., 1974; Smith and Morris, 1980; Rivkin and Voytek, 1987; Boëchat and Giani, 2008; Cuhel and Lean, 1987; Mock and Kroon, 2002; Khotimchenko and Yakoleva, 2005; Ventura et al., 2008; Sterner et al. 1997). Among different factors, temperature was positively correlated with LIP whereas negatively~~

~~correlated with PRT in this study (Table 5), which is consistent with previous works. In addition, we found that PRT and LIP compositions were strongly correlated with DIN loading largely depending on the amount of river input from the Seomjin river which influences on PRT and LIP synthesis and subsequently macromolecular composition of phytoplankton in Gwangyang bay. The concentrations and the calorific contents of FM found in this study were relatively higher in comparison to previous studies in various regions, which reflecting that POM (mainly from phytoplankton) provides a good nutritive condition to maintain this highly productive estuarine ecosystem in Gwangyang bay.~~

~~Recently, significant environmental perturbations in their watersheds and externally from climatic forcings have been reported in various estuaries (Wetz and Yoskowitz, 2013). More intense but less frequent tropical cyclones are expected over the coming century (e.g., Elsner et al., 2008; Knutson et al., 2010) and many changes in drought and flood cycles have been proceeding globally (e.g., Min et al., 2011; Pall et al., 2011; Trenberth and Fasullo, 2012; Trenberth, 2012). The cumulative effects of these perturbations could alter the quantity and quality of biochemical composition of POM and cause subsequent changes in ecosystem structure and trophic dynamics in estuaries (Cloern, 2001; Paerl et al., 2006; Rabalais et al., 2009; Wetz and Yoskowitz, 2013). Therefore, continuous field measurements and observations on biochemical composition of POM as food quality are needed to monitor for better understanding future response of marine ecosystem on potential environmental perturbations in Gwangyang Bay.~~

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Table captions

Table 1. Environmental factors and chl-*a* concentrations in Gwangyang bay during the research period (- : no data).

Table 2. Monthly patterns of ~~R~~rainfall and river input.

Table 3. δ^{13}C values and C:N ratios of POM at surface in Gwangyang bay~~ (surface)~~.

Table 4. Biochemical concentrations and composition, calorific values and contents in Gwangyang bay (- : no data).

Table 5. Significant correlation coefficient (r) among proteins (PRT), lipids (LIP) and environmental factors (ns ; no significance, **; p<0.01). River-inputs were integrated from 20 days prior to our sampling dates.

Table 6. Observed nutrient limitations during the study period.

Table 7. Comparison of biochemical quantity of POM, FM and the calorific contents.

Figure captions

Fig. 1. Sampling location in Gwangyang bay, Korea ; Maps of Korea (a), Southern Coastal Sea (b) and main sampling stations (c).

Fig. 2. Seasonal variation of biochemical composition in Gwangyang bay.

Fig. 3. The positive relationship between river-input and protein composition. River-inputs were integrated from 20 days prior to our sampling dates.

Fig. 4. The inverse relationship between lipid compositions and protein compositions.