Dear Prof. Robinson:

Thank you for spending effort to process our manuscript again. Please find our revised manuscript entitled, “The influence of episodic flooding on a pelagic ecosystem in the East China Sea” [manuscript no: bg-2016-246], from submission system of *Biogeosciences* (the tracked version has also been attached below where most of change are marked in red). We have substantially revised the manuscript in response to comments of the two external reviewers, and we are confident that it is now suitable for publication in *Biogeosciences.* Also, please find our detailed responses to the reviewer comments as listed below.

As you can, perhaps, see from the amount of detail included in our responses, we have taken the reviewers’ comments very seriously in preparing this revised manuscript. In general, we are confident that we have been able to respond clearly and reasonably to these comments. In addition, we have asked a native English speaker (Dr. Anderson Mayfield) to do a thorough editing to improve our manuscript before re-submission. Overall, we feel that the reviewer comments were very helpful and that they contributed to a greatly improved manuscript.

We look forward to your decision concerning our manuscript.

With Best regards,

Chung-Chi

Responses to reviewers' comments on ms no: bg-2016-246 "The influence of episodic flooding on pelagic ecosystem in the East China Sea" (Chen, Gong, Chou, Chung, Hsieh, Shiah, and Chiang)

Referee #1

General comments:

This study presents an interesting analysis of pelagic ecosystem responses in the East China Sea to the large flood event in the Changjiang River in 2010. This research is fundamentally focused on "an episodic event", so it would not be too surprising if the scope of relevant measurement is limited. Nonetheless, the authors conducted a fairly good job of synthesizing what they have learned based on their current and others' previous observations and various indices and metrics (e.g. volumetric values in surface water, averaged over the depth of euphotic zone, and depth-integrated values for the entire ECS and the Changjiang Diluted Water (CDW) region). Overall, the analysis is thorough, but I still have a few major suggestions and revisions in terms of statistics/statistical interpretation to suggest before I think this study is ready for publication. These include the status of nutrient limitations based on significant regression relationships (below comment #8) and the relative strength of coupling/control of one variable to another with the regression slope values (below comment #10). I also suggest authors to clarify their calculations on estimating the effect of freshwater discharge on fCO2 using end-member mixing equations. Below are a range of suggestions, questions, and comments that should be addressed in the revision. Overall, I think this study would be of high interest to the readership after substantial revisions.

Thank you so much for your positive evaluation of our manuscript. We are pleased to see that you generally appreciated our presentation of the results. Indeed, this manuscript intends to explore how episodic flooding affects pelagic ecosystems in the East China Sea. As you commented, the results should be of interest to many readers since extreme rainfall events are predicted to increase globally due to climate change. We drew upon a comprehensive dataset to make our conclusions. We have substantially revised our manuscript following your recommendations, as well as those of the other reviewers, and appreciate the constructive and valuable comments we received. Please see our detailed responses to your comments below. We hope that we have sufficiently addressed your concerns, as they have greatly improved the manuscript. We are now confident that this manuscript is suitable for publication in *Biogeosciences*.

Specific Comments:

1. *Abstract, line 43: The sentence ": : : which were not characterized by low SSS in 2009" is not correct. Table 1 indicates SSS in CDW zone was also lower than the entire area (the area for all sampling stations) in 2009.*

> **We apologize for the confusion. Indeed, the SSS in the CDW zone was also lower than the entire ECS study area in 2009. However, we were specifically referring to stations at the CDW zone in 2010 that were *not* previously characterized by low SSS in 2009. To clarify this, this sentence has been slightly modified to become "*The higher CR in 2010 could be attributed to phytoplankton respiration, especially at stations in the CDW zone that were not previously characterized by low sea surface salinity in 2009.*" Please also refer to our response to your comment 10 for more details on this issue.**

2. *Keywords, line 51: It would be better to be more specific. Perhaps you could add "flooding", "CDW", "freshwater discharge" and also "Yangtze River"?*

> **Thank you for the valuable suggestion. The suggested keywords have been added, with the exception of "CDW" since it is a non-standard abbreviation.**

3. *Comments on Figure 1: 1) The color of the SSS contour plot is confusing to read. Usually with salinity contours, the bluer the fresher and the redder the saltier, 2) you could add the color bars for Figures 1 and 2 both, and 3) please increase the font size.*

> **Thank you for pointing out the common color code contours for salinity. We have now changed our figure to conform to the norms in the field. In addition, the following changes have also been made: 1) color bars were added, 2) the font size was increased per your suggestion, and 3) the symbols for the sampling stations were enlarged. Collectively, we believe your comments have aided in the creation of an improved and easier to read figure. Please also refer to our reply to comment 10 of Reviewer #2 on a similar issue.**

4. *Comments on Table 1: 1) I think it is critical to compare if there are significant differences between the entire area and CDW zone for all variables in each year as well as overall all 2 years combined, and 2) why zooplankton values are not reported? They are in Table 2, so it should be able to calculate them.*

> **Thank you for the valuable suggestion. We do agree that it is important to rule out whether there was a difference between the CDW zone and the other**

areas in the ECS in each year. However, we tended not to compare between the entire area and the CDW zone since they were dependent on each other. As you pointed out, significant differences were evident for almost all variables (Table 1) between the CDW zone and the other regions in the ECS in each year, except for nitrate and phosphate in 2009. To avoid confusion but still provide this information to the reader, we choose to portray this result in the table caption since the comparison found in Table 1 was already complicated enough. However, we will be happy to show it in Table 1 if you still feel that it is necessary.

As for zooplankton values, they were only collected for the whole water column, and not only for the surface water. Therefore, they were not presented in Table 1 in a comparable format.

5. *Comments on Table 2: 1) To be consistent with Table 1, you could use brackets for values in the CDW zone instead of parentheses. Also, in Table 1 you could report average values for the entire area (what are in parentheses for now) without parentheses and their ranges in parentheses instead (e.g. SSS: 32.62+/-2.07 (23.80-34.11)).*

Good point! For consistency, parentheses have been replaced by brackets in Table 2, as suggested.

As for the suggested format on Table 1, it has also been changed accordingly.

6. *Results & discussion, line 226: Please clarify and write more clearly if 2003 was also an anomalous flooding year and how does its area of CDW zone compare with that in 2010.*

Thank you for the valuable suggestion. To clarify, this sentence has been slightly modified to become “*A low transparency value was documented in June 2003 in the ECS, during which the CDW area was 43.1 x10^3 km^2 (~40% of the CDW area of the 2010 flood; Chen et al., 2009), and the average transparency values for the ECS and the CDW were 70.9% and 66.0%, respectively (C.C. Chen, unpublished data).*”

7. *Results & discussion, line 235: Add the sentence what the response time of phytoplankton bloom is to flooding events if reference exists.*

We do agree with your suggestion, and it indeed makes much more sense to add a sentence on this topic. There is, however, little data on this issue. Based on our own dataset in coastal lagoons and limited literature in estuary systems,

we have added the following sentence: "*In estuarine and coastal regions, phytoplankton blooms normally occur within 2-3 weeks after a heavy rainfall event (e.g., Hsieh et al., 2012; Meng et al., 2015; Mulholland et al., 2009).*"

***8.** Results & discussion, line 272: I think you need to be cautious about relying solely on N/P elemental ratio for discussing the status of nutrient limitation. The fact that during the 2010 flood chlorophyll was positively correlated with nitrate and silicate (lines 290) but not to (at alpha = 0.05) phosphate (line 291) suggests limitations of nitrate and silicate predominantly, and to a lesser extent, of phosphate on phytoplankton productivity. This is opposite to your statement that 2010 was more likely affected by phosphate limitation. Similarly, phytoplankton might be limited by all three nutrients in 2009 (lines 294-296). Other suggestion is that it would better to focus only on the area in which nitrate and phosphate values were below detection limits as indicated in Table 1.*

Good point! Yes, you are correct in noting that the insignificant relationship between Chl *a* and phosphate concentration suggests that biomass was not limited significantly by phosphate levels in the 2010 flood. Interestingly, it appears that the insignificant linear relationship (*p* = 0.09) between Chl *a* and [phosphate] in the surface water in 2010 was likely driven by one station with a low Chl *a* value (1.1 mg Chl m^{-3}), but a high phosphate concentration (1.7 μM; Fig. 1f). The linear regression (Chl *a* vs. phosphate) became statistically significant if this potential outlier was excluded from the analysis (*p* < 0.001). Furthermore, the phosphate concentration in the surface water during the 2010 flood was low, with a mean±SD value of 0.17±0.30 μM, and it was similar to the value observed in 2009 (0.13±0.17 μM). In addition, the high N:P molar ratio in the CDW during the 2010 flood was found to be 40.4. Therefore, except for the high phosphate station, phytoplankton biomass in the 2010 flood was more likely limited by phosphate, in terms of both nutrient availability and the N:P molar ratio.

The areas where nitrate and phosphate were not present at detectable levels in 2010 were mostly outside of the CDW zone, and this is especially true for nitrate. Even though a significant linear relationship was observed between Chl *a* and nitrate concentration in 2010, the average nitrate value was still high (10.3 μM) in the CDW zone. Based on the significant relationships observed between Chl *a* and nitrate and silicate, this suggests that nitrate and silicate might be the limiting factors for phytoplankton growth during the 2010 flood. However, in addition to nitrate and silicate, phosphate might be

the most important limiting factor for phytoplankton growth due to its low concentration level and high N:P molar ratio in 2010. In this manuscript, therefore, we try to emphasize that growth of phytoplankton was more likely limited by phosphate, especially in the CDW in 2010. To clarify, this sentence has been slightly modified to become "*Phytoplankton biomass might have also been limited by nitrate and silicate levels in 2010. Based on nutrient levels and the N/P molar ratio, however, phytoplankton growth was more likely limited by phosphate, especially in the CDW zone during the 2010 flood (please refer to Sect. 3.2 for details.).*" Hopefully, this explanation and these data can satisfy your inquiry.

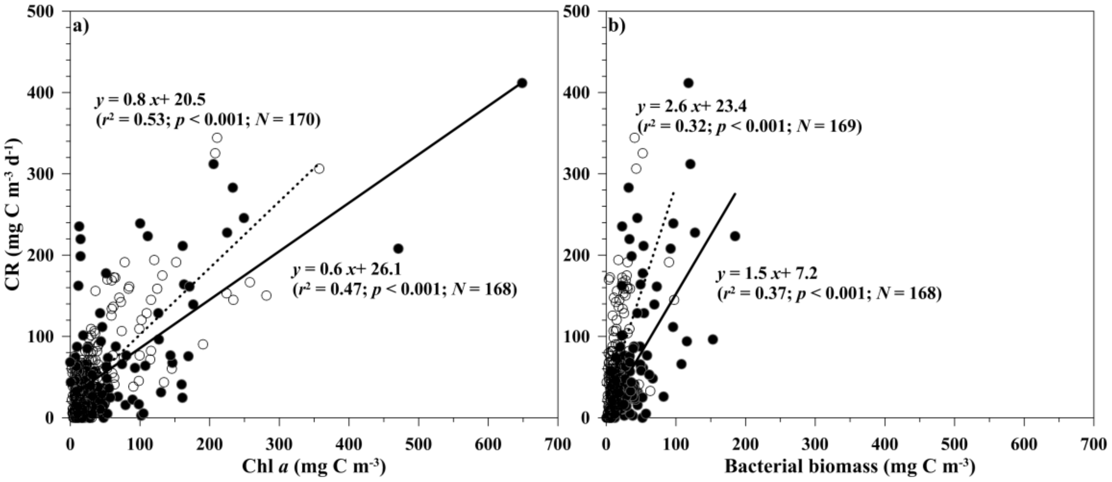
9. *Results & discussion, line 413-414: I do not follow. Please see below comments on Figures 3-5.*

We apologize for the confusion. In our previous version of the manuscript, we had simply tried to reduce the number of panels in the figure. Therefore, both data for 2009 and 2010 were combined into one panel in Fig. 3 for Chl *a* and bacteria. As for the results mentioned in the text, we might have jumped one step ahead to describe the results found in Fig. 5 (please refer to our response to your comment 10 for other details.). As you point out, Fig. 3 suggests that the CR might be dominated by phytoplankton and bacterioplankton in either 2009 or 2010. To clarify this, this sentence has been modified to "*Given the importance of phytoplankton and bacterioplankton to CR rates in both years, as well as their high densities measured herein, it seems likely that these microbial groupings contributed substantially to the CR rate in both 2009 and 2010.*".

10. *Comments on Figures 3, 4, 5: When two variables are regressed onto each other, the slope of regression could be used to assess the strength of coupling between the two or control of one to another – the higher slope, the strong coupling/control, where even a small change in X-values results in a huge response in Y-values. In this regard, for Figure 3 I would consider stronger control of chlorophyll and bacterial biomass on CR in 2010 than in 2009 if you do inter-year comparisons. Figure 4 might also be similarly interpreted (the stronger control of PP on CR in 2010 than in 2009). The same goes for Figure 5. Additionally, if the unit of chlorophyll is converted to that of bacterial biomass, the relative strength of control by each on CR could also be inferred.*

We do agree that the slope of the regression line could be used to assess the

strength of coupling between two parameters. As in our reply to your previous comment regarding Fig. 3, we tried to analyze and understand whether or not the CR rates were related to phytoplankton and/or bacterioplankton biomass. Even though significant relationships were found between CR and 1) Chl *a* and 2) bacteria, this still could not explain why the CR was higher in 2010 than in 2009. Therefore, Fig. 5 (now Fig. 4) was used to further explore whether differences in phytoplankton or bacterioplankton biomass contributed to the higher CR observed in 2010. Interestingly, the extent of the inter-annual (2010 minus 2009) difference in CR was significantly related to differences in Chl *a* concentration ($p < 0.001$) and bacterial biomass ($p < 0.01$). Among the positive CR differences (i.e., 20 of 33 stations), 15 stations were also characterized by positive differences in Chl *a* concentrations, but only two stations had positive differences in bacterial biomass. Interestingly, the stations with positive Chl *a* concentration differences were mostly located within the CDW region in 2010. These results suggest that the higher CR during the 2010 flood might be attributed to phytoplankton, especially in the CDW. As for Fig. 4 (i.e., CR vs. PP), it has been removed from this revision since we only have PP data for 2010, as you pointed out. Based on these analyses, therefore, we try to state in the Abstract that "*The higher CR in 2010 could be attributed to phytoplankton respiration, especially at stations in the CDW zone that were not previously characterized by low sea surface salinity in 2009.*" For your reference, the modified Fig. 3 with Chl *a* converted to carbon units (C:Chl *a* of 52.9; Chang et al., 2003) is presented below:



Chang, J, F.-K. Shiah, G.-W. Gong, K.-P. Chiang. (2003). Cross-shelf variation in carbon-to-chlorophyll a ratios in the East China Sea, summer 1998. Deep-Sea Res. II, 50: 1237-1247.

11. *Results & discussion, line 468: This is only true relative to global average values in coastal oceans. I do not think you could say this unless you compare with P/R value in the non-flooding year, which you do not have the data for.*

> **Yes, you are correct that we do not have P/R data for 2009. Therefore, this paragraph has been removed per your suggestion.**

12. *Results & discussion, lines 487-499: I suggest you provide a full summary of values calculated from endmember mixing equations, including equations and how to calculate uncertainties, RMSE, etc. Also, you might want to more emphasize that the calculations presented in this paragraph give you estimates that are expected by purely physical processes, without taking biological effect into account. Deviation from what is estimated based on endmember mixing model is due to biological effect, which you nicely described in the following paragraph.*

> **The following new paragraph has been added to the revised manuscript to clearly explain the simulation of fCO_2 under a conservative mixing model, including equations and uncertainty analysis: "*Provided that the proportional contributions from freshwater and seawater endmembers are f_1 and f_2 ($f_1+f_2=1$), respectively, the conservative mixing TA and DIC values for a given water sample can be expressed by the following equations:***
>
> $$TA_{mix}=TA_{fw}xf_1+TA_{sw}xf_2$$
>
> $$DIC_{mix}=DIC_{fw}xf_1+DIC_{sw}xf_2$$
>
> ***where the subscripts "mix", "fw", "and "sw" represent values of conservative mixing, freshwater, and seawater endmembers, respectively. The TA and DIC data reported by Zhai et al. (2007) for the Changjiang River in summer were used as the freshwater endmember (both TA_{fw} and $DIC_{fw}=1743$ μmol kg^{-1}), and the surface data at station K in July 2009 and 2010 were chosen to represent the seawater endmember ($TA_{sw}=2241$ μmol kg^{-1} and $DIC_{sw}=1909$ μmol kg^{-1} in 2009; $TA_{sw}=2240$ μmol kg^{-1} and $DIC_{sw}=1904$ μmol kg^{-1} in 2010). Subsequently, the hypothetical fCO_2 from conservative mixing was calculated from the TA_{mix} and DIC_{mix} data using CO2SYS version 2.1 (Pierrot et al. 2006), in which the carbonic acid dissociation constants were adopted from Mehrbach et al. (1973) and refitted by Dickson and Millero (1987). The uncertainty in this simulation mainly derives from errors in the estimations of TA_{mix} and DIC_{mix}. Assuming the errors of the calculated TA_{mix} and DIC_{mix} are ±5 μmol kg^{-1}, this may result in an uncertainty of ±13 μatm in the simulated fCO_2.".***

Technical Corrections:

1. *Line 129: Replace "estimated" with "calculated"*

Thank you for so thoroughly reviewing our manuscript and providing many valuable and constructive suggestions. It has been revised accordingly, and we hope you will find a superior manuscript.

2. *Line 159: Replace "multiple" with "multiplied"*

Thanks! The suggested change has been made.

3. *Line 189: Avoid subjective words like "devastating".*

Thanks! The suggested change has been made. We have used "great" in place of "devastating" in this revision.

4. *Line 240: "immense" to "large"*

Thanks! The suggested change has been made.

5. *Line 264: Replace "16" with canonical Redfield ratio for N:P of 16 or so.*

Thanks! The suggested change has been made.

6. *Line 418: Awkward phrase "to gain greater insight".*

This phrase has been replaced by "*In a further analysis*" in this revision.

7. *Lines 433-444: Please be specific.*

A short sentence has been added to point out that CR might be attributed to variable phytoplankton assemblages.

8. *Line 463: I think it is "overestimated" given the vertical profile of P and R?*

Yes, you are right. Thank you for pointing out this error! Please also refer to our reply to your specific comment 11 for other details.

9. *Line 484-486: Please be specific and give numbers from the calculation.*

The temperature effect on fCO_2 variation has been specifically explained in the revised sentence: "*The effect of temperature on the large variation in fCO_2 observed between the 2009 non-flooding period and the 2010 flood was trivial; the SST difference of 0.7ºC between 2009 and 2010 would only equal a fCO_2 decrease of approximately 10 μatm (Table 1).*".

Referee #2

General comments:

Review of Chung-Chi Chen et al submitted to Biogeosciences. The aim of this paper is stated to 'reveal the effects of riverine input of dissolved inorganic nutrients on the plankton communities that support heterotrophic processes in the East China Sea shelf ecosystem between periods of non-flooding and flooding. Generally the topic of the paper is clearly introduced as a comparison of data collected during summer surveys of the ECS in July 2009 and 2010 with 2010 being a year when exceptional river flows from the Changjiang river impacted the coast waters of the ECS.

The methods are reasonably clearly described with references to several previous papers by the research team. However the collection of zooplankton needs more explanation – if they were vertical hauls through the water column give the depth range. Were the zooplankton preserved in formalin prior to counting?. . ..Also it is rather non-standard to use GF/F filters to collect 14C labelled phytoplankton following incubations. How significant was the loss of small phytoplankton ie <1um on the 14C uptake rates. Also as this 14C data was only collected during the 2010 survey I suggest it could be removed from the paper. Determining oxygen respiration rates from dark incubation of enclosed water samples by difference between initial fixed samples and final incubated bottles using the Winkler method to analyse for dissolved oxygen is a standard approach. However based on only two initial and two final replicates I suggest will yield low precision measurements. It is standard practise to use at least 4 replicates of initial and final bottle measurements. The precision stated is only really the difference divided by the mean of two replicates and I would suggest rather unreliable.

We appreciate that you so thoroughly reviewed our manuscript, and you have provided many valuable and constructive suggestions. We also thank you for agreeing with our dataset's ability to be used to compare between flooding and non-flooding periods. We have taken your comments, as well as those of the other reviewer, very seriously in preparing this revised manuscript. Overall, we feel that the comments were very helpful and contributed to a greatly improved manuscript.

We also apologize for the unclear statements found within the "Materials and Methods" section, and we have done our best to clarify these in the revision. For example, the depth range of sampling and the preservation (with 10% buffered formalin) of zooplankton have now been mentioned. As for primary production, we do agree with your suggestion. Therefore, the related treatise of PP has been removed from the manuscript (including what was previously

Fig. 4).

Per your first major concern, it is tedious and labor-intensive to make community respiration (CR) measurements *in situ*. We did include 672 and 692 CR measurements (initial + dark incubation) made in 2009 and 2010, respectively. Based on our previous measurements, our duplicate measurements have high precision (e.g., Chen et al. 2003). Therefore, duplicate, instead of triplicate, samples were incubated at each sampling depth. Hopefully, this is understandable.

My main problem with this paper however is the section labelled Results and Discussion. This section of the paper is 18 pages long! If the paper is to be resubmitted I strongly recommend that the results and discussion are presented as two different sections and the discussion section greatly shortened. The discussion and interpretation of the data currently included in the paper is at best speculative and in many places vague with the word 'might' used very frequently in numerous sentences. For example Page 19 lines 326-328 Page 19 line 340 Page 21 lines 323-375 Page 22 line 392 plus many more scattered throughout this section.

Thank you for your constructive suggestion. In the previous version, we indeed intended to discuss our results by analyzing them in concert with those of the primary literature. This was because that we did not want to rule out any potential causal factors for the observed outcomes in this study. Therefore, as you correctly pointed out, the manuscript was long and speculative; there are so many potential relationships that could have explained our data. We have tried to make it seem less speculative. In this revision, the ambiguous statements have been largely removed, as evidenced by a dramatic reduction in the page number (from 20 to 15 pages, even including the addition of two pages requested by Reviewer #1). In addition and per your next comment, the Conclusions section has also been greatly shortened (from 3 to 1.5 pages) by removing less significant findings.

The conclusion section also needs to be much shorter and report the studies main findings without including too many references to other studies. In summary I strongly recommend this paper only be considered for publication if following resubmission the results and discussion are rewritten as separate sections and the discussion is greatly shortened and written less speculatively.

Wow! This is amongst the toughest comments we have ever received, and we struggled for a few days to respond. We understand that the long (20 pages)

Results and Discussion was difficult to get through in the previous version of the manuscript. Although a combination of these two sections is permitted by *Biogeosciences*, we appreciate your concern and want to make this dataset and manuscript as accessible as possible. Rather than dividing the two sections, we have instead made an effort to shorten this combined section by removing the most speculative sections. Therefore, a significant amount of text has been removed, including: 1) almost all of the vaguely worded statements in the discussion and 2) text, tables, and figures related to primary production. This can be evident by a dramatic reduction in the page number (from 20 to 15 pages, despite the inclusion of two pages at the request of Reviewer #1) in this combined section. We also greatly shortened the conclusions per your suggestion (from 3 to 1.5 pages). Hopefully, you will now find that the Results and Discussion of this revision is less speculative than the previous version. If, however, you still find this section to be too long and continue to deem it necessary to split into a traditional Results section followed by a short Discussion section, we will be pleased to do so in the next incarnation of the manuscript.

For your reference, the removed text of previous version included lines 161-171, 301-305, 313-328, 353-365, 373-375, 390-393, 400-410, 460-476, and 541-550.

Specific Comments:

1. *Page 2 line 42; 'vigorous plankton metabolic activities especially phytoplankton ' – rather vague- be more specific eg respiration? Production?*

We had somewhat deliberately worded it this way because we don't actually know why CR differed. To clarify, this sentence has been modified to "*The higher CR in 2010 could be attributed to phytoplankton respiration, especially at stations in the CDW zone that were not previously characterized by low sea surface salinity in 2009.*" in this revision.

2. *Page 2 line 43 define 'SSS'*

Thanks! We have now defined "SSS" ("sea surface salinity") at its first usage.

3. *Page 2 line 44 '. . .zooplankton might be . . .' far too vague in abstract.*

You are right, and we do agree with your comment. This sentence has been clarified to become "*…zooplankton were…*" in this revision.

4. *Page 5 line 72 line avoid using the word 'tremendous'*

The word "tremendous" has been replaced by "large" in the revised manuscript.

5. *Page 5 line 78 and elsewhere delete 'psu' salinity has no units now.*

Thank you for pointing this out; "*psu*" has been deleted throughout this revision.

6. *Page12 line 211 'previously documented values' – be more specific ie when?*

We agree with your suggestion, and the actual comparison time (i.e., summer) has been specifically mentioned in this revision.

7. *Page 13 line 230 change 'trailing' to 'previous'.*

Thank you! The suggested change has been made.

8. *Page 15 line 261 the single high phosphate concentration also evident on figure 1 looks to be an analytical anomaly.*

We have re-checked our logbook and did not find any calculation or instrument setting errors that could have resulted in this anomalous data point. Indeed, we seriously considered removing it, as doing so would facilitate our explanation of the data. We discuss this matter above, as the first reviewer also noted this strange result. For example, the linear regression (Chl *a* vs. phosphate) became statistically significant if this outlier was excluded from the analysis ($p < 0.001$; please also refer to our reply to comment 8 of reviewer #1 for more details.). To avoid data tampering/mining, we have opted to keep this data point in this revision, even though it heavily influences the regression analysis.

9. *Page 17 line 304 and table 2 data. I do not believe it is useful or that accurate to estimate the total chlorophyll a etc in the ECS. I suggest deleting table 2.*

Reviewer #1 stated *"Nonetheless, the authors conducted a fairly good job of synthesizing what they have learned based on their current and others' previous observations and various indices and metrics (e.g. volumetric values in surface water, averaged over the depth of euphotic zone, and depth-integrated values for the entire ECS and the Changjiang Diluted Water (CDW) region)".* Indeed, we tried to provide as much oceanographic data as possible to elucidate how pelagic ecosystems respond to flooding. In Table 1,

the average values of Chl *a* and bacterioplankton have been presented for 2009 and 2010. There was no effect of year on Chl *a* levels due to large variation in the dataset. As the region influenced by the river was much larger in 2010, it is difficult to know if the differences between mean values resulted from differences in ecosystem composition and function within this region or from the differences in the total area affected. Table 2 then provides another viewpoint to examine the effect of flooding on the response of the total biomass and other biological variables over the entire ECS and in the CDW zone. To provide the best estimation of total biomass, Surfer 11 (Golden Software, Inc.) was used. In addition, zooplankton was one of the important contributors to CR during the flooding period, and the zooplankton data are only presented in Table 2 in this manuscript. For these reasons, it seems necessary to keep Table 2 in this revision. However, to respond to your concern, the chlorophyll data have been removed from Table 2. Hopefully, our explanation can satisfy your concerns.

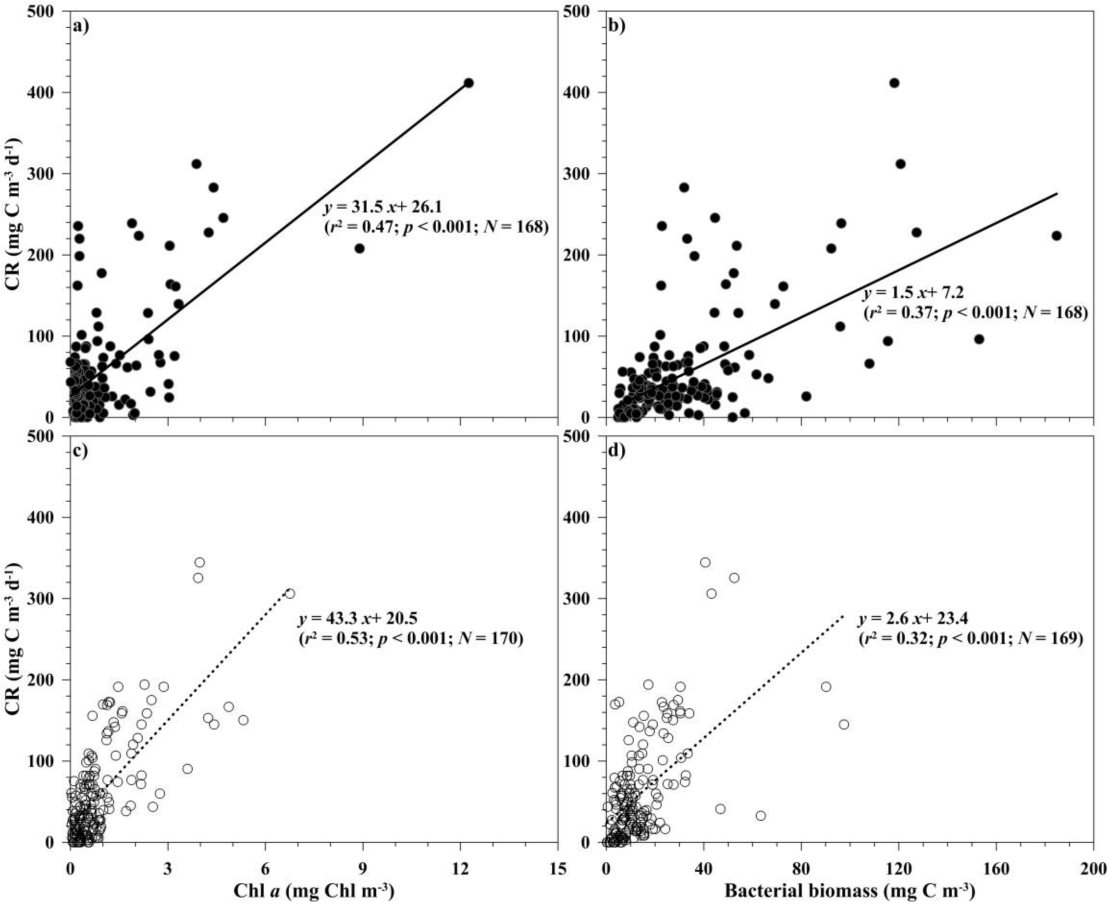
10. *Page 46 and 47 Figure 1 and 2. The contour plots are not very clear. The sampling locations need to be more clearly indicated by lager clear symbols.*

Thank you for pointing out the lack of clarity in the contour plots; reviewer 1 also raised a similar issue. These figures have been modified to be easier to read. For instance, the color code for salinity was changed, color bars were added, the font size was increased, and the sampling station symbols were enlarged. Collectively, we now feel that Figures 1 and 2 look much better, and we hope you do, as well.

11. *Figure 3 Although the relationships shown apparently are significant- the considerable scatter is not very convincing. If the one high chlorophyll point is removed from figure 3a is the relationship still significant? The relationships might be more usefully illustrated if the data from each year is shown on separate plots ie 2009 in upper figure and 2010 on lower figure with axis ranges the same on both figures.*

Even though we expected quite a degree of scatter in our data due to extensive temporal and spatial variation found in nature, we have still taken this suggestion as an opportunity to re-examine our dataset. The positive, linear relationship between CR and Chl *a* was still statistically significant even after the one high chlorophyll data point was removed from this analysis: $y = 31.5 x + 26.1$ ($r^2 = 0.36$; $p < 0.001$; $N = 167$).

We had plotted data from both surveys years together to reduce the number of panels, and, more importantly, to more readily allow for a visual comparison. For your reference, a new figure has been created per your suggestion below. We will be glad to replace the original figure with this new one if you still deem it necessary.



The influence of episodic flooding on a pelagic ecosystem in the East China Sea

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Running header: Effect of flooding on the East China Sea

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ABSTRACT

This study was designed to determine the effects of flooding on a pelagic ecosystem in the East China Sea (ECS), with a focus on plankton community respiration (CR). In July 2010, a flood occurred in the Changjiang River. As a comparison, a variety of abiotic and biotic parameters were monitored both during this flooding event, as well as during a non-flooding period (July 2009). During the flood, the Changjiang diluted water (CDW) zone covered almost two thirds of the ECS, which was approximately six times the area covered during the non-flooding period. The mean nitrate concentration was 3-fold higher during the 2010 flood (6.2 vs. 2.0 μM in 2009). CR was also higher in the 2010 flood: 105.6 mg C m^{-3} d^{-1} vs. only 73.2 mg C m^{-3} d^{-1} in 2009. The higher CR in 2010 could be attributed to phytoplankton respiration, especially at stations in the CDW zone that were not previously characterized by low sea surface salinity in 2009. In addition, zooplankton were another important component contributing to the high CR rate observed during the 2010 flood, a period also associated with a significant degree of $f\mathrm{CO}_2$ drawdown. These results collectively suggest that the 2010 flood had a significant effect on the carbon balance in the ECS; this effect might become more pronounced in the future, as extreme rainfall and flooding events are predicted to increase in both frequency and magnitude due to climate change.

Keywords: Bacteria; Dissolved inorganic nutrients; East China Sea; Flooding; Freshwater discharge; Phytoplankton; Plankton community respiration; Yangtze River

1 INTRODUCTION

Riverine run-off has a profound effect on the production and consumption of organic carbon in coastal ecosystems (e.g., Dagg et al., 2004; Hedges et al., 1997 and references therein). Accompanying freshwater discharge, a substantial amount of dissolved inorganic nutrients (DIN) is routinely dispensed into coastal regions, thus enhancing primary productivity (PP; e.g., Dagg et al., 2004; Nixon et al., 1996). In addition, a large quantity of particulate and dissolved organic matter is discharged via riverine input (e.g., Wang et al., 2012), and high rates of microbial metabolism associated with this discharge have been observed in marine environments (e.g., Hedges et al., 1994; Malone and Ducklow, 1990). River plumes can extend for hundreds of kilometers along the continental shelf, as in the case of the Amazon River (e.g., Müller-Karger et al., 1988).

Overall, the effects of river plumes on coastal ecosystems are strongly related to the volume of the freshwater discharged (e.g., Chen et al., 2009; Dagg et al., 2004; Tian et al., 1993). Thus, understanding how freshwater discharge influences coastal ecological processes is an important factor in modeling global carbon cycling in the ocean. Under projected climate change scenarios, such heavy freshwater discharge events are predicted to become even more pronounced in the near future because of the dramatic frequency and magnitude increases in extreme rainfall events and floods predicted to occur throughout the world in the coming decades (Christensen and

Christensen, 2003; Knox, 1993; Milly et al., 2002; Palmer and Ralsanen, 2002).

The East China Sea (ECS) has an approximate area of 0.5 x 10^6 km^2 and is the largest marginal sea in the Western Pacific. A large amount of freshwater (956 km^3 yr^{-1}) is discharged annually into the ECS, notably by the Changjiang (a.k.a Yangtze) River, which is the fifth largest river in the world in terms of volume discharge (Liu et al., 2010). On average, the maximum amount of discharge occurs in July, and mean monthly discharge has ranged from 33,955 to 40,943 m^3 s^{-1} in years of normal weather during the past decade (Gong et al., 2011; Xu and Milliman, 2009). After having been discharged into the ECS, freshwater mixes with seawater to form the Changjiang diluted water (CDW) zone, the sea surface salinity (SSS) of which is $\leq$ 31 (e.g., Beardsley et al., 1985; Gong et al., 1996). In the CDW, especially in summer, the regional carbon balance is regulated by high rates of plankton community respiration (CR) and PP (Chen et al., 2006; Gong et al., 2003). The rates of CR are positively associated with riverine flow rates (Chen et al., 2009).

In July 2010, a large flood occurred in the Changjiang River (Gong et al., 2011). This event provided an opportunity to understand how flooding affects the ECS shelf ecosystem. Comparative analyses were conducted in which number of physical, chemical, and biological parameters (notably CR) were measured not only during this flood, but also during a period (July 2009) when the riverine flow was relatively low. The main objective of this study was to reveal the effects of riverine input, particularly the associated DIN, on the plankton communities that support heterotrophic processes in the ECS shelf ecosystem between periods of non-flooding and flooding. In addition, the relationship between CR and the fugacity of CO_2 (fCO_2) was examined to determine the contribution of the plankton communities to variations in fCO_2 in periods of non-flooding and flooding.

2 MATERIALS AND METHODS

2.1 Study area and sampling protocol. This study is part of the Long-term Observation and Research of the East China Sea (LORECS) program. Samples were collected from the ECS in the summers of 2009 (June 29 to July 13) and 2010 (July 6 to 18) during two cruises on the *R/V Ocean Researcher I*. The sample stations were located throughout the ECS shelf region (Fig. 1). In July 2010, the discharge from the Changjiang River reached 60,527 $m^3 s^{-1}$, which was significantly higher than in the non-flooding year of 2009 (Gong et al., 2011; Yu et al., 2009). Water samples were collected using Teflon-coated Go-Flo bottles (20 L, General Oceanics Inc., USA) mounted on a General Oceanic Rosette® assembly (Model 1015, General Oceanics Inc.). At each station, six to nine samples were taken at depths of 3 to 50 m, depending on the depth of the water column. Sub-samples were taken for immediate analysis of DIN, chlorophyll *a* (Chl *a*), and bacterial abundance. Plankton CR was also measured on board from seawater sub-samples. The methods used to collect the hydrographic data and analyze the aforementioned response variables followed Chen et al. (2006; 2013; 2009). Descriptions of the methods used are presented briefly in the following sections. It should also be noted that portions of these results were published by Chung et al. (2014) and Gong et al. (2011).

2.2 **Physical and chemical hydrographics.** Seawater temperature, salinity, and transparency were recorded throughout the water column using a SeaBird CTD (USA). Photosynthetically active radiation (PAR) was measured throughout the water column using an irradiance sensor (4π; QSP-200L). The depth of the euphotic zone (Z_E) was taken as the penetration depth of 1% of the surface light. The mixed layer depth (M_D) was based on the potential density criterion of 0.125 units (Levitus, 1982).

A custom-made flow-injection analyzer was used for dissolved inorganic nutrient (e.g., nitrate, phosphate, and silicate) analysis (Gong et al., 2003). Integrated values for the nitrates and other variables assessed in the water column above the Z_E were estimated using the trapezoidal method, in which depth-weighted means are computed from vertical profiles and then multiplied by Z_E (e.g., Smith and Kemp, 1995). The average nitrate concentration over Z_E was calculated from the vertically integrated value divided by Z_E. This calculation was adopted to determine the values of the other measured variables.

The fugacity of CO_2 (fCO_2) in the surface waters was calculated from dissolved inorganic carbon (DIC) and total alkalinity (TA) data using a program designed by Lewis and Wallace

(1998). For details of the TA and DIC measurements, please see Chou et al. (2007).

2.3 Biological variables. The water samples taken for Chl *a* analysis were immediately filtered through GF/F filter paper (Whatman, 47 mm) and stored in liquid nitrogen. The Chl *a* retained on the GF/F filters was quantified fluorometrically (Turner Design 10-AU-005; Parsons et al., 1984). When applicable, Chl *a* was converted to carbon units using a C:Chl ratio of 52.9, which was previously estimated from shelf waters of the ECS (Chang et al., 2003). Surfer 11 (Golden Software, Inc.) was used to estimate total Chl *a* content integrated over Z_E for both the ECS and the CDW (please see below for details.). This estimation was also adopted to determine the total quantities for heterotrophic bacteria and zooplankton across Z_E.

Heterotrophic bacteria samples were fixed in paraformaldehyde at a final concentration of 0.2% (w/v) in the dark for 15 min. They were then immediately frozen in liquid nitrogen and kept at -80°C prior to analysis. The heterotrophic bacteria were stained with the nucleic acid-specific dye SYBR® Green I (emission = 530 ± 30 nm) at a 10^4-fold diluted commercial solution (Molecular Probes, Oregon, USA; (Liu et al., 2002). They were then identified and enumerated using a flow cytometer (FACSAria, Becton-Dickinson, New Jersey, USA). Known numbers of fluorescent beads (TruCOUNT Tubes, Becton-Dickinson) were simultaneously used to calculate the original cell abundance in each sample. Bacterial abundance was converted to carbon units using a conversion factor of 20×10^{-15} g C cell^{-1} (Hobbie et al., 1977; Lee and

Fuhrman, 1987).

Zooplankton samples were collected across the whole water column (ranging from 20 to 198 m, depending on the station), at selected stations using a 330-µm mesh net with a 160-cm diameter opening. Upon retrieval of the net, the contents of the cod-end were immediately preserved in 10% buffered formalin. Zooplankton samples were digitized to extract size information (i.e., body width and length) using the ZooScan integrated system, and the size information was used to calculate the ellipsoidal bio-volume of zooplankton (Garcia-Comas, 2010). The biomass (carbon units) of zooplankton was then calculated using the estimated bio-volume following equations of Alcaraz et al. (2003). To estimate the biomass over Z_E, the total biomass of zooplankton over the whole water column was multiplied by the fraction of "Z_E relative to depth of the water column" at all stations.

The plankton CR, which was calculated as the decrease in dissolved oxygen (O_2) during dark incubation (Gaarder and Grann, 1927), was measured in samples collected from most stations, with two initial and two dark treatment samples taken from 4-6 depths (depth intervals of 3, 5, 10, 15, 20, and/or 25 m depending on the depth of the water column) within the Z_E at each station. The treatment samples were siphoned into 350-mL biological oxygen demand (BOD) bottles and incubated for 24 hrs in a dark chamber filled with running surface water. Maximum temperature changes were 1.33 ± 0.81 and 2.70 ± 1.43°C (mean±SD) during each incubation in 2009 and 2010, respectively. The concentration of O_2 was measured by a direct spectrophotometry method (Pai et al., 1993). The precision of this method was calculated as the root-mean square of the difference between the duplicate samples and was found to be 0.02 and 0.03 mg L^{-1} in 2009 and 2010, respectively. The precision for initial samples in both periods was < 0.01 mg L^{-1}. The difference in O_2 concentration between the initial and the dark treatment was used to compute the CR. A respiration quotient of 1 was assumed in order to convert the respiration from oxygen units to carbon units (Hopkinson Jr., 1985; Parsons et al., 1984).

3 RESULTS and DISCUSSION

3.1 Comparison of hydrographic patterns between flooding and non-flooding periods

In 2010, the Changjiang River began to flood in late May or early June. The mean monthly water discharge was 60,527 m^3 s^{-1}, and the threshold discharge rate was 4-6 x 10^4 m^3 s^{-1}, making it the largest recorded flooding of the Changjiang River over the last decade (http://yu-zhu.vicp.net/). This rate was almost two times larger than that recorded in the non-flooding period in July 2009 (33,955 m^3 s^{-1}; (Gong et al., 2011; Yu et al., 2009). During the flood, a tremendous quantity of freshwater was delivered into the ECS, and the low salinity of the sea surface ($SSS \leq 31$) covered almost two thirds of the continental shelf (Fig. 1b). The SSS in the ECS during the 2010 flood was significantly lower than during the 2009 non-flooding survey period; the mean (± SD for this and all parameters discussed henceforth) values were

30.32 (± 3.60) and 32.62 (± 2.07), respectively (Table 1). During periods of high discharge from the river, particularly during the summer, the CDW zone is generally distributed within the 60-m isobath region between the latitudes of 27 and 32º N along the coast (e.g., Beardsley et al., 1985; Gong et al., 1996). During the 2010 flood, the CDW dispersed towards the south and east and reached as far as the 100-m isobath (Fig. 1b). The substantial quantity of freshwater discharged into the ECS is also reflected in the coverage area of the CDW (e.g., Gong et al., 2011); in the 2010 flood, the CDW area (111.7 x 10^3 km^2) was approximately six times larger than in the 2009 non-flooding period (19.0 x 10^3 km^2).

Although the mean SSS differed significantly between the flooding and non-flooding periods, there was no difference in the temperature of the sea surface (SST; Table 1). The mean values of SST in 2009 (26.8 ± 1.7) and 2010 (and 26.1 ± 2.2ºC) were within the range of the mean SST of the ECS in summer (Chen et al., 2009). The mixed layer depth (M_D) did not significantly vary between survey periods: 13.7 (± 7.3) m in 2009 and 11.3 (± 6.6) m in 2010 (Table 1). However, the average M_D was shallower than documented previously in the summer in the ECS (range: from 16.8 to 28.2 m; Chen et al., 2009). The euphotic depth (Z_E) was not significantly deeper in 2009 (38.9 ± 36.4 m) than in 2010 (33.4 ± 17.3 m; Table 1). Regarding the M_D, the average Z_E in the ECS was also shallower than in a previous study conducted during the summer (Chen et al., 2009). The shallower Z_E could have been indirectly influenced by the transparency of the seawater. The average transparency in summer in the ECS over the 2003-2008 period was 81.9% (C.C. Chen, unpublished data). The average transparency values of the ECS in 2009 and 2010 were 76.7% and 80.5%, respectively (Table 1). The average transparency for the CDW zone was lower in 2009 (70.0%) and higher high in 2010 (78.4%) compared to the previous 6-year average (72.7%; C.C. Chen, unpublished data). This might also explain why Z_E in the CDW in 2009 was only 16.8 m (Table 1).

These findings suggest that the growth of phytoplankton might be limited by the availability of light, especially in the CDW zone in 2009. Generally, the transparency of the coastal ocean might be low during flooding periods due to riverine discharge of terrestrial matter. A low transparency value was documented in June 2003 in the ECS, during which the CDW area was 43.1 x 10^3 km^2 (~40% of the CDW area of the 2010 flood; Chen et al., 2009), and the average transparency values for the ECS and the CDW were 70.9% and 66.0%, respectively (C.C. Chen, unpublished data). The average transparency in the CDW in 2010 (78.4%) was higher than the previous 6-year average (72.7%). This could be partially explained by the fact that most large particulates from terrestrial sources might have been confined to and precipitated in the coastal region, not in the expanded CDW region (e.g., Chung et al., 2012). Furthermore, it should also be noted that the 2010 sampling period was one month after the beginning of this flood. In estuarine and coastal regions, phytoplankton blooms normally occur within 2-3 weeks after a heavy rainfall event (e.g., Hsieh et al., 2012; Meng et al., 2015; Mulholland et al., 2009). Therefore, it is reasonable to speculate that plankton communities were in the late phase of succession in this flood event. The transparency during the 2010 sampling period might, then, have increased due to organic matter (particulate and dissolved) having been uptaken and transferred to higher trophic levels.

In general, a large quantity of dissolved inorganic nutrients is delivered from the Chinese coast to the ECS during the wet season (May to September; Chen et al., 2013; Chen et al., 2009; Gong et al., 1996). A high concentration of nitrates in the fluvial discharge of the Changjiang River was documented in the ECS during the 2010 flood. Furthermore, there was 1) a negative linear relationship between SSS and nitrate concentration ($r^2 = 0.37$, $p < 0.001$, n = 37), 2) a negative linear relationship between SSS and silicate concentration ($r^2 = 0.60$, $p < 0.001$, n = 37), and 3) no correlation between SSS and phosphate concentration. Nitrate concentration (Table 1) was significantly higher in the surface waters of the ECS in the 2010 (6.2 ± 9.8 μM) flood than in the 2009 non-flooding period (2.0 ± 5.3 μM), and similar nitrate concentration differences were perpetuated between sampling times over Z_E (data not shown). During the 2010 flood, the mean nitrate concentration, either in the surface water or averaged over $Z_{E,}$ was higher or comparable to that documented during periods of high riverine discharge in the ECS (Chen et al., 2009; Gong et al., 1996). Nitrate levels reached 37.6 μM in the surface water during the 2010 flood, and the highest nitrate concentrations were observed within the CDW (Fig. 1d).

The phosphate concentration in the surface water (Table 1) did not differ between the 2009 non-flooding period (0.13 ± 0.17 μM) and the 2010 flood (0.17 ± 0.30 μM), nor did it differ in the CDW zone between study years (0.23 and 0.13 μM, respectively). However, it should be noted that there was one station with extremely high phosphate concentration (1.71 μM) in the surface water in the CDW zone during the 2010 flood (Fig. 1f), during which the mean molar ratio of nitrate to phosphate (N/P) was 22.3 ± 20.9. The high N/P molar ratio was even more pronounced in the CDW; it was higher than the Redfield ratio for N:P (i.e., 16) at 14 of the 20 stations and averaged 40.4 (± 22.6). This value was comparable to that of the CDW during high riverine flow periods in the ECS in summer (Chen et al., 2006). During the non-flooding period, the N/P molar ratio was lower than 16, with a mean value of 11.5 (± 20.8).

It has been suggested that phytoplankton growth might be regulated by the availability of nutrients, or the N/P ratio of the available nutrient pool, in the ECS (Gong et al., 1996; Harrison et al., 1990). The results of this study indicate that in the 2009 non-flooding period, phytoplankton biomass might have been regulated by the availability of dissolved inorganic nitrogen to a greater extent than it was during the 2010 flood. Phytoplankton biomass might have also been limited by nitrate and silicate levels in 2010. Based on nutrient levels and the N/P molar ratio, however, phytoplankton growth was more likely limited by phosphate, especially in the CDW zone during the 2010 flood (please refer to Sect. 3.2 for details.). Phytoplankton growth limited by different inorganic nutrients has been observed in estuaries and coastal regions, such as Chesapeake Bay in the United States (Fisher et al., 1992; Harding, 1994). In the ECS, phosphates have been frequently found as a factor limiting phytoplankton growth, especially in the CDW (Chen et al., 2004; Gong et al., 1996; Harrison et al., 1990).

3.2 Plankton activity associated with the Changjiang River flood

Following the discharge of fluvial nutrients into the ECS, phytoplankton are generally abundant in the CDW region. The Chl *a* concentration in the CDW even reached bloom criteria (> 20 mg Chl m^{-3}) in past years in the ECS (Chen et al., 2009; Chen et al., 2003). Surprisingly, the phytoplankton biomass was not as high as expected in this study, even though a high nitrate concentration was observed during the 2010 flood. The mean values of Chl *a* in the surface water of the ECS in 2009 and 2010 were 0.98 (± 1.52) and 1.26 (± 1.27) mg Chl m^{-3}, respectively (Table 1). However, these mean values were still at the high end of the Chl *a* concentration range normally documented in the ECS in the mid-summer through July/August period (Chen et al., 2009). In both periods, the phytoplankton biomass in the surface water was generally higher in the CDW than in other regions of the ECS (Fig. 1g and h). For example, in the 2010 flood, the maximum Chl *a* value reached 5.32 mg Chl m^{-3} in the CDW (Table 1; Fig. 1h). In the 2010 flood, the Chl *a* values were positively correlated with nitrate and silicate concentrations (all $p < 0.001$), but not phosphate concentrations ($p = 0.09$), in the surface water. The linear relationship between Chl *a* and phosphate values in the surface water, however, became significant ($p < 0.001$) if one outlier with a markedly high phosphate concentration (1.71 μM) was excluded from the analysis (Fig. 1f). In the 2009 non-flooding period, the Chl *a* concentration was significantly, positively, and linearly correlated with concentrations of all measured nutrients: nitrate, silicate, and phosphate ($p < 0.01$ in all cases).

The spatial distribution pattern of Chl *a* documented in this study was similar to that found in previous studies of the ECS (Gao and Song, 2005; Gong et al., 2011), and phytoplankton biomass in the surface water (Table 1), or averaged over Z_E (data not shown), did not differ significantly between 2009 and 2010. In the 2010 flood, primary production (PP) in the surface water was 62.1 (±33.8) mg C m^{-3} d^{-1}, comparable to values documented in the ECS in summer by (Chen et al., 2009). In contrast, the PP:Chl *a* value was higher in the 2010 flood (27.1 ± 17.2 mg C mg Chl^{-1} d^{-1}) compared to that documented value (19.7 ± 5.5 mg C mg Chl^{-1} d^{-1}) by Chen et al. (2009). Gong et al. (2011) estimated that over the past decade, the average rate of carbon fixation during flooding periods was about three times higher than during non-flooding periods, and the carbon fixation rate reached 176.0×10^3 tons C d^{-1} in the CDW during the 2010 flood (Gong et al., 2011).

In summer, heterotrophic bacterioplankton are generally more abundant in the CDW of the

ECS than in other regions (Chen et al., 2006; Chen et al., 2009). Chen et al. (2006) suggested that the growth of bacteria along the coast might be stimulated by the substantial amount of organic matter derived from both autochthonous marine production and fluvial runoff. This spatial distribution pattern was also observed in 2009 and 2010. In the 2009 non-flooding period, the mean bacterial biomass in the surface water of the CDW was 77.5 (± 55.7) mg C m^{-3}, over 2-fold higher than in all other areas (31.0 ± 18.6 mg C m^{-3}). Their mean values in the 2010 flood were 24.4 (± 18.6) and 15.0 (± 11.5) mg C m^{-3} in the CDW and other regions, respectively. Further analyses revealed that the bacterial biomass in the surface water was positively and linearly associated with Chl *a* concentrations in both 2009 ($p < 0.01$) and 2010 ($p < 0.05$). This finding applies to the values averaged over Z_E in both periods (both $p < 0.01$). However, the mean Chl *a* concentrations in the surface water were slightly higher in 2010 than in 2009 (Table 1).

In general, an increased amount of organic matter is delivered through fluvial discharge into the ECS during periods of high riverine flow (e.g., Wang et al., 2012). Although these results suggest that the bacterial biomass might be higher in the flooding period than in the non-flooding period, this difference was not verified when using averaged bacterial biomass values in this study. The bacterial biomass in the surface water was significantly higher in the 2009 non-flooding period than during the 2010 flood, with mean values of 39.8 (± 33.7) and 20.4 (±

16.5) mg C m^{-3}, respectively (Table 1). The average bacterial biomass over Z_E was even more pronounced in 2009 than in 2010 (data not shown). However, the total bacterial biomass in the CDW zone was two times higher in 2010 than in 2009, with values of 47.7 and 21.0 x 10^6 kg C, respectively (Table 2).

Zooplankton are amongst the most important contributors to plankton CR (Calbet and Landry, 2004; Hernández-León and Ikeda, 2005; Hopkinson Jr. et al., 1989). In this study, zooplankton were only sampled across the whole water column. However, the average biomass of zooplankton over Z_E can be still estimated, and mean values for the 2010 flood and 2009 non-flooding period were calculated as ,105.7 (± 144.4) and 22.6 (± 25.7) mg C m^{-3}, respectively; this differences was statistically significant ($p < 0.01$). The average zooplankton biomass over Z_E for the CDW zone was 90-fold higher in 2010 than in 2009 (Table 2), suggesting that the flood may have had a significant effect on zooplankton biomass.

3.3 Effects of the Changjiang River flooding on plankton community respiration

Plankton CR is typically defined as the integrated rate of organic carbon consumption by plankton communities (e.g.., Hopkinson Jr. et al., 1989; Rowe et al., 1986). In summer, the mean CR rate in the surface waters of the ECS ranges from 52.2 to 128.4 mg C m^{-3} d^{-1} (Chen et al., 2006; Chen et al., 2009), and it is significantly correlated with fluvial discharge from the Changjiang River (Chen et al., 2009). In this study, the CR in the surface water ranged from 2.7

to 311.9 mg C m^{-3} d^{-1}, with a mean value of 73.2 (± 76.9) mg C m^{-3} d^{-1} in the 2009 non-flooding period (Table 1). During the 2010 flood, the mean rate in the surface water of 105.6 (± 66.7) mg C m^{-3} d^{-1} was significantly higher than in 2009 ($p < 0.01$; Table 1), and CR ranged from 10.9-325.3 mg C m^{-3} d^{-1} (Table 1). The CR rate averaged over the Z_E was statistically similar in both years ($p = 0.08$), with mean values of 76.8 (±53.0) and 66.8 (±68.4) mg C m^{-3} d^{-1}, respectively. In terms of spatial distribution, higher CR rates were mostly observed in the CDW region in both sampling periods, especially along the coast (Fig. 2). Nevertheless, it should be noted that the CDW zone was much larger in 2010 than in 2009.

CR rates were regressed against biomass of phytoplankton, heterotrophic bacteria, and zooplankton, and CR was significantly correlated with both Chl *a* concentration and bacterial biomass for both periods in surface water and when averaged over Z_E (all $p < 0.01$; Fig. 3). The contribution of phytoplankton and/or bacterioplankton to CR is substantial in the ECS, even though the relative contribution varies spatially and temporally (Chen et al., 2006; Chen et al., 2009; Chen et al., 2003) Given the importance of phytoplankton and bacterioplankton to CR rates in both years, as well as their high densities measured herein, it seems likely that these microbial groupings contributed substantially to the CR rate in both 2009 and 2010.

Surprisingly, the mean Chl *a* concentration was slightly higher in 2010 than in 2009, though bacterial biomass was significantly lower in 2010 than in 2009 (Table 1). However, the CR rate was still higher in 2010 than in 2009. In a further analysis, the differences (i.e., 2010 minus 2009) in the average CR, Chl *a* concentration, and bacterial biomass over Z_E at the same station were calculated. The extent of such differences in CR was significantly related to differences in Chl *a* concentration ($p < 0.001$) and bacterial biomass ($p < 0.01$; Fig. 4). The linear relationships were also statistically significant if the values of the differences in the surface water were used (all $p < 0.01$; data not shown). Among the positive CR difference values (i.e., 20 of 33), 15 stations were also characterized by positive differences in Chl *a* concentrations; only 2 stations had positive differences in bacterial biomass. Interestingly, the stations with positive Chl *a* concentration difference values were mostly located within the CDW region in 2010, with the exception of the CDW in 2009. These results suggest that the higher CR in the 2010 flood might be attributed to phytoplankton, especially in the CDW. The mean Chl *a* concentration was only slightly higher in 2010 than in 2009. Therefore, it is reasonable to speculate that the differences in CR rate in both periods might have been partially caused by variation in the composition of the phytoplankton communities. Although the CR attributed to different components of the phytoplankton community was not measured in this study, it was been documented elsewhere; for instance, dinoflagellates have higher carbon-specific respiration rates that many other phytoplankton types (e.g., Lopez-Sandoval et al., 2014).

In addition, zooplankton might also be amongst the potential contributors to the higher CR rate observed in 2010 than in 2009. As stated above, the biomass of zooplankton was significantly higher in 2010 than in 2009. However, the linear relationships between CR and zooplankton biomass over Z_E were not statistically significant in 2009 or 2010. To further explore how plankton communities contributed to CR, the CR rate was regressed against total plankton biomass (i.e., summed biomass of phytoplankton, bacterioplankton, and zooplankton) for both periods, and the linear relationships between CR and total plankton biomass (mg C m^{-3}) over Z_E were significant in both 2009 ($p < 0.001$) and 2010 ($p < 0.01$; Fig. 5).

Similarly significant relationships between CR and total planktonic biomass have also been observed in the summer in the ECS, and phytoplankton and bacterioplankton might be the most important components contributing to CR at such times (Chen et al., 2006). In this study, autotrophic plankton biomass (i.e., phytoplankton) accounted for 41.3% and 45.6% of total planktonic biomass in 2009 and 2010, respectively. As for heterotrophic plankton biomass, bacterioplankton attributed to 38.7% and 11.3% and zooplankton contributed for 20.0% and 43.1% of total plankton biomass in 2009 and 2010, respectively. This suggests that phytoplankton and bacterioplankton might be the most important components attributing to CR in the 2009 non-flooding period. In contrast, during the 2010 flood, the CR rate might have been mostly driven by phytoplankton and zooplankton metabolic activity.

All such conjectures are based on stocks, and biomass might not be directly related to the concurrent CR rate. By using physiological and allometric relationships of variant plankton communities, the plankton CR rate could be estimated from stock values, and significant correlations have indeed been found between measured and estimated rates (Chen et al., 2009). Furthermore, it also should be noted that microzooplankton might be another important contributor to CR, though they were unfortunately not assessed herein.

3.4 Implications of plankton community respiration on coastal ecosystems of the ECS

A further comparative analysis was conducted to determine whether the CR rate affected the fugacity of CO_2 (fCO_2) in the seawater. In 2009, the fCO_2 in the surface water was in the range of 118.7-599.8 μatm, with mean values of 362.9 ± 101.2 μatm (Table 1). This mean value is close to the mean (369.6 μatm) observed in the ECS in August in prior years (Chen et al., 2006). In the 2010 flood, the mean value (297.6 μatm) of fCO_2 in the surface water was significantly lower than in 2009, and ranged from 178.7 to 454.2 μatm (Table 1). It is well known that fCO_2 is temperature dependent, and it increases as the temperature increases (e.g., Goyet et al., 1993). The effect of temperature on the large variation in fCO_2 observed between the 2009 non-flooding period and the 2010 flood was trivial; the SST difference of 0.7°C between 2009 and 2010 would only equal a fCO_2 decrease of approximately 10 μatm (Table 1).

The effect of freshwater input on fCO_2 in the surface water in the ECS has also been suggested to be relatively minor compared to the inter-annual variation of fCO_2 (Chen et al., 2013). To evaluate this, conservative mixing was applied by using TA and DIC data between freshwater and seawater end-members. Provided that the proportional contributions from freshwater and seawater endmembers are f_1 and f_2 ($f_1+f_2=1$), respectively, the conservative mixing TA and DIC values for a given water sample can be expressed by the following equations:

$$TA_{mix}=TA_{fw}xf_1+TA_{sw}xf_2$$

$$DIC_{mix}=DIC_{fw}xf_1+DIC_{sw}xf_2$$

where the subscripts “mix”, “fw”, and “sw” represent values of conservative mixing, freshwater, and seawater endmembers, respectively. The TA and DIC data reported by Zhai et al. (2007) for the Changjiang River in summer were used as the freshwater endmembers (both TA_{fw} and DIC_{fw}=1743 μmol kg^{-1}), and the surface data at station K in July 2009 and 2010 were chosen to represent the seawater endmembers (TA_{sw}=2241 μmol kg^{-1} and DIC_{sw}=1909 μmol kg^{-1} in 2009; TA_{sw}=2240 μmol kg^{-1} and DIC_{sw}=1904 μmol kg^{-1} in 2010). Subsequently, the hypothetical $f\mathrm{CO}_2$ from conservative mixing was calculated from the TA_{mix} and DIC_{mix} data using CO2SYS version 2.1 (Pierrot et al., 2006), in which the carbonic acid dissociation constants were adopted from Mehrbach et al. (1973) and refitted by Dickson and Millero (1987). The uncertainty in this simulation mainly derives from errors in the estimations of TA_{mix} and DIC_{mix}. Assuming the errors of the calculated TA_{mix} and DIC_{mix} are ±5 μmol kg^{-1}, this may result in an uncertainty of

±13 μatm in the simulated $f\mathrm{CO}_2$. The simulated results show that the effect of mixing freshwater and seawater on $f\mathrm{CO}_2$ was nearly the same in both periods. However, a large variation in $f\mathrm{CO}_2$ in the surface water was estimated; it varied from 375.4 to 439.8 μatm within a salinity range of 20.38 to 33.96. This finding implies that surface water $f\mathrm{CO}_2$ in the ECS might increase dramatically, especially during the devastating flood of 2010 where low SSS (≤ 31) characterized almost 70% of the ECS shelf (Fig. 1b). However, in the 2010 flood, surface water with low $f\mathrm{CO}_2$ was observed in the ECS. Therefore, vigorous photosynthetic processes might be a potential cause for the reduction of $f\mathrm{CO}_2$ in the surface water during periods of flooding. Compared to PP values observed in summer in the ECS in previous years (Chen et al., 2009), PP was indeed high during the 2010 flood (Table 1; Chen et al., 2009). Gong et al. (2011) also estimated that over the past decade, the carbon fixation rate during flooding was about three times higher than during non-flooding periods. However, no significant correlation was found between $f\mathrm{CO}_2$ and PP in the 2010 flood, though this may simply be due to having a small sample size for PP. Nevertheless, $f\mathrm{CO}_2$ was significantly correlated with Chl *a* concentration in the pooled 2010 flood dataset ($p < 0.001$). This significant relationship indirectly supports the hypothesis that the reduction in $f\mathrm{CO}_2$ in the 2010 flood might be associated with vigorous phytoplankton metabolic activity.

Furthermore, negative linear relationships were observed between $f\mathrm{CO}_2$ and CR in the surface water during both the 2009 non-flooding period ($p < 0.01$) and the 2010 flood ($p < 0.001$;

Fig. 6). Significant linear relationships were also found using pooled data from each period (all $p < 0.001$). CR has been assumed to be an integrated response of overall plankton activity. These results imply that $f\mathrm{CO}_2$ in the surface water (or the entire water column) is related to plankton activities. To explore the variation in $f\mathrm{CO}_2$ between the non-flooding and flooding period, the difference in $f\mathrm{CO}_2$ and CR at the same station was estimated. Surprisingly, a negative linear relationship was found between the difference in $f\mathrm{CO}_2$ and CR of the flooding and non-flooding periods ($p = 0.001$; Fig. 7). As previously stated, compared to the 2009 non-flooding period, the increase in CR rate in the 2010 flood might be associated with the increase in phytoplankton biomass (Fig. 4a). These results indicate that the significant amount of $f\mathrm{CO}_2$ absorption in the 2010 flood was related to the strength of plankton activity, particularly phytoplankton at stations that were not characterized by low SSS in the 2009 non-flooding period.

4 CONCLUSIONS

Riverine run-off has a profound effect on organic carbon production and consumption in coastal ecosystems across the globe, and these effects will become even more pronounced as storm frequency and magnitude increase in the coming decades. During the 2010 flooding of the Changjiang River, a large quantity of freshwater was discharged into the ECS, and the CDW zone covered almost two thirds of the continental shelf; this represents a 6-fold greater area than during a more typical, non-flooding period (2009). Higher nitrate concentrations, mostly in the river's fluvial discharge, were also measured in the ECS during the flood. Although the phytoplankton biomass showed no significant difference between 2009 and 2010, bacterial biomass in the surface water was significantly higher in the 2009 non-flooding period. Despite this, CR was still higher during the 2010 flood than in the 2009 non-flooding period. The temporal difference (2010 minus 2009) in CR was significantly related to the respective differences in Chl *a* concentration, suggesting that higher CR in the 2010 flood might have been attributed to a higher biomass of phytoplankton, especially at stations located within the CDW region (most of which were not characterized by low SSS in the 2009 non-flooding period). In addition to phytoplankton, zooplankton may also have contributed significantly to the high CR rate observed in the 2010 flood. This could be evidenced from the fact that zooplankton biomass in 2010 accounted for 43.1% of the total plankton biomass. Finally, a negative linear relationship was found between the temporal differences (i.e., 2010 minus 2009) in CR vs. $f\text{CO}_2$. This finding implies that a tremendous quantity of $f\text{CO}_2$ was uptaken during phytoplankton photosynthesis during the flood period. Overall, these results suggest that plankton activity increased due to the substantial input of dissolved inorganic nutrients discharged by the river during the flood. This effect was especially pronounced at stations not previously characterized by low SSS, indicating that the effects of flooding on the ECS shelf ecosystem might be scaled to the magnitude of the flood.

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Table 1. The mean ± SD values for different variables measured in the surface water of the ECS during non-flooding (2009) and flooding (2010) periods, with range of values in parentheses. The mean ± SD values for stations in the area of the Changjiang Diluted Water (CDW) region are in brackets. Variables include transparency (CTD_{TM}; %), salinity (SSS), temperature (SST; °C), fugacity of CO_2 (fCO_2; µatm), nitrate concentration (NO_3^-; µM), phosphate concentration (PO_4^{3-}; µM), silicate concentration (SiO_4^-; µM), chlorophyll *a* concentration (Chl *a*; mg Chl m^{-3}), bacterial biomass (BB; mg C m^{-3}), and plankton community respiration (CR; mg C m^{-3} d^{-1}). The euphotic depth (Z_E; m) and mixed layer depth (M_D; m) are also shown for each year. Mann-Whitney rank-sum test were used to test temporal differences. For reference, it should be noted that the difference between the CDW zone and the other region in the ECS in each year was significant for most of variables ($p <$ 0.05), except nitrate and phosphate in 2009.

Variable	2009 (non-flooding period)	2010 (flood)
Z_E	38.9±36.4 (1.3–190.6) [16.8±7.4]	33.4±17.3 (10.1–82.2) [24.8±10.7]
M_D	13.7±7.3 (5–37) [7.3±3.6]	11.3±6.6 (4–35) [7.9±2.6]
CTD_{TM}	76.7±12.2 (37.2–86.3) [70.0±4.9]	80.5±5.4 (67.7–88.5) [78.4±4.3]**
SSS	32.62±2.07 (23.80–34.11) [29.24±2.52]	30.32±3.60 (19.33–34.27)* [27.95±3.03]
SST	26.8±1.7 (23.3–29.6) [25.0±0.9]	26.1±2.2 (21.0–30.0) [25.1±1.7]
fCO_2	362.9±101.2 (118.7–599.8) [230.4±105.3]	297.6±79.0 (178.7–454.2)* [248.6±54.5]
NO_3^-	2.0±5.3 (0.0–24.3)	6.2±9.8 (0.0–37.6)*

	[4.0±9.1]	[10.3±11.3]*
PO_4^{3-}	0.13±0.17 (0.00–0.83) [0.13±0.07]	0.17±0.30 (0.00–1.71) [0.23±0.37]
SiO_4^-	5.8±5.9 (1.5–24.5) [9.8±7.2]	6.4±7.8 (0.6–36.4) [9.1±9.2]
Chl *a*	0.98±1.52 (0.12–4.41) [2.23±1.46]	1.26±1.27 (0.03–5.32) [1.83±1.35]
BB	39.8±33.7 (10.6–184.8) [54.9±39.6]	20.4±16.5 (3.6–90.2)** [24.4±18.6]**
CR	73.2±76.9 (2.7–311.9) [172.0±109.2]	105.6±66.7 (10.9–325.3)* [142.0±61.2]

*: $p < 0.01$; **: $p < 0.001$

Table 2. Total area (x 10^3 km^2) of the East China Sea (ECS) and Changjiang Diluted Water (CDW) region (in brackets), as well as bacterial (BB; x 10^6 kg C) and zooplankton (Zoo; x 10^6 kg C) biomass over the euphotic depth integrated for the entire ECS and the CDW region (in brackets) during non-flooding (2009) and flooding (2010) periods.

Variables	2009 (non-flooding period)	2010 (flood)
Area	186.0 [19.0]	182.7 [111.7]
BB	222.5 [21.0]	87.3 [47.7]
Zoo	410.3 [6.2]	920.6 [560.8]

FIGURE LEGENDS

Fig. 1. Contour plots of salinity (SSS) and concentrations of nitrate (NO_3^-), phosphate (PO_4^{3-}), and chlorophyll *a* (Chl *a*) in the surface water (2-3 m) in the ECS during non-flooding (2009; left most panels) and flooding (2010; right-most panels) periods. Bottom depth contours are shown as dashed lines both here and in Fig. 2. The sampling stations in both periods are marked by an ex (x) both here and in Fig. 2. The contour intervals of SSS and concentrations of nitrate, phosphate, and Chl *a* are 0.5, 1.0 μM, 0.1 μM, and 0.5 mg Chl m^{-3}, respectively, and the values of the respective contour lines (bold) are = 31, 3.0 μM, 1.0 μM, and 1.0 mg Chl m^{-3}, respectively The range for each parameter is shown at the top of each panel.

Fig. 2. Contour plots of plankton community respiration (CR; mg C m^{-3} d^{-1}) over the euphotic zone of the ECS during a) non-flooding (2009) and b) flooding (2010) periods. The contour interval is 10 mg C m^{-3} d^{-1}. The CR range is shown at the top of each panel.

Fig. 3. Relationships between plankton community respiration (CR; mg C m^{-3} d^{-1}) and a) chlorophyll *a* concentration (Chl *a*; mg Chl m^{-3}) and b) bacterial biomass (mg C m^{-3}) for all data from non-flooding (2009; ●) and flooding (2010; ○) periods. Linear regressions of data from 2009 (solid lines) and 2010 (dashed lines), as well as the respective r^2 and p values, have also been included.

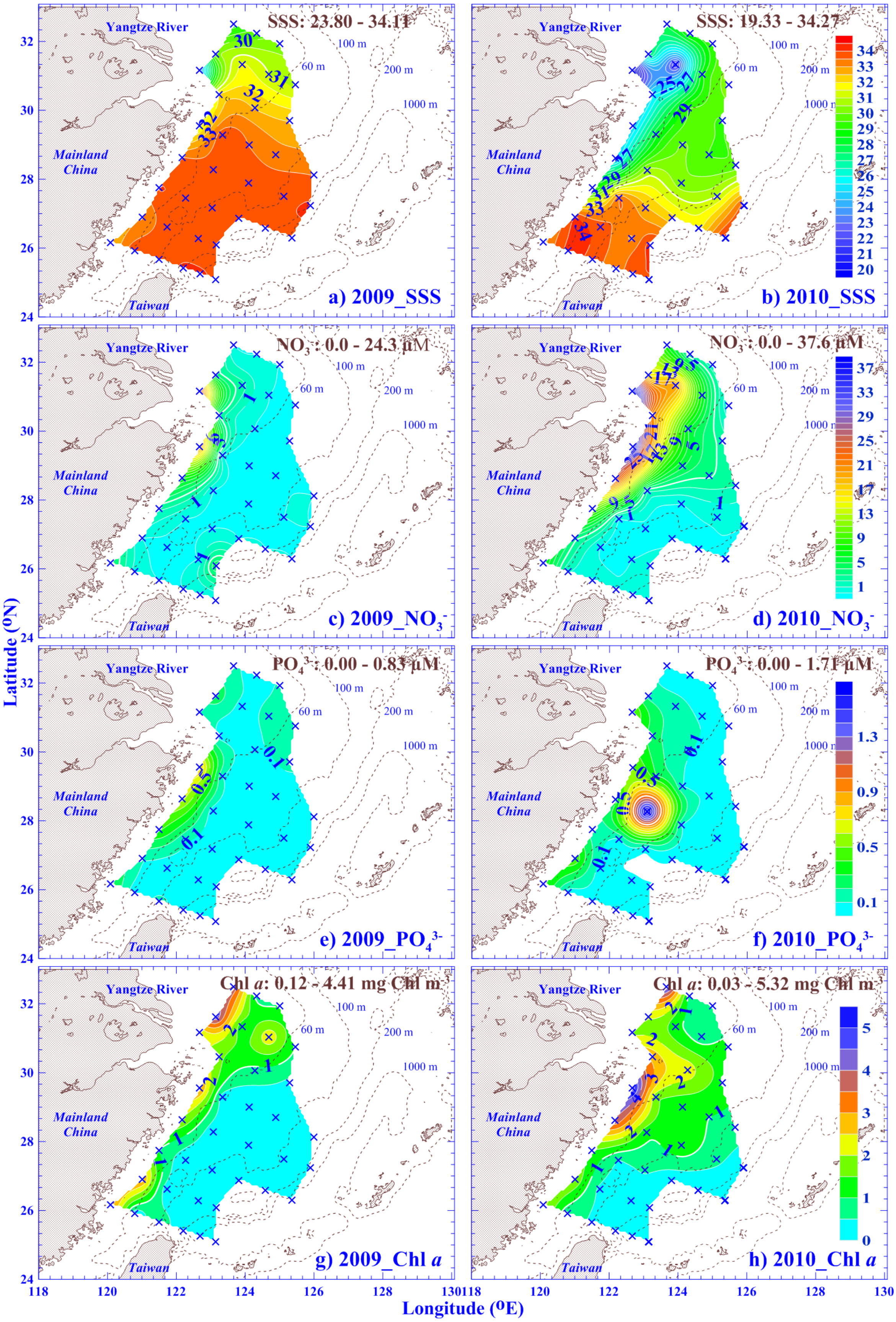
Fig. 4. Differences (Δ) between 2010 and 2009 in plankton community respiration (CR; mg C m^{-3} d^{-1}) versus a) chlorophyll *a* (Chl *a*; mg Chl m^{-3}) and b) bacterial biomass (mg C m^{-3}) over the euphotic zone at the same station. The r^2 and p values have been shown for the best-fit linear regression line (solid line). For reference, the vertical and horizontal dashed lines represent inter-year differences of zero (i.e., Δ = 0).

Fig. 5. Relationship between plankton community respiration (CR) and total plankton biomass (expressed per carbon unit) over Z_E in 2009 (●; solid line) and 2010 (○;

dashed line). The respective r^2 and p values are shown for each linear regression line. Total plankton biomass was the summed biomass of phytoplankton, bacterioplankton, and zooplankton. Please refer to the “Materials and Methods” for details of the carbon conversion for plankton communities.

Fig. 6. Relationships between the fugacity of CO_2 (fCO_2) and plankton community respiration (CR) in the surface water in 2009 (●; solid line) and 2010 (○; dashed line). The respective r^2 and p values are shown for each linear regression line.

Fig. 7. Differences (Δ) between 2010 and 2009 in fCO_2 (μatm) and plankton community respiration (CR; mg C m^{-3} d^{-1}) in the surface water at the same station. For reference, the vertical and horizontal dashed lines represent the inter-annual differences of zero (i.e., $\Delta = 0$).


SSS: 23.80 - 34.11
SSS: 19.33 - 34.27
NO$_3^-$: 0.0 - 24.3 μM
NO$_3^-$: 0.0 - 37.6 μM
PO$_4^{3-}$: 0.00 - 0.83 μM
PO$_4^{3-}$: 0.00 - 1.71 μM
Chl a: 0.12 - 4.41 mg Chl m^{-3}
Chl a: 0.03 - 5.32 mg Chl m^{-3}
Yangtze River
Mainland China
Taiwan
60 m
100 m
200 m
1000 m
a) 2009_SSS
b) 2010_SSS
c) 2009_NO$_3^-$
d) 2010_NO$_3^-$
e) 2009_PO$_4^{3-}$
f) 2010_PO$_4^{3-}$
g) 2009_Chl a
h) 2010_Chl a
Latitude (°N)
Longitude (°E)
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0

Fig. 1

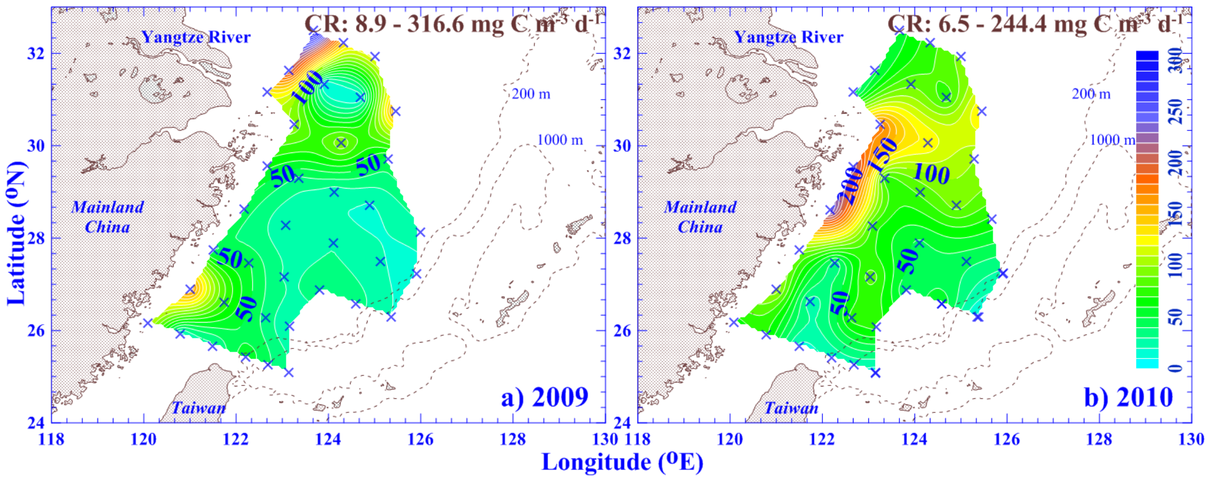

CR: 8.9 - 316.6 mg C m^{-3} d^{-1}
CR: 6.5 - 244.4 mg C m^{-3} d^{-1}
Yangtze River
Mainland China
Taiwan
200 m
1000 m
100
50
150
200
a) 2009
b) 2010
Latitude (°N)
Longitude (°E)
24
26
28
30
32
118
120
122
124
126
128
130
0
50
100
150
200
250
300

Fig. 2

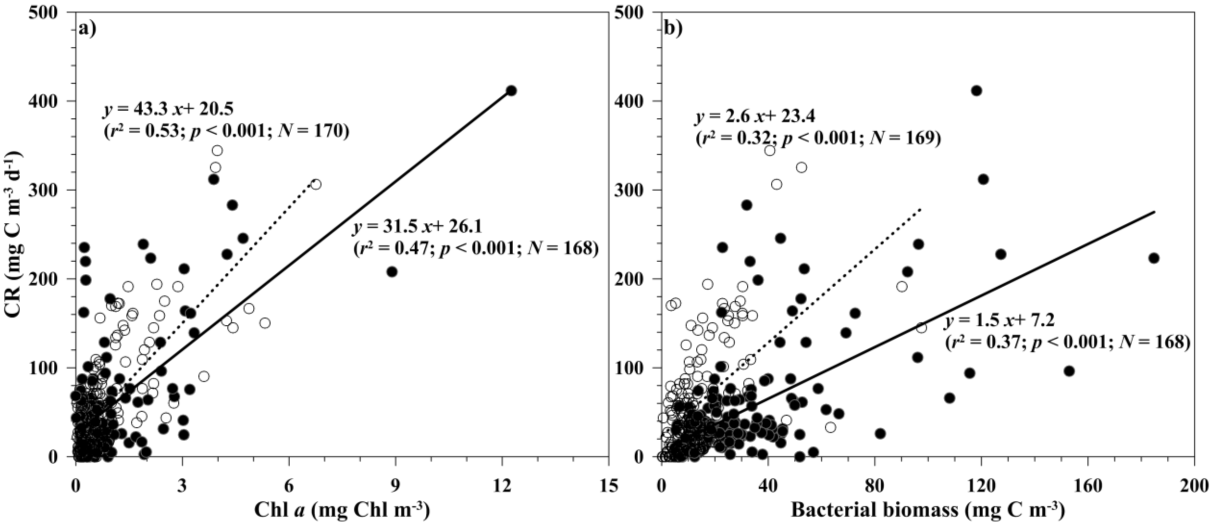

a)
b)
CR (mg C m^{-3} d^{-1})
0
100
200
300
400
500
0
3
6
9
12
15
Chl *a* (mg Chl m^{-3})
y = 43.3 x+ 20.5
(r^2 = 0.53; p < 0.001; N = 170)
y = 31.5 x+ 26.1
(r^2 = 0.47; p < 0.001; N = 168)
0
40
80
120
160
200
Bacterial biomass (mg C m^{-3})
y = 2.6 x+ 23.4
(r^2 = 0.32; p < 0.001; N = 169)
y = 1.5 x+ 7.2
(r^2 = 0.37; p < 0.001; N = 168)

Fig. 3

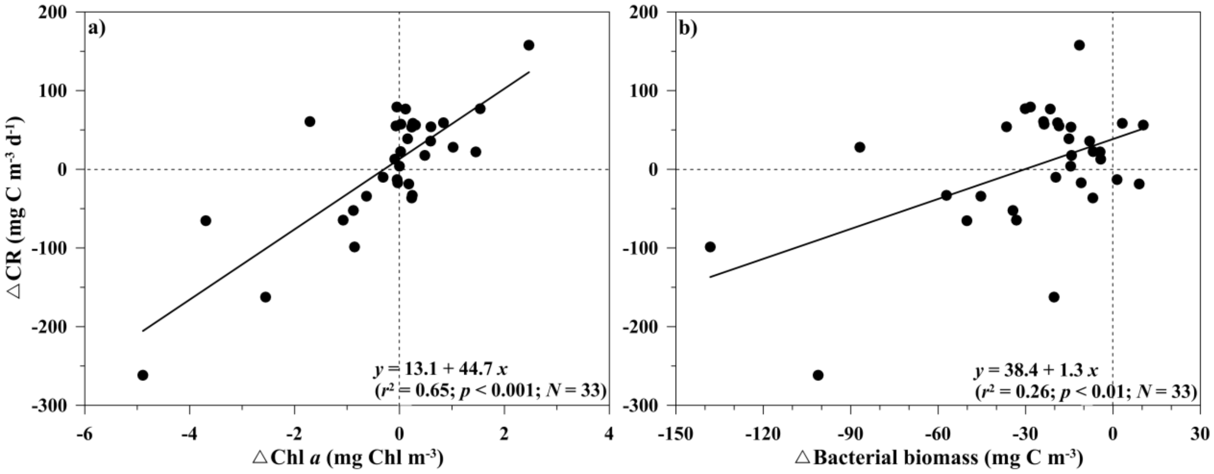
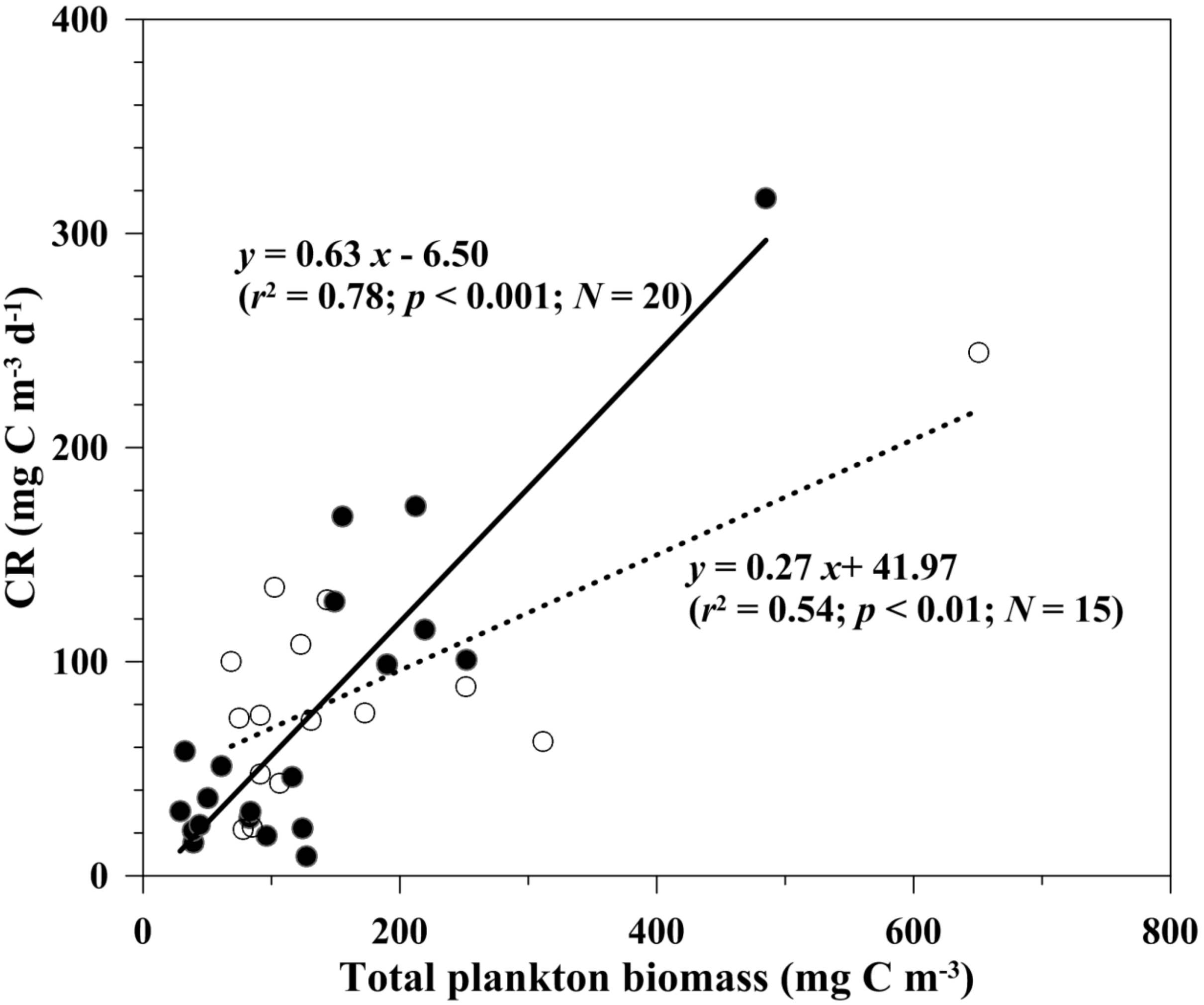

a)
△CR (mg C m-3 d-1)
200
100
0
-100
-200
-300
-6
-4
-2
0
2
4
△Chl a (mg Chl m-3)
y = 13.1 + 44.7 x
(r2 = 0.65; p < 0.001; N = 33)
b)
-150
-120
-90
-60
-30
0
30
△Bacterial biomass (mg C m-3)
y = 38.4 + 1.3 x
(r2 = 0.26; p < 0.01; N = 33)

Fig. 4



y = 0.63 x - 6.50
(r^2 = 0.78; p < 0.001; N = 20)
y = 0.27 x+ 41.97
(r^2 = 0.54; p < 0.01; N = 15)
CR (mg C m-3 d-1)
Total plankton biomass (mg C m-3)
0
100
200
300
400
0
200
400
600
800

Fig. 5

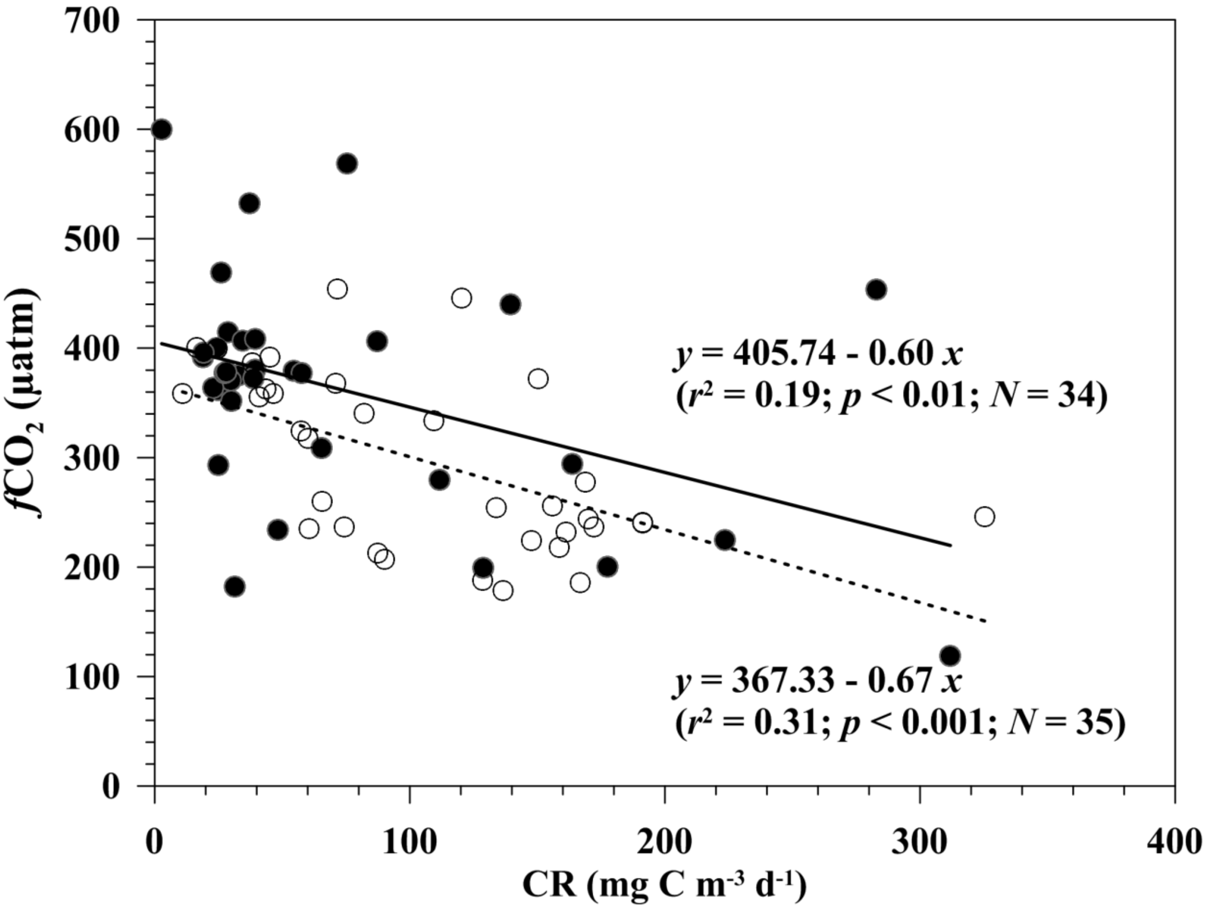
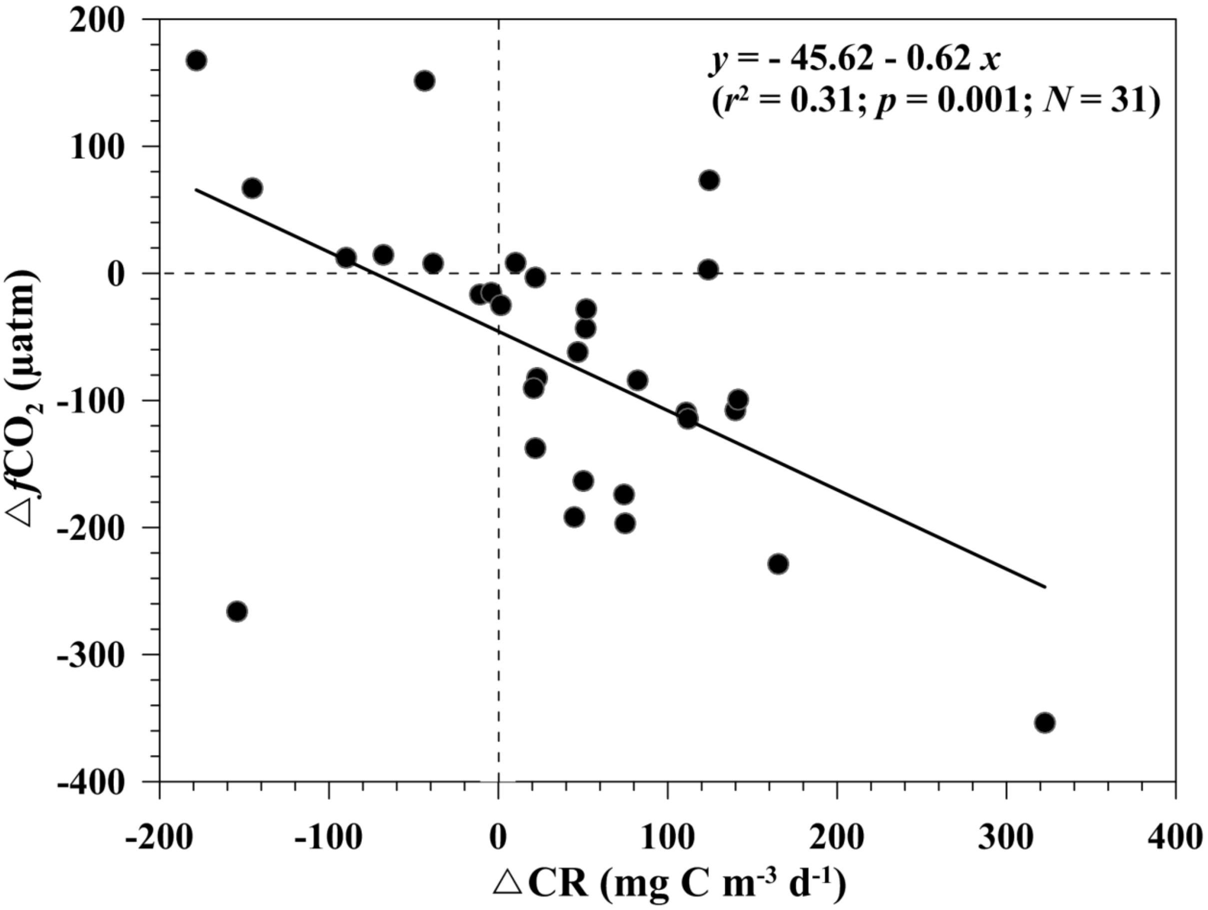

700
600
500
400
300
200
100
0
0
100
200
300
400
fCO$_2$ (µatm)
CR (mg C m^{-3} d^{-1})
y = 405.74 - 0.60 x
(r^2 = 0.19; p < 0.01; N = 34)
y = 367.33 - 0.67 x
(r^2 = 0.31; p < 0.001; N = 35)

Fig. 6


y = - 45.62 - 0.62 x
(r² = 0.31; p = 0.001; N = 31)
200
100
0
-100
-200
-300
-400
-200
-100
0
100
200
300
400
△fCO₂ (µatm)
△CR (mg C m⁻³ d⁻¹)

717 Fig. 7