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Interactive comment on "Distribution of Arctic and Pacific copepods and their habitat in the northern Bering Sea and Chukchi Sea" *by* H. Sasaki et al.

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We really appreciate for your thorough giving comments and helpful suggestion to our study by anonymous referee #2. As you pointed out, our results were obtained from 3-year dataset that includes 2-years (2007-2008) dataset used in Matsuno et al. (2011). Their result, however, mentioned year-to-year changes of mesozooplankon community and not to quantify relationships between the abundance of zooplankton and oceanographic features. We could show the possibility of increasing copepods with early sea-ice retreat quantitatively by using generalized additive models (GAM). Previous studies show the relationships between zooplankton community and water mass structure, however; most of them are presented using clustered water mass structure (Eisner et al., 2013; Ershova et al., 2015). It is difficult to integrate the clustered water

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mass into statistical models such as GAM. Therefore, we could quantitatively index water mass structure using principal component analysis. Integrating indexed water mass structure and sea-ice retreat timing into GAM, we could quantify the relationships between zooplankton abundance and environments in the northern Bering Sea and Chukchi Sea. Of course, our results support the previous published observations. These models could be developed to predict future zooplankton abundance. In this study, we couldn't find the depth where copepods much abundant because we use the abundance of copepods sampled using NORPAC net. Therefore, we assessed the abundance of copepods within whole water column and evaluate the relationships between their abundance and habitat. We use the water mass combination made by two-layered water column as one of the parameter presented the environment of habitat of copepods. As described below, I will revise our manuscript. RC, AR and RS stand for Referees comment, Authors response and Revised sentence, respectively. In addition, I will change the abbreviations of large and small Arctic copepods (Coparc L and CoparcS) to CopLarc and CopSarc, respectively. I carefully proofread English and revise the manuscript before the submission of the revised version.

Specific Comments: 1. Abstract [RC1-1] could be made shorter. The description of the method is too detailed and the part on the T, S and chl a analysis should be skipped. The methods are standard and the data are ancillary anyway.

[AR1-1] Yes. I will delete the detailed description of the part on the T, S and chla analysis. I will make abstract more shorter.

[RS1-1] The advection of warm Pacific water and the reduction of sea-ice extent in the western Arctic Ocean may influence the abundance and distribution of copepods, a key component in food webs. To understand the factors affecting abundance of copepods in the northern Bering Sea and Chukchi Sea, we constructed habitat models explaining the spatial patterns of the large and small Arctic copepods and the Pacific copepods using generalized additive models, separately. Copepods were sampled using NORPAC net. To quantify the structure of water masses, the density gradient as

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magnitude of pycnocline, and temperature and salinity in upper and bottom layers were scored along three axes using principal component analysis (PCA). The timing of sea-ice retreat was determined using satellite image. Integrating sea-ice retreat timing and the structures of water masses indexed by the scores of PCAs into GAM, we could quantify the relationships between zooplankton abundance and environments in the northern Bering Sea and Chukchi Sea. Obvious continuous relationships between the abundance of copepods and indexed water mass were observed. Large Arctic copepods were abundant at the station having high salinity water in bottom layer, but less abundant at the station having warm/fresh water in upper layer. Small Arctic copepods were abundant at the station having warm/saline water in upper layer and cold/high salinity water in bottom layer. In contrast, Pacific copepods were abundant at the station having warm/saline in upper layer and cold/high salinity water in bottom layer. All copepods were abundant at the station with early sea retreat. Our study might indicate potential positive effects of the reduction of sea-ice extent on the distribution of all groups of copepods in the northern Bering Sea and Chukchi Sea.

[RC1-2] Line 3: remove “i.e”

[AR1-2] I will remove “i,e”.

[RC1-3] Line 7: replace “by” by “using”

[AR1-3] I will replace “by” by “using”.

[RC1-4] Line 8: remove “in the seawater”

[AR1-4] I will remove “in the sea water”. I will delete this part from abstract.

[RC1-5] Line 10: remove “the” before “satellite” and put an “s “ at “image”

[AR1-5] I will remove “the” before “satellite” and put an “s “ at “image”.

[AR1-6] Line 11: What is magnitude of pycnocline?

[AR1-6] We described the density gradient as magnitude of pycnocline. We revised

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this sentence.

[RS1-6] To quantify the structure of water masses, the density gradient as magnitude of pycnocline, temperature and salinity in upper and bottom layers were scored along three axes using principal component analysis (PCA).

[RC1-7] Line 23: remove “the” before “sea ice” and replace “at earlier timing” by “early”

[AR1-7] I will remove “the” before “sea ice” and replace “at earlier timing” by “early”.

[RC1-8] The Conclusion reaches too far considering the results that are limited to the shallow (<60 m) Bering and Chukchi Sea. In the deeper Arctic Ocean proper, other important copepods like Calanus hyperboreus and Metridia longa dominate zooplankton biomass.

[AR1-8] As you pointed out, we should not mention the conclusion about bottom around this limited area, so this sentence will be deleted from the revised manuscript.

2. Introduction [RC2-1] The message could be straighten up. This is a very long first paragraph to introduce the subject and it covers a lot of ground. I think that it would gain by being more focused on the topic of the study. First sentence should be rewritten.

[AR2-1] Thank you for your helpful comment. The first paragraph will be deleted and a part of it will be integrated with the second paragraph. The new paragraph will be divided it in two paragraphs

[RS2-1] The northern Bering Sea and Chukchi Sea may be amongst regions where the seasonal sea-ice coverage has changed drastically in this decade (Comiso et al., 2008; Parkinson and Comiso, 2013), possibly because of the increase of the inflow of the Pacific water from the Bering Sea through the Bering Strait (Shimada et al., 2006). The Bering Strait is very shallow (< 30 m) and gentle shelf stretched to Arctic Shelf break through Chukchi Sea. These shallow shelf plays important roles in Arctic, food webs are short and efficient, even small changes in production pathways can affect higher trophic organisms (Grebmeier et al., 2006). The recent change of sea-ice melt

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timing contributes to stratification, the trapping of the nutrient in the surface and lower primary production with insufficient sunlight (Clement 2004). On the contrary, it is suggested that the timing of phytoplankton bloom is also altered (Kahru et al., 2011) and it increases the annual primary production (Arrigo et al., 2008). Changes of the timing and location of primary production and associated grazing by zooplankton have a direct influence on the energy and material transfer to benthic community (Grebmeier et al., 2010). In these Seas, the water masses have been identified based on salinity and temperature (Table 1). The water masses include relatively warm/low salinity Alaskan coastal water (ACW; temperature 2.0–13.0 âŮęC and salinity < 31.8) originated from the eastern Bering Sea; warm/saline Bering shelf water (BSW; 0.0–10.0 âŮęC and 31.8–33.0) originated on the middle Bering shelf; cold/higher salinity Anadyr Water (AW; −1.0–1.5 âŮęC and 32.3–33.3) originated from the Gulf of Anadyr at depth along the continental shelf of the Bering Sea; BSW and AW merged into Bering Sea Anadyr water (BSAW) (Coachman et al., 1975; Springer et al., 1989). Further, cold/lower salinity ice melt water (IMW; < 2.0 âŮęC and < 30.0) originates from sea-ice, and colder/high salinity dense water (DW; < −1.0 âŮęC and 32.0–33.0) formed in the previous winter during freezing over both Bering Sea and Chukchi Sea (Weingartner et al., 2013). These water masses often show vertical settings geographically and seasonally (Iken et al., 2010; Eisner et al., 2013; Weingartner et al., 2013).

[RC2-2] Line 5: “bloom” instead of “blooming”.

[AR2-2] I will replace “blooming” “bloom”.

[RC2-3] To me, formation of sea ice does not stabilize the water column but sea ice melt can contribute.

[AR2-3] Yes, as you indicted, sea ice melt can contribute stabilize the water column. We are sorry for my misuse of the term.

[RC2-4] Line 7: “progresses”? I don’t get it.

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[AR2-4] As you pointed out, “progress” might be wrong. However, I will delete this term along with the revision.

[RC2-5] Line 8: remove “the”

[AR2-5] I will remove “the”.

[RC2-6] Line 10: “to” instead of “the” before “stratification”, “nutrient trapping”

[AR2-6] I will add “to” and delete “the” before “stratification”, “nutrient trapping”.

[RC2-7] Line 12: remove “on” before “higher”

[AR2-7] I will remove “on” before “higher”.

[RC2-8] Line 13: Remove “The” before “change”

[AR2-8] I will remove “The” before “change”.

[RC2-9] Line 16: “to” after “leads”

[AR2-9] I will add “to” after “leads”.

[RC2-10] Line 21: remove “ been”

[AR2-10] I will remove “been” before “changed”.

[RC2-11] Line 25: “relatively warm” instead of “warmer”

[AR2-11] I will use “relatively warm” instead of “warmer”.

[RC2-12] Line 26: here and after put “oC” after the first range and not the second that relates to salinity. Otherwise 31.8-33.0 oC is indeed warm.

[AR2-12] We are sorry for my mistake. As you pointed out, I will modify them.

[RC2-13] Page 18664, line 1: remove “the” before “depth”

[AR2-13] I will remove “the” before “depth”.

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[RC2-14] Line 7: remove “the” before “both”

[AR2-14] I will remove “the” before “both”.

[RC2-15] Line 13: “are” instead of “could be”

[AR2-15] I will use “are” instead of “could be”.

[RC2-16] Line 17: the use of “quantify”? I wonder if “assess” would be better

[AR2-16] As you suggested, I will use “assess”.

[RC2-17] Line 20: remove “sized” after “large” and after “small”

[AR2-17] I will remove “sized”.

[RC2-18] Line 22: replace “distributed” by “abundant”

[AR2-18] I will replace “distributed” by “abundant”.

[RC2-19] Line 23: “Metridia” instead of “Meridia”. “Neocalanus” instead of “Neocalunus”

[AR2-19] We are sorry for my misspelling. I will modify “Meridia” to “Metridia” and “Neocalunus” to “Neocalanus”.

[RC2-20] Line 26: the inflow is not always warm.

[AR2-20] As you pointed out, Pacific inflow is not always warm, so we will delete “warm”.

[RC2-21] Line 27: sentence should be rewritten.

[AR2-21] As you suggested, I will rewrite the description.

[RC2-22] Page 18665, line 1: “their” instead of “its”

[AR2-22] I will use “their” instead of “its”.

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[RC2-23] Line 2: sentence should be rewritten for sake of clarity. Probably some redundancy with sentence at line 17 of previous page.

[AR2-23] As you pointed out, I will rewrite the sentence and delete line 17 of Page 18664.

[RS2-23] To predict these responses of copepods to the environmental changes from now on, it is important to quantitatively understand the spatial patterns of copepods and characteristics of their habitat.

[RC2-24] Line 7: The ship did not collect the data. Some parts of the last paragraph would probably fit better in the Materials and Methods.

[AR2-24] As you pointed out, the ship did not collect the data. We collected the data on the ship. We are sorry for my misuse. And, I will move the explanation of the survey methods to the section of Materials and Methods.

3. Materials and Methods

[RC3-1] Line 3: Again, it is not the ship by itself that conducted this sampling. "(1392t)" not useful.

[AR3-1] As you pointed out, the ship did not collect the data. I will delete "(1392t)".

[RC3-2] Line 10: "of" instead of "with"

[AR3-2] I will use "of" instead of "with".

[RC3-3] Line 12: "to" instead of "with".

[AR3-3] I will use "to" instead of "with".

[RC3-4] Line 12: "Depended on distribution, generation length and reproduction of copepods referred Falk-Petersen et al. (2009) and Dvoretsky and Dvoretsky (2009), and we summarized the copepods species into three groups :" This first part of the long is difficult to understand. It should be rewritten.

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[AR3-4] Thank you for useful suggestion. As you pointed out, I will reconstruct and rewrite the sentence.

[RS3-4] Falk-Petersen et al. (2009) and Dvoretsky and Dvoretsky (2009) referred the characteristic of distribution, length of generation and reproduction of copepods. In accordance with these two references, we summarized the copepods species into three group:"

[RC3-5] Line 16: Here and after: "s" at "occur". "Once" instead of "at one time"

[AR3-5] I will add "s" at "occur", and use "Once" instead of "at one time""

[RC3-6] Line 20: "using a" instead of "by"

[AR3-6] I will use "using" instead of "by".

[RC3-7] Line 21: "Water samples for chlorophyll a were taken with:"

[AR3-7] I will modify.

[RC3-8] Line 24: "with" instead of "by"

[AR3-8] I will use "with" instead of "by".

[RC3-9] Page 18667, Line 1: "obtained" instead of "calculated by using NASA Team

[AR3-9] I will use "obtained".

[RC3-10] Page 18667, Line 11: "environmental variables" instead of "environments"

[AR3-10] I will use "environmental variables" instead of "environments".

[RC3-11] Page 18667, Line 13: remove "them" after "defined"

[AR3-12] I will remove "them" after "defined".

[RC3-12] Page 18667, Line 19: remove "Given"

[AR3-12] I will remove "Given".

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[RC3-13] Page 18667, Line 21: “their” instead of “its”

[AR3-13] I will use “their” instead of “its”.

[RC3-14] Page 18667, Line 25: “s” at “image”

[AR3-14] I will add “s”

[RC3-15] Page 18668, line 20: “verify” instead of “verifying”

[AR3-15] I will replace “verify” to “verifying”

[RC3-16] Page 18668, Line 22: “Explained deviance”?

[AR3-16] This is correct. “Deviance explained ” is index of fitting and calculated as follows: (1- Residual Deviance/Null Deviance)*100 where Residual deviance indicates the deviance produced by the model that includes explanatory variables. Null deviance indicates the deviance produced by the model with out explanatory variable. If needed, I will add a short note on this Table.

4. Results [RC4-1] Divide the long first sentences into 2 sentences.

[AR4-1] I will think more constructively about your suggestion.

[RS4-1] The first principal component (PC1) explained 47.1% of total variability. In the score of PC1, the coefficient of loading was positive for d/dDmax, indicating that the magnitude of stratification increased with an increase in PC1. On the contrary, PC1 is strongly negative for TUPP and TBOT, indicating that the temperature in the whole water mass was lower with higher PC1 (Table 4).

[RC4-2] Page 18670, Line 10: “especially with”

[AR4-2] I will use “especially with”.

[RC4-3] Page 18670, Line 19: if Calanus glacialis is the only member of Coparc-L, why not keep its name instead of the less meaningful Coparc-L acronym?

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[AR4-3] As you pointed out, the name Calanus glacialis might be used in manuscript. However, we have divided copepods thorough the perspective of life history, so we wanted to use “Large” for C. glacialis, which have 2-year lifetime.

[RC4-4] Page 18670, Line 20: “represented” instead of “occupied”. “of the total abundance” after “%”. “was” after “and”

[AR4-4] I will use “represented” instead of “occupied”, and add “of the total abundance” and “was” after “%” and “and”, respectively.

[RC4-5] Page 18670, Line 22: I guess Coparc-S included other taxa than Pseudocalanus? Then what would be the point of mentioning that Pseudocalanus was included into this group? Or did the authors mean to indicate that Pseudocalanus dominated this group?

[AR4-5] The taxa included in Coparc-S are shown in Table 2. In this table, Pseudocalanus includes “undefined Pseudocalanus taxa”, not indicating “the group dominated by Pseudocalanus”.

[RC4-6] Page 18671, Line 9: “s” at “stations”

[AR4-6] I will add “s” at “station”.

[RC4-7] Page 18671, Line 10: remove “the” after “where”

[AR4-7] I will remove “the” after “where”.

[RC4-8] Page 18671, Line 20: “ranging” instead of “ranged”

[AR4-8] I will use “raging” instead of “ranged”.

5. Discussion

[RC5-1] Subsection 4.1. I think it’s a mistake not to start the Discussion with selling the most compelling results of the study. As it is now, it does not entice the reader interested in zooplankton distribution in the Bering-Chukchi region to read further. I would

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reshuffle altogether the information in this subsection of the Discussion to present it with the copepods distribution to describe in a more synthetic way their different habitat.

[AR5-1] Thank you for useful suggestion. As you pointed out, we will reconstruct Discussion and integrate this subsection with other two subsections.

[RC5-2] Subsection 4.2 Line 8: remove “were” after “species”

[AR5-2] I will remove “were” after “species”

[RC5-3] Line 11: “For example, large Arctic copepods (Coparc-L) were slightly abundant in the water with cold/lower salinity IMW at upper layer and the colder/high salinity DW in bottom layer corresponding to higher PC1 and low–medium PC2 and PC3, or cold/high–higher salinity BSAW and AW in both layer corresponding to medium PC1, medium–high PC2 and low–medium PC3.” I find this sentence terribly difficult to understand. The authors should try to rework it and avoid jargons in the Discussion. In general I find this first paragraph hard to read.

[AR5-3] We are sorry for our lack of explanation. As you pointed out, we have to reconstruct our explanation about the interpretation to avoid jargons.

[RS5-3] For example, large Arctic copepods (Coparc-L) were slightly abundant in the water with cold/lower salinity IMW at upper layer and the colder/high salinity DW in bottom layer (PC > 1, -1< PC2 < -0.8 and -1 < PC3 < 0), or cold/high–higher salinity BSAW and AW in both layers (-1.5 < PC1 <1, -0.8 < PC2 <1.2 and PC3 < -1).

[RC5-4] Line 16: “more abundant” instead of “concentrated”?

[AR5-4] I will use “more abundant” instead of “concentrated”.

[RC5-5] Line 20: But then, where do we go once this is said?

[AR5-5] We are sorry for lacking disruption. Calanus glacialis which categorized as Coparc-L in this study has been reported that they are abundant in the water mass

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with ACW at the upper layer and BSAW at the bottom layer (Eisner et al. 2013). Although Corarc-L is abundant in the water mass with BSAW/AW, they are not abundant in the water mass with ACW in our study. Our result slightly contradicts previous study, however, the presence of BSAW/AW is important for Coparc-L. I add the description on the revised manuscript.

[RS5-5] Coparc-L in this study has been reported that they are abundant in the water mass with ACW at the upper layer and BSAW at the bottom layer (Eisner et al. 2013). Although Corarc-L is abundant in the water mass with BSAW/AW, they are not abundant in the water mass with ACW in our study. Our result slightly contradicts previous study, however, the presence of BSAW/AW is important for Coparc-L.

[RC5-6] Line 24: “salinity” instead of “saline”

[AR5-6] I will use “saline” instead of “salinity”.

[RC5-7] Line 27: “Pseudocalanus” instead of “Pseudocalunus”

[AR5-7] We are sorry for my misspelling. I will modify it.

[RC5-8] Page 18674, line 9: ”Falk-Petersen”

[AR5-8] We are sorry for my misspelling. I will modify it.

[RC5-9] Line 10: “spring” and not “pring”

[AR5-9] We are sorry for my misspelling. I will modify it.

[RC5-10] Line 12. Pseudocalanus might not be able to accumulate as much lipids as Calanus but it can withstand the overwintering season in the high Arctic and it can feed on ice-algae (Hattori and Saito 1997). I don’t think that the argument presented by the authors is valid if Pseudocalanus spp. dominate the Coparc-S. Or the species are subarctic but then they should not be considered as arctic.

Hattori, H., and H. Saito. 1997. Diel changes in vertical distribution and feeding activity

of copepods in ice-covered Resolute Passage, Canadian Arctic, in spring 1992. J. Mar. Syst. 11: 205-219. [AR5-10] We really appreciate for your thorough comments and helpful suggestion to this part of discussion. As you pointed out, Pseudocalanus feed on ice-algae and can accumulate lipids to withstand the overwintering season in the high Arctic area (Hattori and Saito 1997), so we change the discussion as follows;

[RS5-10] In this study, the Coparc-S was dominated by Pseudocalanus such as Pseudocalanus acuspes, P. mimus, P. minutus, P. newmani, and undefined Pseudocalanus spp. (mean 72 % of the abundance of Coparc-S). Puseudocalanus distribute throughout the Bering Sea shelf and Arctic area (Frost, 1989). Because Pseudocalanus was suspected to due to the fact that is initially abundant in the warm water originated from Bering Sea, they were much abundant in the warm water such as ACW and BSW.

Frost BW (1989) A taxonomy of the marine calanoid copepod genus Pseudocalanus. Can J Zool 67:525–551

[RC5-11] Line 14: remove “s” from” zooplanktons”

[AR5-11] I will remove “s” from “zooplankton”.

Subsection 4.3

[RC5-12] The first paragraph is too long and too far from the results of this study. Start by presenting the findings of your study before spending a lot of time on other things such as timing of blooms. Furthermore, this topic has already ben touched upon in the Introduction.

[AR5-12] We really appreciate for your thorough comments and helpful suggestion to this part of discussion. We will delete the first sentence and reconstruct the paragraph.

[RS-5-12] In this study, the positive effects of earlier sea-ice retreat on the abundance of all copepod groups have shown in the result of GAM (Fig. 5). Especially, the effect of early sea-ice retreat for Coppac is more obvious than the two groups. Coppac typified by C. marshallae and N. cristatus are often transported from Bering Sea through the

Bering Strait (Lame et al., 2008; Hopcroft et al., 2010; Matsuno et al., 2011). Sea-ice reduction strongly related to the increase of the inflow of the Pacific water from the Bering Sea through the Bering Strait (Shimada et al., 2006). Increasing water mass transportation into Chukchi Sea (Woodgate et al., 2012), sea-ice retreat will enhance the invasion northward of larger Pacific water species. Our results might reflect this condition, future increases of advection from Bering Sea would carry more Pacific zooplankton through Bering Strait with even further penetration into the Arctic. For Coparc-L and Coparc-S that can reproduce in Arctic, temperature and food are important for their growth. It has been reported that a strong significant relationships between mean developmental stage of C. glacialis and surface temperature (Ershova et al. 2015). Early sea-ice retreat leads longer ice-free period and warm temperature. In our study, aTSR negatively correlated with Uavet and Bavet (= -0.59 and -0.69, spearman's correlation test $p < 0.001$), that is, the sampling stations with early sea-ice retreat have relatively high temperature and good for their growth. In Chukchi Sea, early sea-ice retreat cause spring bloom in open water (Fujiwara et al., 2015). For Copepods, the spring bloom is important as their energy source. Thus, earlier sea-ice retreat might have positive effects on growth and reproduction of copepods in the northern Bering Sea and Chukchi Sea.

[RC5-13] Page 18675, line 22: The lack of strong relationship between abundance of small copepods and phytoplankton may also be due to the fact that the coarse net (>300 μm) used does not sample quantitatively the young copepodite stages.

[AR5-13] As you pointed out, the young copepodite stages were suspected not to be sampled quantitatively by using the coarse net (> 300μm) such as NORPAC net used for our sampling. Therefore, we add the short note about it on the discussion part.

[RC5-14] Page 18676, line 2: "Falk-Petersen"

[AR5-14] We are sorry for my misspelling. I will modify it.

[RC5-15] Line 16: "shallower" and not "sallower".

[AR5-15] We are sorry for my misspelling. I will modify it.

[RC5-16] It is difficult to gauge the argument presented here because the authors don't give the minimum salinity in the shallower areas or the total copepod abundances. To some extent in deeper areas, there are more niches and thus more zooplankton.

[AR5-16] As you pointed out, it is difficult to lead our discussion from our result. As we mentioned in manuscript, it is the fact that the sampling stations near the land have relatively low salinity (= 0.53, spearman's lank correlation test in SUPP vs. Bdepth $p < 0.01$). The low salinity area, however, was located not only near the land also near sea-ice. Therefore, it is not enough to explain the reason why copepods are less abundant at shallower area. In this survey, because shallower area correlated with longitude (= -0.73 spearman's lank correlation test in longitude (oE) vs. Bdepth $p < 0.001$), the result was simply interpreted that copepods less abundant near the land. As shown in Figure 5, the least number of copepods are recorded at sampling station of 25 m Bdepth. Except for these two stations, Coparc-L is not so much related to Bdepth, while Coppac and Coparc-S is gradually increasing with depth. We will change the discussion.

[RS5-16] In this survey, because shallower area correlated with longitude (= -0.73 spearman's lank correlation test in longitude (oE) vs. Bdepth $p < 0.001$), the result reflects that copepods less abundant near the land. As shown in Figure 5, the least number of copepods are recorded at sampling station of 25 m Bdepth. Except for these two stations, Coparc-L is not so much related to Bdepth, while Coppac and Coparc-S is gradually increasing with depth.

[RC5-17] Line 19: remove " and its communities". "has" instead of "have"

[AR5-17] I will remove "and its communities" and replace "have" "has".

Interactive comment on Biogeosciences Discuss., 12, 18661, 2015.