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Biogeosciences Discussions

Interactive comment on "Arctic (Svalbard Islands) Active and Exported Diatom Stocks and Cell Health Status" *by* Susana Agustí et al.

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Actions taken to accommodate the comments of reviewer #2.-

Reviewer#2- This MS sheds a light on the role and fate of diatoms over a course of a spring bloom in the Arctic Ocean, based on the estimates of their mortality, senescent rate, and the population with fast sinking rate. These estimations were designed to test a hypothesis in which Si-depletion triggers (1) senescence of diatoms and (2) selective sinking of the dying population. Because of intense CO2-sequation in the Arctic Ocean, this hypothesis is valuable to be tested, but the results in this study unlikely support this hypothesis.

Authors: We thank you the reviewer for the useful comments and the time devoted to

revising the manuscript. We agree that the results presented are limited in terms of testing the hypothesis of a direct relationship between the percentages of living cells, whether found at the photic layer or exported, with Si-depletion, as a direct link with Si depletion can be suggested, but not demonstrated, since nitrate levels were also low when Si was depleted (as also pointed out by rev. #1). Instead, our study provides a more reliable test of hypothesis (2). We have now revised this manuscript to focus on hypothesis (2), while more broadly suggesting that nutrient – not exclusively Si – depletion leads to senescence of diatoms. As a general comment we also outline the inherent difficulties of addressing questions on diatom blooms in the Arctic that require direct sampling. Ship time is typically secured 2 years ahead and there is no margin to accommodate to the nuances encountered every year, which involve different phenology of the blooms and unpredictable seaice conditions. Hence, such cruises need be adaptive, more so because the goals of all other teams sharing ship time are adaptive themselves. Conducting such studies in polar waters, on which we are highly experienced (both Arctic and southern Ocean), involves, therefore, considerable doses of contingency. For instance, the reviewer raises, rightly so, concerns on the reliability of the experiments, since often a single experiment was conducted. We would have liked to conduct many more experiments, but this was precluded by operational reasons. We have, thus, toned down the conclusions derived from the experiments, and used them more as supportive evidence for the collective insights derived from the entire set of measurements, rather than stand-alone evidence. Action: We modified those paragraphs related to hypothesis (1) to increase clarity, as follows: -In the abstract, pg 1, lines 35-37. We corrected the paragraph that now reads: "The results conform to a conceptual model where diatoms grow during the bloom until resources are depleted, and support a link between diatom cell health status and sedimentation fluxes in the Arctic." -pg. 7, lines 24-30. We modified the discussion as follows: "When compared across the contrasting stages of bloom development represented in the data set analyzed here, the results presented conform to a conceptual model where nutrients, including Si (Rey 2012; Krause et al., 2018), and mixed layer drives the growth of di-

atoms during the Arctic spring bloom (Wassmann et al., 1997; Reigstad et al 2002). For diatoms, Si depletion results in two potential physiological issues: yield limitation (i.e. diatom standing stock is too high to be supported by the available silicic acid) and intense kinetic/growth limitation (i.e. depleted silicic acid silicic acid limits diatom Si uptake to such a degree that growth must slow, Krause et al., 2018)." - and in pg. 8, lines 28-29 : "Deterioration of diatom health, such as occurring when reaching acute silicon or other resources limitation along the spring bloom,. . .".

Reviewer#2 For example, high % living diatoms in the upper layer was achieved at Stns 6, 7 and 8 with low silicic acid concentration, but this result doesn't meet (1). It could be explained, at least partly, by rapid selective sinking of dead populations as shown in Fig. 5. But, low % living diatoms at Stn. 4 with high silicic acid concentration wasn resulted from shift of equilibrium point between mortality rate and sinking rate toward higher mortality than at the stations with high % living diatoms, again far away from (1).

Authors: We agree that the results presented do not suffice to identify Si limitation; a diagnosis of whether Si limits diatom production should be accompanied by additional analyses and experimental additions. In the manuscript of Krause et al. 2018, kinetic data during the same cruise indicated that in three of four experiments KS (half-saturation constant for Si(OH)4) was approximately 2.0 μM, indicating that Si was already exhausted in the stations showing the higher biomasses. In the Polar Front we observed a situation of post-bloom, and Ks there was found to be lower. Action: We revised the manuscript and modified the text in the discussion, and more broadly referred to nutrient, rather than just silicon, limitation. We added a paragraph in the discussion, indicating the situation at the different stations sampled, concerning the environmental conditions found including mixing (as suggested by reviewer #2) and the health status of the cells: - In pg. 7 lines 10-20, the new paragraph reads: "Quantification of the % of living cells helped identify the different stages of the arctic spring bloom at the stations sampled. A pre-bloom situation, characterized by low cell abundance and a small percentage of living cells, was found at station #4, located further west off Svalbard

Islands, where silicic acid and nitrogen concentrations were high and the UPM was deeper than in other arctic stations. The healthiest diatom community was observed at station #5, where the high stratification and Si(OH)4 concentration above the half saturation constant (Ks) of 2 μM (from kinetic experiments in the same region by Krause et al. 2018) helped the diatoms support active growth. The highest cell abundance was observed at station #8, but the lower % of living diatoms and the Si(OH)4 concentration well below the Ks value indicated that the bloom was reaching the maximum capacity, although diatom sinking was still low. A post-bloom situation was identified at the polar front community, with similar percentages of living cells at the photic and aphotic zones as a result of high sinking induced by Si and nitrogen limitation."

Reviewer#2.- I am a little bit concerned about reliability of the incubation experiment because of lack of positive control (light incubation). My question is if senescence was actually induced by darkness, despite of low silicic acid concentration and difference in incubation temperature from sampling temperature. -Authors: We agree that the incubations could inform on the mortality when reaching the aphotic zone, but do not represent the response to "darkness" due to the lack of a parallel light control. Action: We modified the text to reduce the emphasis on "darkness" and clarify that those incubations may represent the response to the environmental conditions below the photic layer, that involve darkness and other changes. In pg 6, lines 25-26: "The experiment testing diatom survival in aphotic zone light conditions conducted indicated that once diatom cells sink below the photic layer, they would die rapidly." In pg 7, lines 4-6: "Moreover, our experimental assessment of diatom survival incubated at aphotic conditions suggested that once sinking below the photic layer, diatoms cells could die at half-lives of 21.8 to 30.2 hours across species." In pg 12, in the Figure 6 heading: "Decay in the cell abundance of living (blue diamonds) and total cells (orange squares) of arctic diatoms when exposed to aphotic zone light conditions."

Reviewer#2.- Also, I am concerned about reproducibility of the results from the sinking experiment. But, large variation in % living of aphotic diatoms is very interesting

and dose it relate to selective sinking of dying/dead population? A unique feature of this study is collection of natural microphytoplankton community by the Bottle-Net, and thus I would like to suggest to conduct more detailed species-level analysis to test the hypothesis or put aside the hypothesis. -Authors: We agree that more sinking experiments will be convenient, but we were not able to duplicate the sinking experiment because the column was used by the zooplankton group for sampling marine snow, and our experiment required more than 48 hours to be completed. Provided we present a single experiment, we have toned down the conclusions and use the experiment as an additional source of evidence, rather than a conclusive demonstration on its own right. - We agree with the reviewer that the presentation of results from the experiment we were able to conduct would benefit from adding more detailed information at the species level in the results. Reviewer #1 also suggested to add more detailed results, and we added more detailed data in the revised manuscript at the taxonomic level. Action: -We added a new Figure to the revised manuscript where we show the composition of the diatom community in the photic and aphotic layers. This is the new Figure 4, in the revised manuscript. In pg. 5-6, lines 33-38, 1-4, we indicated: "The diatom community at the beginning of the cruise was dominated by Fragilariopsis spp. and Chaetoceros spp., and changed at stations 6-7-8 to communities dominated by Fragilariopsis spp. and Thalassiosira spp. that dominated the biomass where the largest diatom bloom was found (station #8, Fig. 4). Community composition changed at the Polar Front and Barents Sea stations (Fig. 4) with a larger contribution of Navicula pelagica (included in "Other", Fig. 4). The diversity of the diatoms found at the aphotic zone differed in several stations from that found at the photic layer (Fig. 4). The large celled Thalassiosira sp. colonies dominated the aphotic community in several stations although they were not dominant at the photic community (Fig. 4). At station #4, the community sampled was more diverse at the aphotic than at the photic layer (Fig. 4) indicating high sinking despite the low biomass." - We changed the old Figure 4 to show a new Figure 5, with two panels. Panel (a) shows the proportion (mean $\pm$ SE) of the water-column population stock found in the aphotic zone for the different diatom taxa.

Panel (b) the relationship between the percentage of living diatoms cells in the photic layer and the proportion of the water-column population stock found in the aphotic zone but for all the dominant taxa. The new figure is more informative and highly significant (R2 of 0.39 and p< 0.001). - In pg. 6 lines 4-16, the revised text was also modified as follows: "The stock of diatoms that had sunk below the photic layer comprised, on average, 24.2 $\pm$ 6.7 % of the total water column stock, with this fraction ranging considerably between groups (Fig. 5). The proportion of biomass of the large celled Thalassiosira colonies that had sunk below the photic layer was the largest, and that of Chaetoceros spp. the smallest (Fig. 5). Station #4 in pre-bloom status showed the larger proportion of the biomass below the aphotic layer and station #8, supporting the largest diatom bloom, the lowest. At station #8, however, the population of the dominant Thalassiosira species contained 54.8 % of living cells and was paralleled with a significant contribution of dead cells at the aphotic layer (Fig. 4), suggesting the initiation of the collapse of the bloom despite the considerable biomass standing in the photic layer. Similarly, Fragilariopsis senescence at the photic layer of station #3 (only 35.1 % of cells were alive at the photic layer) helps explain its larger contribution at the aphotic layer (Fig. 4). There was a significant negative relationship between the percent of the diatom stock population that had sunk below the photic layer and the percent of living cells in the photic layer (R2 = 0.39, P <0.001, Fig. 5b), indicating that healthy, actively growing populations largely remain in the surface, whereas senescent ones sink out of the photic layer. "

Specific comments

Reviewer#2.- Incubation experiment: How did Authors get a highly active population (93.3% of % living) besides moderate % living population (average, 59.4%)? Authors: We agree that the information was presented in a confusing manner. It was provider in the methods section and it is the mean corresponding only to the two dominant species. The communities were sampled at Erik Eriksen Strait where the % living cells of 70% was higher than the cruise average of 59.4%. Action: We removed this information

from the methods section to avoid confusion.

Reviewer#2.- % biomass in aphotic zone: Values in text and Fig. 4 seem not to meet the results in Table 1, if they are calculated as the ratio of Aphotic diatoms/(Aphotic diatoms + Photic diatoms), and the axis titles of Fig. 4 seem to be inverted. Please check them. But I would suggest to delete Fig. 4, because a negative correlation appears to be achieved by only one result of Stn 4. Authors: The original Figure 4 showed the average values obtained for the dominant species at each station. This explains the mismatch observed by the reviewer between the data in Table 1 and those in Figure 4. Action: We revised and reorganize this information for consistency. Action: As indicated above, we modified Figure 4 in the revised version of the manuscript, showing now the relationship of the dominant diatom groups (new Figure 5). This relationship is stronger and is based on a larger number of data. We also revised and corrected some typos in the Table.

Reviewer#2.- Why was the upper sampling depth of some aphotic samples (Stns 4, 5, 7 and 8) set at deeper than 10 m below of the lower sampling depth of the upper layer? Authors: Those stations were strongly stratified as observed in the CTD profiles of fluorescence and light, and 10 m separation was enough to perfectly separate the sampling of the two layers to ensure samples did not overlap.

Reviewer#2.- Do the terms of “upper layer”, “photic layer” and “the surface layer” mean distinct depth zones? Action: We agree, and have revised the manuscript to used “photic” throughout.

Reviewer#2.- Table 1: Chlorophyll a concentrations and mixed layer depth are valuable for understanding the status of the study site. Action: We calculated and added data of the upper mixed layer (UPM) for each station in the revised Table 1. We do not have the data of chlorophyll a concentration for all the stations, as this was not analyzed for all the stations. We provide the data on the abundance of cells, as it is a good indicator of the phytoplankton biomass at each station, and also add the range in Chla values

obtained during the study in the results section.

New plots are copied below

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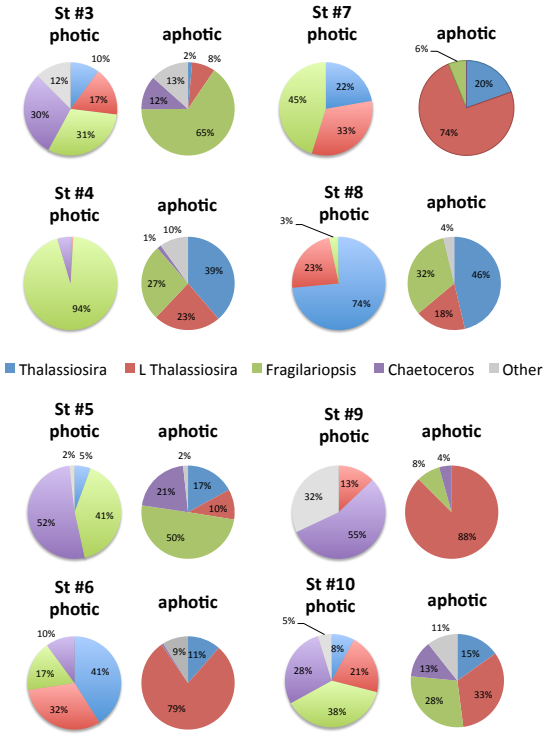

Fig. 1. New Figure 4: Pie charts showing the diatom community at the photic and aphotic zones. The colors correspond to different taxa

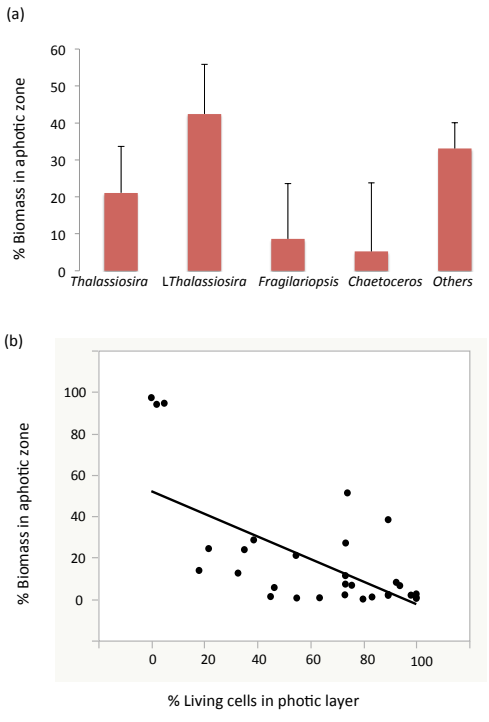

Fig. 2. New Figure 5: with new plots (a) and (b)