Anonymous Referee#1

General comments:
This is a very important paper for the marine silicon biogeochemical community. The data presented on the silica cycle in the ultra oligrotrophic South Pacific are the very first from this region and thus extremely valuable. While the extremely low biomass and silica production rates are not surprising it is extremely important that they be quantified. Those data aid in our understanding of the contribution of subtropical gyres to global silica standing stocks and silica production. While I am 100% in favor of seeing this data published it was disappointing that silica production rates were only measured at two truly oligotrophic stations. So while the authors use these data to place the observed rates in a global context the extrapolation is extreme as fully acknowledged by the authors. The authors were able to conduct some very fine kinetic studies that show active silicic acid uptake by the < 2 µm size fraction. Few diatoms would be expected in this size fraction pointing to uptake by non-diatoms. There is significant confusion as to the kinetic experiments in terms of size fractionation that must be clarified before publication. More on that below. The quantitation of diatom taxa and abundance is extensive and valuable. I have no major issue with the interpretation of the data or the analyses. My suggestions for improvements are detailed below.

Specific comments: The title of the work emphasizes the finding that a significant fraction of the observed uptake was in the picoplankton size class. The paper contains so much more than this. Please consider expanding the title to something like “Silicon cycle in the Tropical South Pacific: contribution to the global Si cycle and evidence for an active pico-size siliceous plankton”.
Thank you for your suggestion, we have corrected the title accordingly.

Line 40: This paragraph is very long. Maybe break it at line 40.
Corrected.

Line 42: The data available from the north Pacific subtropical gyre cited later in the paper would be relevant here as well.

Line 40-56. This is a suggestion only. Our understanding of the role of subtropical gyres in the global Si cycle began in the Sargasso Sea which through extrapolation led the fairly high estimates for the contribution of these regions to global silica production. Data from the north Pacific led to a reduction in that estimate and the data presented here from the south Pacific lower it yet again. So what we are learning is that the Pacific is very different form the Atlantic and that the North and South Pacific differ from each other. This perspective is lacking in this paragraph which focuses on extrapolating silica production to carbon. It might be worthwhile to add a section that stays focused on silicon as later in the paper silicon budgets are presented.

Indeed, we agree with both previous comments, and see how this persective is lacking.

We have rewritten that part of the introduction section as follows :

"Diatoms are known to contribute more importantly to primary production in meso- to eutrophic systems, yet several studies have emphasized that even if they are not dominant in oligotrophic regions, they may still contribute up to 10-20 % of C primary production in the Equatorial Pacific (Blain et al., 1997). In the oligotrophic Sargasso Sea (BATS station), their contribution was estimated to be as high as 26-48 % of new annual primary production (Brzezinski and Nelson, 1995) and to represent up to 30 % of Particulate Organic Carbon (POC) export, leading to an upward revision of the contribution of oligotrophic gyres to global Si budgets (Nelson and Brzezinski, 1997). Similar studies carried out in the Northern Pacific (HOT station) led to new estimates, as diatoms were found to be less important contributors to primary production. A combination of both Atlantic and North Pacific oligotrophic gyres budgets led to a revised contribution of 13 Tmol Si y^{-1}, a 51 % diminition of the previous estimate (Brzezinski et al., 2011)."

And in the conclusion:
"The mid-ocean gyres contribution to Si production was recently revised down to 5-7% of the total by Brzezinski et al. (2011) building on estimates from the North Subtropical Pacific Gyre. The present study points to even lower values for the South Pacific Gyre, confirming its ultra-oligotrophic nature, and should further decrease this estimate. These findings underscore the differences in functionning of different subtropical oligotrophic gyres between the North Atlantic, North Pacific and South Pacific and clearly warrant for improved coverage of these areas and for more complete elemental studies (from Si production to export).

Line 58: maybe 'studies provide evidence for a role. . .' rather than 'studies have furthermore evidenced a role'.
Corrected.

Line 75: Maybe '. . .strategies and analyses were conducted on both cruises. . ." rather than ". . .strategies and homogenous analyses were conducted . . .".
Corrected.

Line 85, 86: Maybe ". . . transects that employed a common sampling strategy of short and long duration stations." Rather than '. . .transects with similar sampling strategy of short and long duration stations."
Corrected.

Line 99: Given the very low nutrient concentrations it the reader would benefit from knowing the detection limits of the specific nutrient analyses employed.
The following line was added : "During BIOSOPE, nitrate (NO3-) detection limit was 0.05 µM (accuracy of ± 0.05 µM), phosphate (PO43-) detection limit was 0.02 µM (accuracy of ± 0.05 µM), orthosilicic acid (Si(OH)4) detection limit was 0.05 µM (accuracy of ± 0.05 µM). During OUTPACE the quantification limit was 0.05 µM for all nutrients."

Line 119: ‘quarters’ instead of ‘4’. ‘Plastic’ petri dishes right?
Corrected.

Line 127: What method was used to remove the interference from HF in the LSi colorimetric analysis: boric acid or dilution?
HF is diluted in filtered boric acid in our protocol. Added.

Line 131: Kinetic assays? Do you mean you conducted time courses to test the efficiency of different digestion times?
We meant that kinetic assays of the first NaOH extraction were carried out to determine on a few samples the optimal extraction time when all BSi is digested and prior to the linear increase of DSi showing the subsequent leaching of LSi. We have modified the sentence as follows :

“This is particularly the case when high LSi concentrations are present. Kinetic assays of orthosilicic acid were conducted in some samples from the Marquesas, Gyre, East-Gyre and near Upwelling stations during BIOSOPE to determine the optimal extraction time for BSi digestion, and results revealed negligible LSi interferences after an extraction time of 60 min.”

Line 138-139: Please elaborate. It is unclear how the addition of Si was used to correct for dissolution in the face of the combined influence of dissolution of captured siliceous particles and the admixture of ambient water.
This section has been detailed as follows : “Biogenic silica export fluxes were determined from drifting sediment traps deployed for 4 consecutive days at three depths (153, 328, 519 m) at the three long duration stations of the OUTPACE cruise. For each trap samples, 160 mL were filtered onto 0.6 µm polycarbonate membranes and the filters were treated following a two-step digestion as described above. In addition to the BSi measurements, the dissolved Si measured directly in the supernatant of each trap at the time of subsampling minus the initial dissolved Si content in the seawater used to fill the trap was added to the final BSi concentrations, to account for BSi dissolution in the trap samples during storage. This step proved necessary, as BSi dissolution ranged between 16 and 90 % depending on the samples.”

Line 141 Si & VSi rather than Si/VSi. Si/VSi looks like you are dividing one rate by the other. Line 150: ‘averaged’ instead of ‘average’
Corrected.

Line 151. Many details are missing from this section of the methods. There is no indication of size fractions. Later in the paper it is claimed that kinetics were size fractioned like biomass, but I only see one set of kinetic curves and it is not clear what size fraction they represent (Fig 8.). Also in this section there is no mention of a 32Si addition.
We had mentioned that samples for kinetic curves were treated as described for in situ

samples (i.e. received a spike of 632 KBq and were filtered onto stacked 0.2, 2 and 10 µm filters). However due to experimental problems during filtration for the kinetic experiments, we have decided to remove the kinetic section alltogether (see below for further details).

Lines 187-196. The observation that the nitracline is much deeper than the silicicline is also observed in the Sargasso but not nearly to the same extent. It might be interesting to speculate as to why these depths differ in the discussion.
This difference is mostly the case during BIOSOPE, and could be the result of the strong Si-pump operating in the coastal upwelling, leading to advection of low-Si waters westwards towards the gyre (Dugdale and Wilkerson, 1998). However, the discussion part of this paper is dedicated to budgets, diatom community and evidence for Si uptake in the picosize fraction, hence bottom up control factors, linked to hydrology are not a key point of this paper. We feel it would be out of place to start this in the discussion.

Line 198: rather than 'The distribution of orthosilicic acid concentrations were less clearly contrasted, . . .' maybe 'Horizontal gradients were not as strong for orthosilicic acid. . ..".
Corrected.

Line 211: 'existed" rather than 'subsisted"
Corrected.

Line 212: "magnitude" instead of "amplitude".
Corrected.

Line 216: Maybe:" The Chla a distribution during BIOSCOPE was similar to that observed during OUPACE with extremely. . ."
Corrected.

Line 238: The units in the figures for BSi and LSi are in micromoles per liter whereas in the text the concentrations are discussed as nanomoles per liter. Be consistent. I would suggest changing the figure to nanomoles per liter as it gets rid of leading zeros.
The BSi/LSi figures have been changed to nmol L-1 to be consistent with text and the color bar increased in non linearity to better show low concentrations.

267: Maybe "LSi concentration was highest at both ends of the transect but concentrations remained below those of BSI with average LSi values. . ."
Corrected.

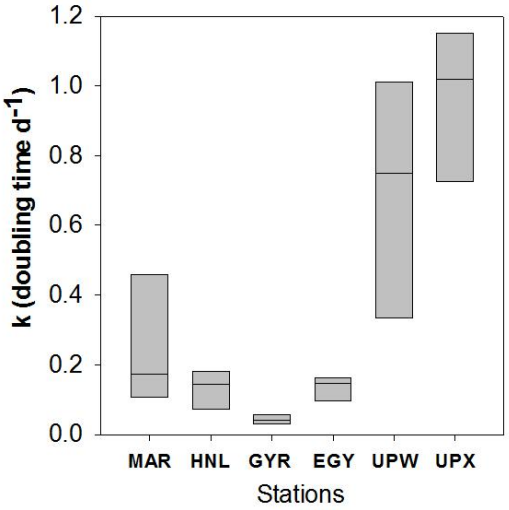
Line 271: Here the reader learns that kinetic experiments were size fractionated. Move this information to the Methods. More importantly only one size fraction is shown in fig 8. Where is the data from the other fraction? Also the legend for Fig 8 should indicate the fraction shown.

According to your comments and some other reviewer's comment on too high VSi values,

we have gone back to our raw data and found some inconsistencies in size-fractionated filtration between rSi and BSi. Some filters for rSi retained too much 32Si (either due to clogging or uncareful rinsing of samples), yielding too much rSi over BSi explaining the high VSi values. If the shape of the kinetic uptake is globally fine, we acknowledge this problem, but unfortunately see no way of correcting the data adequately. We have thus chosen to remove these data entirely.

Line 273; Maybe ". . . rank order of most productive stations follow the pattern observed for BSi with the highest values observed at UPW followed by UPX and MAR stations."
Corrected.

Line 281: It might be useful to readers if the specific rates are also translated into implied doubling times as this will give a sense of how fast or slow growth might be in the various areas.
Figure 8 (former kinetic figure) was replaced with the following showing K (doubling time) for each station.



Line 295: It is unclear what size fraction is shown in the Fig 8. Fix legend. Also where is the data for the other fraction. Please clarify.
It was the 0,2-2 µm size-fraction, but this figure has now been removed as explained above.

Line316: Maybe "the lowest" rather than"record low".
Corrected.

Line 359-360: Maybe "We obtained size-fractionated biomass and . . . OUTPACEprogram and size fractionated production. . .during the BIOSCOPEprogram.
Corrected.

Line362: This is a long paragraph. Maybe break here.
Corrected.

Line377: “documented” instead of “evidenced”
Corrected.

Line387: Here is a place where the influence of data from the Pacific on global budgets can be emphasized. The contribution fell when data from the NPSG was added and now it goes down again when the south Pacific is considered.
We have added this reference in the following sentence : “ This budget has been recently revised down to 13 Tmol Si y-1 when considering budgets from the North Pacific (Nelson and Brzezinksi, 1997) reducing the contribution of subtropical gyres to 5-7% of global marine silica production (Brzezinksi et al., 2011; Tréguer and de La Rocha, 2013).”

Line390: The limited number of measurements is disappointing, but treated objectively.
We agree. Unfortunately the extent of funding at the time of the cruise and available quantity of 32Si did not allow for more sampling, nor replicate measurements.

Line 408: The flux is indeed incredibly low: wow! However, my appreciation of this is vague given that I do not understand the correction for dissolution in the traps discussed above.
This has been corrected as described above (answer to comment on lines 138-139).

Line 426: Maybe: DCM’s are common in mid-ocean gyres and are known to be often dominated by pico-sized phytoplankton (Chavez et al. 1996), Studies documenting. . .. . .”
Corrected.

Line 448: As I read this discussion I find the text informative but I wonder if the stated trends might be reinforced through a non-dimensional scaling or other analysis that would provide an objective way to illustrate many of the inferred trends.

As we give mean and SD values for each zone, we feel that it is sufficient to characterize each region (that are defined hydrologically), as we are not trying to show any statistical differences between regions.

Line490: This is a very long paragraph. Maybe subdivide.
Corrected.

Line 542: Somewhere in this section the differences between the shape of the kinetic curves obtained herefor pico-size fraction and those for cultured Synechococcus should be discussed. In culture Synechococcus have linear uptake kinetics within the concentration range examined here whereas the data from the South Pacific clearly show a hyperbolic response. It’s difficult to know for sure, but it might be possible that the organism responsible for Si uptake in the small size fraction in the South Pacific is something other than Synechococcus which would be very interesting.
These kinetics have been removed and can therefore not be mentionned in the discussion.

Line 545-546: Confusing sentence. Maybe “Significant BSi in the pico-sized fraction could be explained as an artifact from detritus or the contribution from a previously unrecognized taxa.”
Corrected as follows: “The significant contribution of the pico-size fraction to the BSi stocks during both cruises could be explained by the presence of detrital components, however its contribution to Si(OH)4 uptake during BIOSOPE was really surprising but can be explained in the light of new findings”

Line 552 “by” rather than ‘with”
Corrected.

Line 555: To finish this argument the expected shape of a curve resulting purely from fragments should be given. I would think the signal would then be very noisy and inconsistent which is not observed.
Corrected as follows: “If the former hypothesis was true, we would expect approximately the same amounts of broken fragments on all filters (i.e. for each increasing Si concentrations) and the shape of the curve would not be hyperbolic.”

Interactive comment on “Silicon cycle in the Tropical South Pacific: evidence for an active pico-sized siliceous plankton” by Karine Leblanc
et al.
Anonymous Referee #2

This is a good paper with timely and relevant information on a poorly studied region of the ocean. It has a both rate/biomass information along with floristic data, a combination not often available. It is unfortunate that the gyres had only a limited sampling.
The data is tantalizing in what is seen, but more sampling in this area is required to confirm the extremely low rates. It is a great deal of information to present and there are some areas where either the paper structure or text is confusing. As I note below, the methods need considerable improvement. The description of replication and error bars is unacceptably vague. Claims of differences are not justified by any statistical analysis. There are very few measures of variability given and reader is left to wonder if replicates were even collected. Each measurement should have a standard deviation, confidence interval or some other metric of variability. The methods need to explicitly note which samples were collected in duplicate, triplicate, etc. On line 150, the uptake measurements were noted to have a precision of 10-25% for the less productive station. What is it for more productive stations? To me, the use of separate figures for hydrology, nutrients, BSi, and rates creates difficulty in interpreting the information. Multiple pages of figures are needed to understand one cruise. It would be much more clear if all the data were in a single (or perhaps 2 adjacent) multi-panel figures. However, it requires a rewrite of the manuscript to discuss each cruise in parallel rather than dealing with hydrology, nutrients, etc from the two cruises together. Since the cruises are very separate in time and space, there is no reason to treat one data type at a time.
As the focus of this paper was to established basin/regional budgets for Si, we felt that discussing each parameter together, despite the temporal gap between the two cruises was more appropriate than presenting both cruises one after another, to get a sense of regional variability and that this would feel less repetitive for the reader.

Cell counts are very time consuming and tedious. Thus, it is always disappointing when the information is lumped into a single pool of diatoms in Figures.
We do have cell abundance per species, but first, the data set for the BIOSOPE cruise was already published once in Gomez et al . 2007 in a different form but with extensive tables of diatom taxa list (Table 2 therein). The data from OUTPACE is also available which is how we managed to estimate C biomass from each taxa and calculate relative contribution to POC in %. We felt that adding yet another graph with species relative contribution which requires a long legend and many colors to convey diatom diversity was not absolutely necessary within the scope of this paper, and that Fig.9 and Table 2 were sufficient. But since the data is available we have added a link for data access in the data availability statement.

From the methods, it is quite impossible to determine if diatom counts were from the same depths as the BSi or a subset.
Diatom cell counts were done on the same Niskins as BSi/LSi measurements. We have

added the following “Seawater samples *collected from the same CTDs and Niskins as particulate Si samples* were ...”

Please clarify this. If the data density is there, please add this to the figures as a contour plot.
Potential density isolines were added to Figures 3 and 4 as white contour overlays.

The data availability statement is not present nor is there an explanation of why it is not present. This is not acceptable and I cannot recommend publication until this condition is met (as noted in the Instructions to Authors for the journal).
This is an omission. The following statement has been added.
“Data is available upon request through both cruises databases. For the OUTPACE cruise, see http://www.seanoe.org/data/00446/55743/
For the BIOSOPE cruise, see: http://www.seanoe.org/data/00446/55722/
These links will be running very shortly and before resubmission of revised version.

The figures lack panel labels except for Fig. 7. This needs to be corrected for publication.
This was added to all Figures and Figure legend.

Paragraph breaks need to be used for clarity, be they line spacing or indentations.
This has been corrected on several occasions where paragrahs were indeed very long.

Line: comment 19: Chlorophyll does not need to be capitalized.
corrected

33-34: I am not sure what “silica production. . .comparable to . . .all areas of diatomaceous sediment” means. One is a rate per volume per time, the other is mass per volume sediment. Please clarify.
Yes the sentence was not very clear. It is a statement from Nelson et al 95 that was not clearly rewritten, we have modified the sentence as follows :
“ their silica production would be comparable to that of areas overlying major diatomaceous sediment accumulation zones.”

39: need to define chl a abbreviation first.
Chla has now been written in full text, as definition is given later.

50-56: While these cited authors suggested these mechanisms may be leading to diatoms blooms, they have little direct experimental or observational data to this point. Wilson (2011) was later modified when a stratification value was discovered to be to high (see later work by Wilson et al. 2013) and Calil et al and Guidi et al. have done much more direct work on the role of mesoscale features than Krause et al. (2009, 2010). These are all key points to make,but please cite the correct papers.
We were actually trying to find references related to diatom blooms, even though we did not state this clearly in this sentence “Furthermore, oligotrophic regions are known to experience considerable variability in nutrient injections leading to episodical blooms depending on the

occurrence of internal waves (Wilson, 2011), meso-scale eddies (Krause et al., 2010) storms (Krause et al., 2009), or dust deposition events (Wilson, 2003)."
Looking at Guidi et al. 2012 (Does eddy-eddy interaction control surface phytoplankton distribution and carbon export in the North Pacific Subtropical Gyre?), we did not find any mention of the stimulation of a diatom but rather only mention of Trichodesmium bloom which was not the reference we were trying to highlight. We have added Calil et al 2011 in the list of references concerning local upwellings or dust deposition events.

104: please provide temperature and length of precombustion
4h at 250°C (now included)

116: cascading is probably not the best word choice. Sequential or stacked is more accurate.
"Cascading" has been replaced by the word "stacked"

123: digestion, not attack
corrected

122-134. I am curious how standards were treated to have the same pH value as the samples. Si is a pH sensitive assay, so this merits some consideration.
When filters are digested in NaOH, the supernatant is subsequentely neutralized with HCl so that pH is close to neutral. Tests of DSi standard curves made in the same NaOH-HCl matrix as samples wer not significantly different from standard curves done in milliQ water. However when running DSi analysis directly on seawater samples, then low silicate water is used as the standard curve matrix, as salinity does impact by ~10% the calculated DSi concentrations.

143: please specify how the light measurement was made and then applied to generate the incubation depth.
The text states : "Euphotic layer depths (Ze) were calculated as described in Raimbault et al. (2008) and Moutin et al. (2018)." We have added the following detail: "Sampling depths were adjusted to on deck incubators screen attenuation using measurements from an in situ PAR sensor (LI-COR instrument) mounted on the CTD frame."

151: Si uptake from the chlorophyll maximum. This description needs clarification. Was uptake measured as per section 3.7 or were changes in BSi measured as per section 3.6? The kinetic curve incubation lasted 8 hours, the in-situ incubation lasted dawn to dusk. Are there potential artifacts associated with the timing of division cycles? Later in the paper, it appears isotope uptake experiments were conducted, but the reader should not have to wait until then to know this. Finally, how relevant is this measurement to the waters above the DCM?
Si uptake kinetics were carried following the method described in setcion 3,6. For more clarity, several methodological additions were made in this section (32Si added, size of filters). The header for both section were clarified by mentionning that both bulk Si uptake and Si kinetic

experiments were size-fractionated. In situ incubations were combined with 14C, 13C, 15N and O2 fluxes measurements and immersed 24h, whereas kinetic experiments were carried out during 8 h in paralell in on deck incubators fitted with neutral nickel screens. Given the limited amount of available 32Si and the extremely low biomass observed during biosope except at the DCM, a choice was made to only perform size-fractionated kinetic experiments at the DCM level, or at both DCM and surface levels if ever some biomass was observed at the surface. About the incubation duration, we make the hypothesis that populations are not synchronous and that Si uptake should be constant over 24 h. Furthermore, upon addition of cold Si(OH)4, stimulation of uptake occurs and as thumb rule we try to stay below a threshold of 10% of consumption of initial available Si, which is why the incubations were stopped after 8h. We surmise that size fractionated kinetics uptake experiments carried out outside of the DCM would have yielded no measurable counts on the scintillation counter, given the absence of Si biomass, and expect our kinetic results to represent the most active diatom community present in the euphotic layer. However, the results of kinetic experiments were removed entirely due to experimental problems on borad (likely filtration issues) which yielded incoherent results between size-fractions and unrealistic VSi values.

162: please list the net specifics: mouth opening and mesh size
The following information was added : ”During the OUTPACE cruise, additional WP2 phyto-net hauls (mouth opening 0.26 m^2 ; 35 µm mesh-size) were undertaken at each site integrating the 0-150 m water column”

216: This sentence is not clear. Please rephrase. It is apparently a comparison joined by the word than. I’m not sure what you are trying to say.
This sentence was rephrased as follows : “The Chl*a* distribution during BIOSOPE was similar to that observed during OUPACE, with extremely low surface concentrations and a very deep Chl*a* maximum located between 180 - 200 m ranging between 0.15 and 0.18 µg L^{-1}.”

266: attributed, not assimilated.
corrected

268: What is this unit of variability? Standard deviations? confidence interval? If you wish to say they are different, please refer to a statistical test showing this. The ± ranges overlap considerably. I am not convinced.
The unit is the standard deviation. Indeed, differences are not statistically significant, which is why we did not state “significantly” higher, but merely “higher”. Yet we have corrected as follows : “The importance of the picoplanktonic Si biomass was higher in the SPG (36 ± 12 %, n=14) than over the MA (22 ± 10 %, n=5) but not statistically different ($p > 0.05$).”

269+: The same comment applies here. Are the duplicates? Triplicates? Error bars? Statistics? The rates have up to 25% precision errors, so this is important.
Unfortunately, given the limited amount of 32Si available, there were no duplicates on any of the 32Si uptake or kinetic measurements, which is why no error bar is indicated.

312+: contribution to biomass implies some conversion to a common currency (carbon, chl). How did you do this?
We have added the following explanation in section 3.9 : “Seawater samples were preserved with acidified Lugol’s solution and stored at 4ºC. For the BIOSOPE cruise, a 500 mL aliquot of the sample was concentrated by sedimentation in glass cylinders for six days. Diatoms were counted following the method described by Gomez et al. (2007). For the OUTPACE cruise, a 100 mL aliquot of the sample was concentrated in an Utermöhl sedimentation chamber for 48h. Diatom sizes were measured for each species for an average number of 20 cells when possible, and converted to biovolume and C biomass following the method described in Leblanc et al. (2012). C biomass per species were then compared to chemically determined POC concentrations to yield a percent contribution to C biomass.”

322: richness based on quantitative counts or the net tows? In either case, the authors need to specifiy the total number of cells examined. If it is 50 cells in one case and 500 in another, that will clearly influence the community richness observed.
By richness we only meant number of taxa as indicated in Figure 9c, and we did not use any common diversity indexes. The number of taxa was derived from quantitative cell counts from Niskin bottles sampled at the surface and DCM at each site.The richness as mentionned above is based solely on the number of different taxa present in an entire sedimentation cuve. For the BIOSOPE cruise, the counting method was to sediment 500 ml. Hence counted cells would be half of the cellular abundances indicated for this cruise. For the OUTPACE cruise, we counted 100 mL aliquots, hence counted cells were equaled to 1/10th of the cellular concentration. Methods were different as the data was obtained from the publically available cruise database and counting not performed in our research group. The details about the volume of the aliquots counted has now been added to section 3.9.

326: Dominance within the diatom community needs to be specified as based on abundance or size/surface area. One large Coscinodiscus or Rhizosolenia will equal many small bicapitate Nitzschia.
In this paragraph we indeed meant numerical abundance, which has been underscored now in the text. We did not present biomass estimates per species as the paper already presents and extensive dataset and only present global contribution to POC estimates. Indeed abundances were extremely low at some sites and subsequent conversions would be based on too few counts. It is agreed that large diatoms represent a disproportionate contribution to biomass compared to smaller species, but we did not feel that adding this level of detail in the discussion would be useful in the present paper. Furthermore this level of detail (specific contribution to biomass) is not available for the BIOSOPE cruise during which diatom sizes were not measured.

The Table 1 citation seems out of place. I think you mean Table 2.
Yes this has been corrected.

489: The authors may wish to consider the work of Shipe et al. (1999) where they noted large

rare diatoms contributed up to 26% of the Si uptake in the north Pacific. There is no information on these giant diatoms, either solitary or aggregated, from the south Pacific. Any observations they have on this would be very relevant.

Line 523 : pennates were the most numerically abundant species (but also the most actively silicifying as evidenced by PDMPO staining - data not shown) but it is true that large sized diatoms such as Pseudosolenia calcar avis contribute disproportionately to C biomass compared to small pennates. In our calculation, 23 500 cells of Pseudo-nitzschia sp. represented 78% of total abundance but only 1 % of C biomass. Contrarily, 190 cells of Pseudo-solenia calcar-avis represented 0,6 % of total abondance but 90% of calculated biomass.

The following sentence was added line 576 : “However, it should be noted that if small fast growing pennates were numerically dominant, their relative contribution to C biomass was very small compared to that of few larger centrics such as Pseudosolenia calcar-avis, which when present dominated in terms of biomass, similarly to what had already been observed in the South Pacific with large Rhizosolenia (Shipe et al., 1999).”

593: This study is not a time series as per HOT and BATS, so the topic sentence implication that this work adds to time-series work in the south Pacific is not correct.

We did not imply that our work was similar to time-series data, and stated that we provide complementary data from two cruises, our point was to say that we propose comprehensive data of stocks, fluxes, kietincs and diatom taxonomy and abundance that are not usually provided all together in biogeochemical studies. We removed the term “complementary” from the sentence in order to remove the meaning that our data are similar to time-series.

Figures Fig. 4: The change in color scale is a bit confusing since the tendency to compare the two transects. If Fig. 4 Outpace were the same color scale as the Bioscope figure, then all the detail of the DCM would disappear. Likewise, the use of the Outpace color scale for the Bioscope would create detail.

Indeed but the ranges are very different, making it difficult to convey the profile details with the same colors. We have tweeked the median and non-linear settings of the color bar of the BIOSOPE cruise, so that the green color is close to 0.2 µg L^{-1} in both pannels.

Fig. 9: there are typos in the 2nd panel figure axis.

Corrected

Interactive comment on “Silicon cycle in the Tropical South Pacific: evidence for an active pico-sized siliceous plankton” by Karine Leblanc et al.

Anonymous Referee #3
Received and published: 6 June 2018

Overall this is a solid study which presents a wealth of data from a vast and undersampled region. While not groundbreaking, it could be impactful if it spurs more study of Si cycling in this region. Generally, I agree with most of the study (the authors have done a commendable job with the cell count and taxonomy components) but have a few main comments:

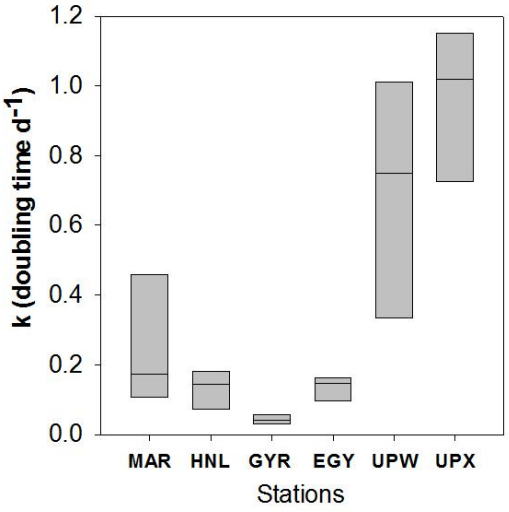
- The contribution of Synechococcus: the authors have compelling data which is consistent with recent studies but this facet is under developed. Given the Silicon per cell for Synechococcus in the two publications these authors cite (Baines et al. 2012, Ohnemus et al. 2016), could they do a similar budget of Synechoccocus silica here? Given the size of this project, surely there must be some flow cytometry data.

Ohnemus 2016 : “However, Si contents were highly variable and generally uncorrelated with measured environmental variables, suggesting that less direct effects such as community structure may drive Si accumulation in these ecosystems.” From the Table 2 in this paper, the authors estimate a contribution of Syn to the small fraction of BSi to range from 0.3 to 34 % though these contributions were always < 4% of total bSi, but they had Si per cell estimates from SXRF for each sample, and this ranged from 14 to 64 amol cell-1. We did calculate those estimates while writing this apper, but we felt that due to the strong variability and the absence of direct estimates for Si cellular quotas in Syn, this was not worth adding.
We however have these estimates and thus propose to add this sentence to the discussion as follows :
“ Using the range of measured Si cellular content per *Synechococcus* cells given in Ohnemus et al. (2016) of 14 to 64 amol Si cell^{-1} and *Synechococococcus* abundance data from the same casts obtained in flow cytometry (data courtesy of S. Duhamel, Lamont Doherty, NY), this yields a potential contribution of 3 to 14 % of *Synechococcus* to the small BSi fraction, which is close to the previous estimates.”

- Additionally, the isotope data is excellent to have but the rates for the kinetic data are unrealistic and not adequately discussed. For instance, 3.0 d-1 implies 4.3 doublings per day, 4.0 d-1 implies 5.8 doublings per day. Among all the experiments shown in Fig 8, all rates are exceptionally high as to be not believable. I think the authors need to better justify whether these data are useful and, if not, then perhaps consider eliminating.

According to your comments on too high VSi values, we have gone back to our raw data and found some inconsistencies in size-fractionated filtration between rSi and BSi. Some filters for rSi retained too much 32Si (either due to clogging or uncareful rinsing of

samples), yielding too much rSi over BSi explaining the high VSi values. If the shape of the kinetic uptake is globally fine, we acknowledge this problem, but unfortunately see no way of correcting the data adequately. We have thus chosen to remove this data entirely. We have left the vertical profiles for rSi data and replaced figure 8 (kinetics) by a figure of the mean k (doubling time) for each station.



Beyond these issues, I have numerous minor comments:

Line 64-66: Baines's estimates were indirect and extrapolated significantly, and were based on bSi associated with living cells (instead of total bSi).

Noted, we have removed this citation in this sentence.

Line 118: why the difference in filter sizes? Does this affect your results and interpretations?

During the BIOSOPE cruise, filter size (0.2 and 2µm) were chosen to reflect the standard operational size-classes of pico- and nanophytoplankton. The published work in between those two cruises dealing with the presence of Si in the picosize fraction was published using filter sizes of 0.4 and 3 µm (Baines et al., 2012), and since we wanted to confirm or not these first results, we decided to use the same filter sizes for comparison.

Line 128: given such low bSi measured, it seems like this precision is quite high (i.e. high noise to signal ratio). May the authors please explain why they would not consider this an issue?
Going back to our data, we have corrected this statement as follows :"The detection limit was 1 nmol L^{-1} for both BSi and LSi and quantification limits were 5 and 6 nmol L^{-1} for BSi and LSi respectively." We are indeed very close to detection limits at some depths during both cruises, but we did not have replicates to estimate accuracy. We do feel that the accuracy estimates, that has been estimated to 4 and 6 nmol L^{-1} respectively but for other cruises, if applied here would not significantly change any of the calculated budgets or

interpretation data, which would remain some of the lowest ever measured. We do observe that our measured in situ BSi concentrations were lowest than in most other papers, but we propose to add the following statement in the budget section, in order to underline the potential uncertainty on these baseline values. "

"For oceanic HNLC areas, values obtained (0.8 to 5.6 mmol Si m^{-2} d^{-1}) cover the range of rates measured in HNLC to mesotrophic systems of the North Atlantic, Central Equatorial Pacific and Mediterranean Sea. However, integrated rates obtained for the oligotrophic area of the South Eastern Pacific Gyre are to our knowledge among the lowest ever measured, *even taking into account the error associated to budget estimates this close to analytical detection limits."*

Line 149: Cerenkov counting is much less efficient than standard liquid scintillation methods correct? Given the low biomass (and thus low sample signal), did the Cerenkov background counts allow adequate resolution of analytically significant signals?

Cerenkov counting efficiency was estimated to be 42 % for this cruise, it is usually considered close to that value (~50%). Going over to liquid scintillation may have increased all cpm counts, but then also those of blanks, thus not improving the precision of the method.

Line 154: why go up to 36 uM? Are there prior studies which have gone this high? Recent work (Shrestha & Hildebrand 2015) show that above 25 uM diatoms start turning off silicon transporters.

Indeed the highest chosen concentration was probably too high, but it sometimes allow to show for a more linear response of Si uptake. In any case, the BIOSOPE cruise on which kientic experiments were made was conducted in 2005 so quite some time before the study you mention.

Line 229: given the high values, would the median (instead of average) be better here?

The median is now indicated at the end of the sentence, but is not notably different (13 instead of 17 nmol L^{-1}).

Line 275: 15 nmol/L/d given such low bSi means these cells are pretty active (e.g. 1 doubling per day)

Line 281, 298-299: Vmax is so high, it seems to be an error (see general comment).

See response above concerning VSi estimates

Line 296: it doesn't say in the figure caption that these are just for pico sizes, please Clarify.

This has been added to the Figure legend.

Line 353: what is the percent dissolution among these samples, could those be used to infer dissolution rates in the water column and compare to biomass-specific rates?

The % dissolution is indicated in the method section (line X) and was comprised between 16 and 90%. However it does not reflect in situ dissolution rates, but dissolution in trap samples kept at 4°C between sampling and analysis, hence not comparable to in situ rates.

Line 564: may you cite evidence for siliceous parmales in this region, aren't these only routinely observed in the subarctic North Pacific.
No they are not, there is evidence for large scale distribution, notably also for the Southern Ocean, but also large abundances have been oserved in the South Eastern Pacific (see Fig. 4 in Ichinomiya et al, 2016, ISME journal), where they can represent more than 1 % of total photosynthetic reads at both the surface and DCM depths.

Line 582: how so? There are two problems: the quotas published by Ohnemus et al. 2016 are low and the standing stock of picoplankton isn't high enough to consistently drawdown Si. Second, if these standing stocks did get high enough, then to remove Si, this material would need to be exported; yet the export rates quantified in this region were the lowest observed. This feels like a disconnect.

We agree that this role is probably not major, and have thus removed the term in the sentence. However, drawdown may be high by Synchococcus while it is also likely grazed and recycled in the surface layer. High temperatures are likely to remineralize a large part of assimilated Si in the surface layer, even though a previous drawdown and export prior to our study is necessary to explain the low silicic acid concentrations observed at the surface, and is not attributable to Synechococcus activity.

Figure 2, 3: could the color scale be more logarithmic (like in Figure 4) and similar to allow easier comparison?

We prefered giving the maximum details with color range for each graph, but have homogenized since all co-authors requested this.

Figure 7: perhaps a log scale to see the low values easier?
We modified the graph accordingly (see below)

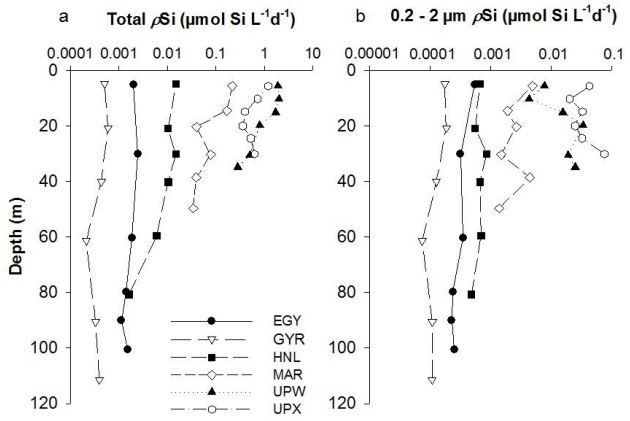


Figure 9: please detail how the lower panel values were calculated

This is now described in the method section as follows :

“Diatom sizes were measured for each species for an average number of 20 cells when possible, and converted to biovolume and C biomass following the method described in Leblanc et al. (2012). C biomass per species were then compared to chemically determined POC concentrations to yield a percent contribution to C biomass.”

Silicon cycle in the Tropical South Pacific: contribution to the global Si cycle and evidence for an active pico-sized siliceous plankton

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1 Abstract

This article presents data regarding the Si biogeochemical cycle during two oceanographic cruises conducted in the Southern Tropical Pacific (BIOSOPE and OUTPACE cruises) in 2005 and 2015. It involves the first Si stock measurements in this understudied region, encompassing various oceanic systems from New Caledonia to the Chilean upwelling between 8 and 34° S. Some of the lowest levels of biogenic silica standing stocks ever measured were found in this area, notably in the Southern Pacific Gyre, where Chlorophyll a concentrations are most depleted worldwide. Integrated biogenic silica stocks are as low as 1.08 ± 0.95 mmol m^{-2}, and are the lowest stocks measured in the Southern Pacific. Size-fractionated biogenic silica concentrations revealed a non-negligible contribution of the pico-sized fraction (<2-3 µm) to biogenic silica standing stocks, representing 26 ± 12 % of total biogenic silica during the OUTPACE cruise and 11 ± 9 % during the BIOSOPE cruise. These results indicate significant accumulation in this size-class, which was undocumented for in 2005, but has since then been related to Si uptake by *Synechococcus* cells. Si uptake measurements carried out during BIOSOPE confirmed biological Si uptake by this size-fraction. We further present diatoms community structure associated with the stock measurements for a global overview of the Si cycle in the Southern Tropical Pacific.

2 Introduction

Siliceous phytoplankton, especially diatoms, are often associated with nutrient-rich eutrophic ecosystems. However, the global budget of biogenic silica production by Nelson *et al.* (1995) already pointed out the importance of these organisms in oligotrophic areas where, despite their low concentration and due to the geographical extension of these systems, their silica production would be comparable to that of areas overlying major diatomaceous sediment accumulation zones. However, studies that have documented the Si cycle in the Pacific Ocean, the largest oligotrophic area of the World Ocean, mainly focused on the Equatorial region, and the northern Subtropical gyre. This article presents the first set of field results from the Southern Pacific Ocean between 8 and 34° S spanning from New Caledonia over to the Chilean upwelling, and notably, from the most Chlorophyll a-depleted region at a worldwide scale (Ras et al., 2008): the South Pacific Gyre (SPG).

Diatoms are known to contribute more importantly to primary production in meso- to eutrophic systems, yet several studies have emphasized that even if they are not dominant in oligotrophic regions, they may still contribute up to 10-20 % of C primary production in the Equatorial Pacific (Blain et al., 1997). In the oligotrophic Sargasso Sea (BATS station), their contribution ~~may be~~ was estimated to be as high as 26-48 % of new annual primary production (Brzezinski and Nelson, 1995) and ~~they may~~ to represent up to 30 % of Particulate Organic Carbon (POC) export ~~(Nelson and Brzezinski, 1997)~~, leading to an upward revision of the contribution of oligotrophic gyres to global Si budgets (Nelson and Brzezinski, 1997). Similar studies carried out in the Northern Pacific (HOT station) led to new estimates, as diatoms were found to be less important contributors to primary production. A combination of both Atlantic and North Pacific oligotrophic gyres budgets led to a revised contribution of 13 Tmol Si y^{-1}, a 51 % diminition of the previous estimate (Brzezinski et al., 2011).

In the Eastern Equatorial Pacific (EEP), it has been shown that diatoms experience chronic Si-limitation along the Eastern Equatorial divergence in the so-called High Nutrient Low Silicate Low Chlorophyll (HNLSiLC) system (Dugdale and Wilkerson, 1998) as well as Si-Fe co-limitation (Blain et al., 1997; Leynaert et al., 2001). Furthermore, oligotrophic regions are known to experience considerable variability in nutrient injections leading to episodical blooms depending on the occurrence of internal waves (Wilson, 2011), meso-scale eddies (Krause et al., 2010) storms (Krause et al., 2009), or local upwellings or dust deposition events (Wilson, 2003 ;

Calil et al., 2011). In nitrogen (N) depleted areas, punctual diatom blooms in the form of Diatom Diazotroph Associations (DDAs) are also known to occur and to contribute both to new primary production (Dore et al., 2008; Brzezinski et al., 2011) but also to benefit to non-diazotrophic diatoms through secondary N-release (Bonnet et al., 2016; Leblanc et al., 2016).

While biogenic silica was classically associated to the largest size fractions, especially microplankton, a series of recent studies ~~have furthermore~~provide evidence~~d~~ for a role for picophytoplankton such as *Synechococcus* in the Si cycle, showing that this ubiquitous lineage is able to take up and accumulate Si (~~Baines et al., 2012;~~ Ohnemus et al., 2016; Krause et al., 2017; Brzezinski et al., 2017). This was evidenced in the field in the Equatorial Pacific, the Sargasso Sea, as well as in culture work, suggesting a widespread diffuse role for this organism, which could be more prominent in oligotrophic environments where diatoms are in low abundance. In the EEP, and despite very variable cellular Si content, *Synechococcus* represented for instance 40 % of water column biogenic silica (BSi) inventory compared to diatoms in 2004, and twice that of diatoms the following year (Baines et al., 2012). The role of small nano-sized diatoms has also probably been overlooked and we recently pointed out their general occurrence at the worldwide scale and their occasional regional importance in diatom blooms (Leblanc *et al.*, 2018).

Here we present the first set of field results from the Southern Pacific Ocean between 8 and 34° S spanning from New Caledonia over to the Chilean upwelling, and notably, from the most depleted Chl*a* region worldwide (Ras *et al.*, 2008), the South Pacific Gyre (SPG). Results were obtained from two cruises carried out a decade apart following longitudinal sections first in the South Eastern Pacific (SEP) between the Marquesas Islands and the Chilean upwelling, crossing the South Pacific Gyre (BIOSOPE cruise, Oct-Dec 2004) and next in the Southern Western Pacific (SWP) between New Caledonia and Tahiti (OUTPACE cruise, Feb-Apr. 2015). Very similar sampling strategies and ~~homogeneous~~ analyses were conducted regarding the Si cycle and provide new data in this under sampled region. We detail size-fractionated BSi inventories in the water column, Si export fluxes, associated diatom community structure composition as well Si uptake and kinetic rates in the Southern Pacific. Our key results show some of the lowest BSi stocks ever measured, which may warrant for a new revision of the contribution of oligotrophic areas to the global Si cycle, and confirm recent findings of an active biological uptake of Si in the pico-sized fraction.

3 Material and methods

3.1 Sampling strategy

Results presented here encompass data from two French oceanographic cruises located in the Southern Pacific Ocean (from 10 to 30° S), covering two transects ~~with~~that employed a common~~similar~~ sampling ~~sampling~~ strategy~~ies~~ of short and long duration stations. The BIOSOPE (BIogeochemistry and Optics SOuth Pacific Experiment) cruise was undertaken in 2004, while the OUTPACE cruise took place in 2015, both aboard the R/V *L'Atalante*. The BIOSOPE transect was sampled between the Marquesas Islands (141° W, 8° S) and Concepción (Chile) (72° W, 35° S), between October 24th and November 12th 2004. The OUTPACE transect was sampled between New Caledonia (159° W, 22° S) and Tahiti (160° W, 20° S) between February 18th and April 3rd 2015 (Fig. 1).

3.2 Hydrology

Water sampling and measurements of temperature and salinity were performed using a SeaBird SBE 911plus CTD/Carousel system fitted with an in situ fluorometer and 24 Niskin bottles. More details about the BIOSOPE cruise strategy are given in the Biogeoscience special issue introductory article by Claustre et al., (2008) while the OUTPACE cruise strategy is detailed in Moutin et al. (2017). Euphotic layer depths (Ze) were calculated as described in Raimbault et al. (2008) and Moutin et al. (2018). Sampling depths were adjusted to on deck incubators screen attenuation using measurements from an in situ PAR sensor (LI-COR instrument) mounted on the CTD frame.

3.3 Inorganic nutrients

Nutrients were collected in 20 mL PE vials and analyzed directly on a SEAL Analytical auto-analyzer following Aminot and Kérouel (2007) on board during BIOSOPE and at the laboratory during OUTPACE from frozen (-20°C) samples. During BIOSOPE, nitrate (NO_3^-) detection limit was 0.05 µM (accuracy of ± 0.05 µM), phosphate (PO_4^{3-}) detection limit was 0.02 µM (accuracy of ± 0.05 µM), orthosilicic acid ($Si(OH)_4$) detection limit was 0.05 µM (accuracy of ± 0.05 µM). During OUTPACE the quantification limit was 0.05 µM for all nutrients.

3.4 Particulate Organic Carbon (POC)

Seawater samples (~2 L) were filtered through pre-combusted (for 4h at 450°C) 25 mm GF/F filters, dried at 60 °C and stored in 1.5 mL eppendorfs PE tubes. Particulate Organic Carbon (POC) was analyzed on a CHN elemental analyzer (combustion tempertaure at 925°C) (Perkin Elmer, 2400 series).

3.5 Total Chlorophyll *a* (TChl*a*)

For pigment analyses, 2 L of seawater were filtered through 25 mm GF/F filters and stored in liquid nitrogen and -80°C until processing. Extraction was done in 3 mL 100% methanol, followed by sonication and clarification by filtration on a new GF/F filter. Extracted pigments (Chl*a* and fucoxanthin) were then analyzed by HPLC (High Performance Liquid Chromatography) according to the procedure detailed in Ras et al. (2008).

3.6 Particulate Biogenic and Lithogenic Silica (BSi/LSi)

Samples were collected for silicon stocks as particulate biogenic and lithogenic silica (BSi and LSi) and dissolved orthosilicic acid ($Si(OH)_4$) similarly on both cruises. For BSi/LSi, between 1.5 and 2.5 L Niskin samples were filtered through stacked~~cascading~~ polycarbonate 47 mm filters. During BIOSOPE, whole samples were filtered through three ~~cascading~~stacked filters of 0.2, 2, and 10 µm. During OUTPACE, the size-fractionation used was 0.4 and 3 µm respectively. Filters were rinsed with 0.2 µm filtered seawater, folded in 4quarters and placed in plastic Petri dishes and dried overnight at 60°C. Filters were then stored at room temperature and analyzed in the laboratory. BSi and LSi were measured using Paasche (1973) as modified by Nelson et al. (1989): BSi and LSi were extracted on the same filter after successive basic and acid treatments. BSi was extracted during a hot sodium hydroxide (NaOH 0.2 N) ~~attack~~digestion (60 min), which converted BSi into the dissolved orthosilicic acid form. $Si(OH)_4$ was then quantified using the Strickland and Parsons (1972) spectrophotometric method. After the first basic ~~attack~~ digestion, filters were rinsed free of remaining $Si(OH)_4$ and dried again at 60°C. LSi, preserved in the sample, was then treated with hydrofluoric acid (HF 2.9 N) for 48 h. Samples were then diluted in saturated boric acid (H_3BO_3). In the same way, LSi was measured through quantification of the dissolved $Si(OH)_4$ form. The detection limit was 1 nmol L^{-1} for both BSi and LSi and quantification limits were 5 and 6 nmol L^{-1} for BSi and LSi respectively.~~Precisions for BSi and~~

~~LSi measurements were 4 and 6 nmol L^{-1} respectively (twice the standard deviation of blanks)~~. It has been demonstrated that for coastal samples, significant leaching of orthosilicic acid from LSi could occur during the first NaOH ~~attack~~digestion (up to 15 %) (Ragueneau and Tréguer, 1994). This is particularly the case when high LSi concentrations are present. Kinetic assays of orthosilicic acid were conducted in some samples from the Marquesas, Gyre, East-Gyre and near Upwelling stations during BIOSOPE to determine the optimal extraction time for BSi digestion, ~~but~~ and results revealed negligible LSi interferences after an extraction time of 60 min.

Biogenic silica export fluxes were determined from drifting sediment traps deployed for 4 consecutive days at three depths (153, 328, 519 m) at the three long duration stations of the OUTPACE cruise. For each trap samples, 160 mL were filtered onto 0.6 µm polycarbonate membranes and the filters were treated following a two-step digestion as described above. In addition to the BSi measurements, the dissolved Si measured directly in the supernatant of each trap at the time of subsampling minus the initial dissolved Si content in the seawater used to fill the trap was added to the final BSi concentrations, ~~Each trap was deployed for 4 consecutive days, and the average daily flux was quantified by adding the amount of dissolved Si in each trap to the measured BSi concentration~~ to account for BSi dissolution in the trap samples during storage. This step proved necessary, as BSi dissolution ranged between 16 and 90 % depending on the samples.

3.7 ~~S~~Si ~~bulk~~ize-fractionated bulk Si and specific uptake rates (ρ Si & VSi)

During BIOSOPE, dawn-to-dawn in situ Si uptake experiments were performed using an immersed production line, at six incubation depths (50 %, 25 %, 15 %, 8 %, 4 % and 1 % light level). Seawater (275 mL) samples were spiked with 632 Bq of radiolabeled ^{32}Si-silicic acid solution (specific activity of 23.46 kBq µg-Si $^{-1}$). For all samples, $Si(OH)_4$ addition did not exceed 0.4 % of the initial concentration. After incubation, samples were filtered through ~~cascading~~stacked polycarbonate membranes (0.2, 2 and 10 µm, 47 mm). Filters were rinsed with filtered (0.2 µm) seawater, and placed in scintillation vials. The ^{32}Si uptake was measured in a Packard 1600-TR scintillation counter by Cerenkov effect, following the method described by Tréguer and Lindner (1991) and Leynaert (1993). Precision of the method averages 10 % to ~~25~~30 % for the less productive station, estimated from repeated counts. Diatom doubling times k (in d^{-1}) were calculated as follows :

$$K = \ln((\rho Si + BSi)/BSi) \quad \text{(Eq. 1)}$$

~~**3.8 Si uptake kinetics**~~

~~Samples used were collected from the same Niskin bottles as those used for in situ incubation at the depth of the Chl*a* maximum. Six samples from each depth received non-radioactive $Si(OH)_4$ additions so that concentrations increased respectively by 0, 1.1, 2.3, 4.5, 13.6, 36.4 µM. Bottles were incubated on board in a deck incubator for 8h using neutral nickel screens. Samples were thereafter treated as described for in situ samples. Kinetic parameters Ks and Vmax were calculated by fitting the data to a hyperbolic curve using the Sigmaplot® hyperbola fit.~~

3.9 Siliceous phytoplankton determinations

Seawater samples collected from the same CTDs and Niskins as particulate Si samples were preserved with acidified Lugol's solution and stored at 4ºC. For the BIOSOPE cruise, a~~A~~ 500 mL aliquot of the sample was concentrated by sedimentation in glass cylinders for six days. Diatoms were counted following the method described by Gomez et al. (2007). For the OUTPACE cruise, a 100 mL aliquot of the sample was concentrated in an Utermöhl sedimentation chamber for 48h. Diatom sizes were measured for each species for an average number of 20 cells when possible, and converted to biovolume and C biomass following the method described in Leblanc et al. (2012). C biomass per species were then compared to chemically determined POC concentrations to yield a percent contribution to C biomass.

3.10 Phytoplankton net samples

During the OUTPACE cruise, additional WP2 phyto-net hauls (mouth opening 0.26 m^2 ; 35 µm mesh-size) were undertaken at each site integrating the 0-150 m water column, except at stations LD-C, 14 and 15 where they integrated the 0-200 m water column due to the presence of a very deep Deep Chlorophyll *a* Maximum (DCM). Samples were preserved in acidified lugol, and observed in a Sedgewick-rafter chamber. A semi-quantitative species list (dominant, common, rare) was established.

4 Results

4.1 Hydrological systems and nutrient availability

The hydrological structures crossed during the two transects have been carefully detailed in companion papers (Claustre et al., 2008; Moutin et al., 2018; Fumenia et al., 2018) and will not be presented in detail here. For the sake of clarity in the present article, main hydrological systems are described as follows. During the BIOSOPE cruise, five main hydrological systems were defined from West to East: the HNLC system comprising long duration (LD) stations MAR (Marquesas) and HNL and station 1; the South Tropical Pacific (STP) system from stations 2 to 6; the central part of the South Pacific Gyre (SPG) from station 7 to 13 including the LD station GYR; the Eastern Gyre HNLC area from stations 14 to 19 including LD station EGY (Eastern Gyre); and the coastal Peru-Chile Upwelling system from station 20 to 21 including LD stations UPW and UPX. During OUTPACE, two main systems were encountered, from West to East, the MA (Melanesian Archipelago) from stations 1 to 12 and including LD stations A and B, and the South Pacific Gyre (SPG) from stations 13 to 15 and including LD station C.

During both cruises, eutrophic to ultra-oligotrophic conditions were encountered. During OUTPACE, $Si(OH)_4$ concentrations were <1 µM at all stations in the surface layer, with values as low as 0.3-0.6 µM at 5 m depth at certain stations (Fig. 2). The 1 µM isoline was centered at ~100 m in the western part of the MA, and deepened to ~200 m in the SPG. Concentrations at 300 m were quite low (<2 µM) over the entire transect. Nitrate concentrations were similarly depleted in the surface layer, with values <0.05-0.1 µM in the first 80 m in the western part of the MA (until station 6), which deepened to 100 m over the rest of the transect. Yet nitrate concentrations increased with depth more rapidly than orthosilicic acid, reaching concentrations close to 7 µM at 300 m depth.

Phosphate was below detection limits in the western part of the MA (stations 1 to 11, and station B) over the first 50 m, but increased to values comprised between 0.1 and 0.2 µM in the SPG. Concentrations only increased to 0.6-0.7 µM at 300 m depth.

During BIOSOPE, both the nitracline and phosphacline extended very deeply (~200 m) in the regions of the STP, SPG and Eastern Gyre (Fig. 3). They surfaced at both ends of the transect in the upwelling system and near the Marquesas Islands, but contrary to nitrate which was severely depleted, phosphate was never found <0.1 µM in the surface layer (except at the subsurface at site 14). ~~The distribution of~~Horizontal gradients were not as strong for orthosilicic acid-

~~concentrations were less clearly contrasted~~, with general surface values comprised between 0.5 and 1 µM in the surface layer, except in the western part of the transect from station 1 to the GYR station, and in the upwelling system, where concentrations were > 1 µM and up to 8.9 µM at the surface and increasing rapidly with depth.

4.2 Total Chl*a* and fucoxanthin distribution

Total Chl*a* (TChl*a*) distributions are presented for both cruises along longitudinal transects together with fucoxanthin concentrations, a diagnostic pigment for diatoms (Fig. 4a, b). During OUTPACE, the Melanesian Archipelago system was clearly enriched in TChl*a* compared to the South Pacific Gyre and showed non-negligible concentrations in surface layers as well as a pronounced DCM reaching up to 0.45 µg L^{-1} at station 11. The observed DCM progressively deepened eastwards, from 70 m depth at LD-A to 108 m at station 12. The DCM depth generally closely followed the euphotic layer depth (Z_{eu}) or was located just below it. The highest surface concentrations were found at stations 1 to 6, between New Caledonia and Vanuatu (0.17 to 0.34 µg L^{-1}) while the SPG surface water stations showed a depletion in Chl*a* (0.02 to 0.04 µg L^{-1}). A DCM ~~subsisted~~existed in this region, but was observed to be deeper (125 to 150 m) and of lower ~~amplitude~~magnitude (0.17 to 0.23 µg L^{-1}) than in the MA region. Fucoxanthin concentrations closely followed the DCM, but were extremely low over the entire transect, with a maximum concentration of 17 ng L^{-1} in the MA and of 4 ng L^{-1} in the SPG.

The Chl*a* distribution during BIOSOPE was similar to that observed during OUPACE~~The BIOSOPE cruise evidenced a very similar Chl*a* distribution in the central SPG than during the OUTPACE cruise~~, with extremely low surface concentrations and a very deep Chl*a* maximum located between 180 - 200 m ranging between 0.15 and 0.18 µg L^{-1}. On both sides of the central SPG, the DCM shoaled towards the surface at the MAR station at the western end of the transect (0.48 µg L^{-1} at 30 m) and at the UPW station at the eastern end of the transect (3.06 µg L^{-1} at 40 m). Fucoxanthin concentrations did not exceed 9 ng L^{-1} at any station between the STP and the Eastern Gyre (between LD-HNL and station 17), thus showing ranges similar to the OUTPACE cruise measurements. Fucoxanthin increased moderately at the MAR station (85 ng L^{-1}), while it peaked in the Peru-Chile upwelling system with concentrations reaching 1,595 ng L^{-1} at LD-UPW but remained much lower at the LD-UPX station (200 ng L^{-1}).

4.3 Total and size-fractionated Biogenic and Lithogenic Silica standing stocks

Total Biogenic silica (BSi) concentrations were extremely low during the OUTPACE cruise (Fig. 5a) and ranged between 2 and 121 nmol L^{-1} in the surface layers, with an average concentration of 17 nmol L^{-1} (median value 13 nmol L^{-1}). Similarly to TChl*a* and fucoxanthin, the highest BSi levels were encountered over the MA, with peak values mostly found at the surface, at stations 1 and 2 and from stations 4 to 7, and with very moderate increases at depth (stations 5 and 10). The average BSi concentration decreased from 20 to 8 nmol L^{-1} from the MA to the SPG. In the SPG, maximum BSi levels were found at the DCM, between 125 and 150 m. Total Lithogenic Silica (LSi) concentrations were measured in a very similar range (Fig. 5b), between 2 and 195 nmol L^{-1}, with a peak value at station 2 at 100 m. Also, LSi was ranged from 5 to 30 nmol L^{-1} over the transect, with highest values observed close to 100 m, while averaged concentrations followed the same trend as BSi, decreasing from 16 to 9 nmol L^{-1} between the MA and the SPG.

During the BIOSOPE cruise, three main regions could be differentiated: a first region covering the ultra-oligotrophic central area from station 1 to station 20, where average BSi concentrations were as low as 8 nmol L^{-1} (Fig. 5c). At the western end of the transect, the first three stations in the vicinity of the Marquesas Islands had higher concentrations with average values of 104 nmol L^{-1}. The eastern end of the transect, located in the Peru-Chile Upwelling system, displayed much higher and variable values, averaging 644 nmol L^{-1}, with a maximum concentration of 2,440 nmol L^{-1} at the UPW station at 60 m. At both ends of the transect, siliceous biomass was mainly distributed in the upper 100 m. Lithogenic silica followed the same trends (Fig. 5d), with extremely low values over the central area (average of 7 nmol L^{-1}) with a few peaks close to 30 nmol L^{-1} (stations 12 and EGY). LSi concentrations were highest at both ends of the transect but concentrations remained below those of BSi~~LSi was again higher at both ends of the transect but with less amplitude than BSi~~, with average LSi values of 26 nmol L^{-1} close to the Marquesas, and of 57 nmol L^{-1} in the coastal upwelling system. The maximum values close to 150 nmol L^{-1} were associated to the BSi maximums at the UPW sites.

Size-fractionated integrated BSi stocks were calculated for both cruises over the 0-125 m layer, except for the BIOSOPE cruise at station UPW1, which was only integrated over 50 m and at stations UPX1 and UPX2 which were integrated over 100 m (Fig. 6a, b, Appendix 1). Total BSi stocks were similarly very low in the ultra oligotrophic central gyre and averaged 1 mmol Si m^{-2} during both cruises. During BIOSOPE, the stocks measured closed to the Marquesas averaged

9.85 mmol Si m^{-2} (with a peak of 24.12 mmol Si m^{-2} at the MAR station). On the eastern end of the transect, stocks increased to a peak value of 142.81 mmol Si m^{-2} at the UPW2 station and averaged 65.68 mmol Si m^{-2} over the coastal upwelling system. Size-fractionation was only carried out at the long duration stations, but showed an overall non negligible contribution of the pico-sized fraction (0.2-2 µm) to BSi standing stocks of 11 ± 9 %. This contribution of the pico-size fraction to integrated siliceous biomass was highest at the GYR, EGY and UPX1 stations reaching 25, 18 and 24 % respectively.

During OUTPACE, integrated BSi stocks ranged between 1.25 and 4.11 mmol Si m^{-2} over the MA, and decreased to 0.84 to 1.28 mmol Si m^{-2} over the SPG (Fig. 6c, Appendix 2). Here, size-fractionation was conducted at all sites and the contribution of the 0.4 - 3 µm, which will be ~~assimilated~~ttributed to the pico-size fraction hereafter, was higher than during BIOSOPE, with an average contribution of 26 ± 12 %. The importance of the picoplanktonic Si biomass was higher in the SPG (36 ± 12 %, n=14) than over the MA (22 ± 10 %, n=5) but not statistically different ($p > 0.05$).

4.4 Si uptake rates ~~and kinetic constants~~

Si uptake rate measurements using the ^{32}Si radioactive isotope were only conducted during the BIOSOPE cruise. ~~The same size-fractionation was applied to production and kinetic experiment samples.~~ Rank order of most productive stations follow the pattern observed for BSi with the highest values observed at UPW followed by UPX and MAR stations. Vertical profiles of gross production rates (ρSi) confirm the previous stock information and show that the most productive stations, in decreasing order of importance, are the UPW, UPX and MAR stations (Fig. 7a), with 1.98, 1.19 and 0.22 µmol Si L^{-1} d^{-1} at 10 m respectively. Si uptake rates remained below 0.015 µmol Si L^{-1} d^{-1} at central HNLC and oligotrophic stations HNL, EGY and GYR. Si uptake rates in the picoplanktonic size fraction showed similar trends (Fig. 7b), despite higher values at UPX (0.076 µmol Si L^{-1} d^{-1}) than at UPW (0.034 µmol Si L^{-1} d^{-1}). Uptake rates in that size fraction were intermediate at the MAR station with maximum value of 0.005 µmol Si L^{-1} d^{-1}, while it remained below 0.001 µmol Si L^{-1} d^{-1} at the central stations. Specific Si uptake (VSi normalized to BSi) rates for the picoplanktonic size fraction were even more elevated and reached maximum values of 3.64, 1.32, 0.75, 0.37 and 0.14 d^{-1} at the UPW, UPX, HNL, EGY and MAR stations respectively. Total specific Si uptake rates were extremely high in the coastal upwelling system,

with values of 2.57 and 1.75 d^{-1} at UPX and UPW respectively, and lower but still elevated values at the MAR station (0.75 d^{-1}). VSi at the central stations (HNL, EGY, GYR) were moderate to low and ranged between 0.02 and 0.24 d^{-1}.

Total ΣρSi reached 52.4 mmol Si m^{-2} d^{-1} at UPW2 station, an order of magnitude higher that the rate measured at the MAR station (5.9 mmol Si m^{-2} d^{-1}) and 3 orders of magnitude higher than at EGY, where the lowest value was obtained (0.04 mmol Si m^{-2} d^{-1}). Integrated picoplanktonic Si uptake rates (ΣρSi for 0.2-2 µm) were highest at both upwelling stations (Table 1), followed by the MAR station. The relative average contribution of the picoplanktonic size fraction to total Si uptake rates was highest at the central stations (32 % at GYR, 19 % at EGY and 11 % at HNL) while it was lowest on both ends of the transect (5 % at MAR, and 3 and 7 % at UPW and UPX stations).

Diatom doubling times were calculated at each depth following Eq. (1) and are shown in Fig. 8 for each station. The lowest k were found at the HNL, GYR and EGY stations where median values remained < 0.2 d^{-1}. The median value was similar at the MAR station but with a larger interquartile and a higher maximum value of 0.56 d^{-1}. Doubling times were most elevated at the UPW (0.75 d^{-1}) and UPX (0.92 d^{-1}) stations and the maximum value for the cruise was 1.27 d^{-1} at the UPX station at the surface.

~~Si uptake kinetic experiments were conducted at some long duration stations at the surface and/or depth of the DCM depending on the location of biomass. Results for the picoplanktonic fraction clearly indicate an active biological uptake (Fig. 8), generally following hyperbolic uptake kinetics. The hyperbolic curve fitting failed for only 2 out of the 8 kinetic uptake experiments performed on the 0.2-2 µm size-fraction (at the DCM at the HNL station and at the surface at the UPX station). Maximum theoretical specific uptake rates (V_{max}) values were high, ranging from 1.9 d^{-1} at the MAR station to 6.1 d^{-1} at the surface at the UPX station. Half-saturation constants (K_S) were also elevated ranging from 5.4 µM at the MAR station to as much as 38.3 µM at the UPX station and in all cases much higher than ambient $Si(OH)_4$ concentrations.~~

4.5 Diatom distribution and community structure

Microscopical examinations confirmed the presence of diatoms at every station during both cruises. Diatoms were found in very low abundances during the OUTPACE cruise and only reached maximum values of 20,000-30,000 cells L^{-1} on two occasions, at stations LD-B at the

surface and at station 5 at the DCM (Fig. 9a). Mean diatom concentrations in the MA at the surface were 4,440 ± 7,650 cells L^{-1} while at the DCM, mean concentrations were about 2-fold lower (2,250 ± 4,990 cells L^{-1}). Diatom abundance decreased dramatically in the SPG, with values as low as 25 ± 19 cells L^{-1} at the surface layers and 145 ± 54 cells L^{-1} at the DCM. The richness of diatoms was higher in the MA than in the SPG, with an average number of taxa of respectively 9 ± 4 and 2 ± 1 in the surface layer (Fig. 9b). The richness increased at the DCM level, with 12 ± 8 taxa in the MA and 5 ± 1 taxa in the SPG. Diatom contribution to biomass was accordingly extremely low and remained below 3 % (Fig. 9c). The diatom contribution to C biomass increased more significantly only at two stations: at station LD-B (9 % at the surface) and at station 5 where the maximum value for the cruise was observed (11.5 % at the DCM).

During BIOSOPE, the central stations showed ~~a record~~the lowest diatom abundance with less than 100 cells L^{-1} from stations 2 to EGY (Fig. 10). The eastern part of the SPG and the HNL stations were characterized by slightly higher abundances (from 100 to 1,000 cells L^{-1}), followed by the UPX station, where abundances were similar to the MAR station at the surface (~25,000 cells L^{-1}). Highest abundances were observed at the UPW, with bloom values of 256,000 cells L^{-1} on average (with a peak abundance of 565,000 cells L^{-1} at the surface). Similar results compared to OUTPACE showed an extremely low richness at all central stations (data not shown) with on average 3 ± 2 diatom taxa, while richness increased at the western HNLC region with 13 ± 4 taxa at the MAR and HNL stations. Richness was highest at the UPW station with 20 ± 4 taxa and decreased again at the UPX station (5 ± 3).

The dominant diatom species for each system sampled over the course of the two cruises are summarized in Table ~~1~~2 and Appendix 3. During OUTPACE, very similar species were encountered in both regions and were mainly dominated by pennate species such as *Pseudo-nitzschia* spp., *P. delicatissima*, *Cylindrotheca closterium* and *Mastogloia woodiana*. However, Diatom-Diazotroph Associations (DDAs) such as *Rhizosolenia styliformis*, *Climacodium frauenfeldianum* and *Hemiaulus hauckii* were more abundantly found in the MA. Other siliceous organisms such as radiolaria were also more abundant in the SPG and at LD-B than in the MA (Appendix 3). Overall microplanktonic diazotroph abundance were much higher over the MA than in the gyre, with a predominance in plankton nets of *Trichodesmium*, *Richelia intracellularis* (alone or in DDAs), *Crocosphaera* and other filamentous cyanobacteria such as *Katagnymene* (Appendix 3).

Diatom community structure for the BIOSOPE cruise has already been discussed extensively in Gomez et al. (2007). In summary, the stations characterized by medium diatom abundances such as MAR, HNL, 18, 20 and EGY (Fig. 10) were mainly dominated by the pennate diatom *Pseudo-nitzschia delicatissima* in particular at the MAR station, where it represented on average 90 % of all diatoms over the 0-100 m layer. Extremely low abundance stations (< 200 cells L^{-1}) from the middle of the SPG (stations 2 to 14) did not show any consistent community, with varying dominant species across stations and along vertical profiles as well. Maximum abundances at these sites were consistenly found at depth, between 100 and 200 m. In the Peru-Chile upwelling, diatom community structure was mostly dominated by small and colonial centric species such as *Chaetoceros compressus* and *Bacteriastrum* spp. at the UPW station where abundances were highest (565,000 cells L^{-1}) and such as *Skeletonema* sp. and *Thalassiosira anguste-lineata* at the UPX station where abundances decreased to 10,000-40,000 cells L^{-1}. In this system, the highest abundances were found in the first 10 m.

4.6 Si export fluxes

Particulate silica export fluxes were measured from drifting trap deployments at each long duration station during OUTPACE and are presented in Table 3. BSi daily export fluxes below the mixed layer at 153, 328 and 529 m were extremely low at all sites, with lowest values at site A (0.5 to 0.1 µmol Si m^{-2} d^{-1}), highest at site B (3 to 5 µmol Si m^{-2} d^{-1}) and intermediate at site C (0.5 to 2 µmol Si m^{-2} d^{-1}).

5 Discussion

5.1 Si budgets for the South Pacific

In the following section, values from previous studies are compared (Table 4) with the results obtained across this under-studied region of the Pacific Ocean, which is characterized by the most oligotrophic and Chl*a* depleted waters worldwide (Ras et al., 2008). ~~On one hand,~~We obtained size-fractionated biomass and export fluxes ~~were obtained~~ during the OUTPACE program, ~~while on the other hand,~~ and size-fractionated production and biomass budgets ~~were quantified~~ during the BIOSOPE program.

Regarding values obtained at both ends of the BIOSOPE transects, i.e. in the Peru-Chile upwelling system and in the HNLC system surrounding the Marquesas Islandss, $\Sigma\rho$ Si rates

compare well with previous studies from other similar regions (Table 4). Integrated Si production rates at the UPW stations are in the middle range (42-52 mmol Si m^{-2} d^{-1}) of what was previously found in coastal upwellings. Values are however almost double to what was previously observed in the Peru upwelling by Nelson et al. (1981), although less productive than the Monterey Bay and Baja Californian upwelling systems (Nelson and Goering, 1978; Brzezinski et al., 1997). For oceanic HNLC areas, values obtained (0.8 to 5.6 mmol Si m^{-2} d^{-1}) cover the range of rates measured in HNLC to mesotrophic systems of the North Atlantic, Central Equatorial Pacific and Mediterranean Sea. However, integrated rates obtained for the oligotrophic area of the South Eastern Pacific Gyre are to our knowledge among the lowest ever measured, even taking into account the error associated to budget estimates this close to analytical detection limits. ~~Indeed ,~~ ~~v~~Values range from 0.04 to 0.20 mmol Si m^{-2} d^{-1}, they are thus lower than average values previously measured at BATS and ALOHA stations (0.42 and 0.19 mmol Si m^{-2} d^{-1} respectively) (Brzezinski and Kosman, 1996; Nelson and Brzezinski, 1997; Brzezinski et al., 2011). However, they are similar to measurements performed in autumn (0.04-0.08 mmol Si m^{-2} d^{-1}) in a severely Si-limited regime of the North Atlantic (Leblanc et al., 2005b). Previous studies have ~~evidenc~~documented limitation of diatom Si production by Si (Leynaert et al., 2001), but more recently evidence of co-limitation by both Si and Fe was found in the central Equatorial Pacific (Brzezinski et al., 2008). This would be a more than likely scenario for the SPG, given the very low silicic acid (Fig.2 & 3) and Fe concentrations (0.1 nM and ferricline below 350 m depth, Blain et al., 2008) measured during both cruises.

The approximate surface area of mid-ocean gyres was estimated to be 1.3 x 10^8 km^2 (representing approximately 1/3 of the global ocean) yielding a global contribution of only 26 Tmol Si y^{-1} gross silica production, i.e. approximately 9-13% of the budget calculated for the global ocean of 240 Tmol Si y^{-1} according to Nelson et al. (1995). This budget has been recently revised down to 13 Tmol Si y^{-1} when considering budgets from the North Pacific (Nelson and Brzezinksi, 1997) reducing the contribution of subtropical gyres to 5-7% of global marine silica production (Brzezinksi et al., 2011; Tréguer and de La Rocha, 2013). However, the range provided in Nelson et al. (1995) in the calculation of their global Si production fluxes for mid-ocean gyres was of 0.2 – 1.6 mmol m^{-2} d^{-1}. Our values would, once again, lower the contribution of these vast oceanic regions to global Si production, although the present data is only based on two production station measurements and warrants further measurements for this region. Nevertheless,

it can be expected that the most ultra-oligotrophic region of the world ocean would contribute even less to total Si production than the other oligotrophic systems listed in Table 4 and that in particular, the Si production in the ultra-oligotrophic Southern Tropical Gyre would be lower than the Northern Tropical Gyre.

Integrated Si biomass also reflects the very low contribution of diatoms in this system, which was more than 2-fold lower in in the South Pacific Gyre than in the Melanesian Archipelago (Table 5). In the SPG, the lowest Si stocks were measured (~1 mmol Si m^{-2}), and were similar to lower-end values found in the ultra-oligotrophic Eastern Mediterranean Basin in autumn and in other oligotrophic areas of the North Pacific Subtropical Gyre and of the Sargasso Sea (Table 5 and references therein). It is probable that $\Sigma\rho$Si production and BSi stocks could have been slightly higher less than a month earlier in the season on the western part of the OUTPACE transect in the MA. Indeed, the satellite-based temporal evolution of Chl*a* at stations LD-A and LD-B showed decreasing concentrations at the time of sampling (de Verneil et al., 2018), while the situation did not show any temporal evolution for the SPG, thus suggesting that the biogenic silica budget for this area is quite conservative under a close to steady-state situation.

Lastly, our Si export flux measurements by drifting sediment traps are the lowest ever measured and are about two orders of magnitude lower than those from other oligotrophic sites such as BATS in the Atlantic or ALOHA in the Pacific Ocean (Table 6). They represent a strongly negligible fraction of surface Si stocks, implying no sedimentation at the time of sampling, and that active recycling and grazing occurred in the surface layer. Indeed, surface temperatures higher than 29°C at all long duration sites, may favor intense dissolution in the upper layer, while active zooplankton grazing was also documented, removing between 3 and 21% of phytoplankton stocks daily (Carlotti et al., 2018). The virtual absence of silica export from the surface layer well agrees with the conclusion of Nelson *et al.* (1995) that no siliceous sediment is accumulating beneath the central ocean gyres.

5.2 Siliceous plankton community structure in the South Tropical Pacific

The main feature observed during OUTPACE was a bi-modal distribution of diatom communities, either at the surface and/or at the DCM level depending on stations, which deepened towards the East, following the increasing oligotrophy gradient, similarly to what was previously described in the Mediterranean Sea (Crombet et al., 2011). A similar feature, showing a particularly deep

DCM, up to 190 m in the SPG at 1.2-fold the euphotic depth (Ras et al., 2008), was observed during BIOSOPE, revealing a known strategy for autotrophic plankton cells in nutrient depleted waters to stay at the depth where the best light vs nutrient ratio is obtained (Quéguiner, 2013).

While DCM's are common in mid-ocean gyres and are known to be often dominated by pico-sized phytoplankton~~If the presence of DCMs in oligotrophic mid-ocean gyres are well known, associated to the dominance of small pico-sized phytoplankton~~ (Chavez et al., 1996), studies documenting phytoplankton community structure in the South Tropical Pacific Ocean, an area formerly called a « biological desert », are still very scarce. In the review of planktonic diatom distribution by Guillard and Kilham (1977) referencing biocenoses for all main oceanic water bodies and for which thousands of articles were processed, the diatom composition for the South Tropical region was referred to as « No species given (flora too poor) ». Since then only a few studies mentioning phytoplankton community structure, mostly located along the equator were published, such as Chavez et al. (1990); Chavez et al. (1991); Iriarte and Fryxell (1995); Kaczmarska and Fryxell (1995); and Blain et al. (1997). In Semina and Levashova (1993) some biogeographical distribution of phytoplankton including diatoms is given for the entire Pacific region, yet the Southern tropical region is limited to more historical Russian data and rely on very few stations. The only diatom distribution for the South Tropical Gyre was published for the present data set by Gomez et al. (2007) in the BIOSOPE special issue. Hence the present data contributes to documenting a severely understudied, yet vast area of the world ocean.

The oceanic regions covered during both cruises may be clustered into three main ecological systems with relatively similar diatom community structures: the nutrient-rich coastal upwelling system near the Peru-Chile coast, where diatom concentrations exceeded 100,000 cells L^{-1}, the Fe-fertilized areas of the Melanesian Archipelago and West of Marquesas Islands, where concentrations could locally exceed 10,000 cells L^{-1}, and all the other ultra-oligotrophic regions (mainly the South Pacific Gyre system) characterized by extremely low diatom abundances, usually <200 cells L^{-1}.

The upwelling area was characterized by a distinct community, not found in the other regions, composed of typical neritic and centric colonial species such as *Skeletonema* sp., *Bacteriastrum* spp., *Chaetoceros compressus*, *Thalassiosira subtilis* and *T. anguste-lineata*. These first three species were already documented as abundant in the Chile upwelling by Avaria and Munoz (1987), whereas *T. anguste-lineata* was reported along the Chilean coast from 20°S to 36°S

(Rivera et al., 1996) and was also documented in the upwelling system West of the Galapagos Islands (Jimenez, 1981). The highest ρSi production values were measured at the offshore UPW station where *Bacteriastrum* spp. and *Chaetoceros compressus* co-occurred as the two dominant species, whereas ρSi rates were halved at the closest coastal station UPX, associated to lower abundances of diatoms, with co-occurring dominance by *Skeletonema* sp. and *Thalassiosira anguste-lineata*.

The HNLC regions off the Marquesas Islands (MAR) and in the Eastern Gyre (stations 14-20, BIOSOPE) and the oligotrophic region (N-deprived but Fe-fertilized region of the MA), with bloom situations at stations 5 and LD-B (OUTPACE), showed strong similarities in terms of diatom community structure and were all mainly dominated by the medium-sized pennate diatoms of the *Pseudo-nitzschia delicatissima/subpacifica* species complex. These pennate species are commonly reported for the Central and Equatorial Pacific Ocean (Guillard and Kilham, 1977; Iriarte and Fryxell, 1995; Blain et al., 1997). During BIOSOPE, *Pseudo-nitzschia delicatissima* were often seen forming « needle balls » of ~100 µm diameter which suggests an anti-grazing strategy from micro-grazers (Gomez et al., 2007), a strategy already described by several authors (Hasle, 1960; Buck and Chavez, 1994; Iriarte and Fryxell, 1995). Predominance of pennate diatoms over centrics has previously been observed in the N-depleted environment of the Equatorial Pacific (Blain et al., 1997; Kobayashi and Takahashi, 2002), and could correspond to an ecological response to diffusion-limited uptake rates, favoring elongated shapes, as suggested by Chisholm (1992). Furthermore, net samples from the OUTPACE cruise showed a numerically dominant contribution of *Cylindrotheca closterium* over 0-150 m at most stations of the MA (Appendix 3), with a strong dominance at LD-B, even though their contribution to biomass is minor given their small size. However, it should be noted that if small fast growing pennates were numerically dominant, their relative contribution to C biomass was very small compared to that of few larger centrics such as *Pseudosolenia calcar-avis*, which when present dominated in terms of biomass, similarly to what had already been observed in the South Pacific with large Rhizosolenia (Shipe et al., 1999). *Pseudo-nitzschia* sp. and *Cylindrotheca closterium* have been shown to bloom upon Fe-addition experiments (Chavez et al., 1991; Fryxell and Kaczmarska, 1994; Leblanc et al., 2005a; Assmy et al., 2007) and may reflect the significantly higher dissolved Fe concentrations measured in the MA (average 1.9 nM in the first 100 m) compared to the SPG (0.3 nM) (Guieu et al., in rev). In the Equatorial Pacific, Fe-amendment

experiments evidenced the rapid growth of *Cylindrotheca closterium*, with a high doubling rate close to 3 d^{-1} (Fryxell and Kaczmarska, 1994), which can explain why this species is often numerically dominant.

Fast growing colonial centric diatoms such as *Chaetoceros* spp. were notably absent from the MA, except at stations 5 and LD-B, where mesoscale circulation increased fertilization (de Verneil et al., 2018) and allowed a moderate growth (observed in both Niskin samples and net hauls), resulting in an increased contribution of diatoms to total C biomass of approximately 10% (Fig. 9c). Other typical bloom species such as *Thalassiosira* spp. were completely absent from the species from the Niskin samples but observed at low abundance in some net haul samples. Nonetheless, very large centrics typical of oligotrophic waters such as *Rhizsolenia calcar-avis* (Guillard and Kilham, 1977) were present in low numbers at all stations and in all net hauls, and represented a non-negligible contribution to biomass despite their low abundance.

One difference with the N-replete Marquesas HNLC system was that the hydrological conditions of the MA were highly favorable for the growth of diazotrophs, with warm waters (>29°C), depleted N in the surface layer associated to high Fe levels, while P was likely the ultimate controlling factor of N-input by N_2-fixation in this region (Moutin et al., 2008; Moutin et al., 2018). N_2-fixation rates were among the highest ever measured in the open ocean during OUTPACE in this region (Bonnet et al., 2017), and the development of a mixed community, composed of filamenteous cyanobacteria such as *Trichodesmium* spp. and other spiraled-shaped species, unicellular diazotrophs such as UCYN, *Crocosphaera watsonii*, and Diatom-Diazotroph Associations (DDAs) was observed (Appendix 3). The highest rates were measured at the surface at stations 1, 5, 6 and LD-B (Caffin et al., this issue) and the major contributor to N_2-fixation in MA waters was by far *Trichodesmium* (Bonnet et al., 2018). In the Niskin cell counts, DDAs known to live in association with the diazotroph *Richelia intracellularis* such as *Hemiaulus hauckii, Chaetoceros compressus* and several species of *Rhizosolenia* such as *R. styliformis, R. bergonii, R. imbricata* and the centric *Climacodium frauenfeldianum* known to harbor a genus related to *Cyanothece* sp. (Carpenter, 2002) were all found in low abundance in the water sample cell counts, contributing to less than 1% of total diatoms. Exceptions were observed at sites 1 and 2 where their contributions increased to 2.3 and 8% respectively. The low contribution of DDAs to the diazotrophs community was confirmed by direct cell counts and nifH gene sequencing (Stenegren et al., 2018). Notably, the presence of *Richelia intracellularis* was not observed in the

Niskin lugol-fixed water samples, but *Rhizosolenia styliformis* with *Richelia*, and some isolated *Richelia* cells were observed abundantly in net hauls. The latter were found to be dominant at stations 1 and LD-B, where the highest fixation rates were measured. *Richelia*, alone or in association with *R. styliformis* were much less abundant in the South Pacific Gyre, where Fe is prone to be the limiting nutrient for N_2-fixation rates despite higher P availability, pointing to less favorable growth conditions for diazotrophs. Yet, the overall dominance of *Trichodesmium, Crocosphaera* and other filamenteous cyanobacteria (Appendix 3) in the net samples reveals that DDAs were very minor contributors to N_2-fixation during OUTPACE. This was also evidenced through NanoSIMS analyses (Caffin et al., 2018).

In order to explain the growth of diatoms in this severely N-depleted region, one can quote the use of diazotroph-derived nitrogen (DDN), i.e. the secondary release of N_2 fixed by diazotrophs, which showed to be efficiently channeled through the entire plankton community during the VAHINE mesocosm experiment (Bonnet et al., 2016). In this latter study off shore New Caledonia, *Cylindrotheca closterium* grew extensively after a stimulation of diazotrophy after P-addition in large volume in situ mesocosms in New Caledonia (Leblanc et al., 2016). As previous studies had already observed a co-occurrence of elevated *C. closterium* with several diazotrophs (Devassy et al., 1978; Bonnet et al., 2016), this recurrent association tends to confirm our previous hypothesis of a likely efficient use of DDN released as NH_4 by this fast growing species (Leblanc et al., 2016). This could be another factor, besides Fe-availability, explaining its success. A similar hypothesis may be invoked for the presence of *Mastogloia woodiana*, a pennate diatom known to be occasionally dominant in the North Pacific Subtropical Gyre blooms (Dore et al., 2008; Villareal et al., 2011). It is also a characteristic species of oligotrophic areas (Guillard and Kilham, 1977), often observed in association with other DDAs, which could similarly benefit from secondary N-release (Villareal et al., 2011; Krause et al., 2013).

Lastly, the ultra-oligotrophic region of the SPG investigated both during OUTPACE and BIOSOPE revealed a base-line contribution of diatoms with often less than 200 cells L^{-1} at the DCM and close to zero at the surface. In addition, a dominance of small and large pennate species was observed, such as *Nitzschia bicapitata*, *Pseudo-nitzschia delicatissima*, *Thalassiothrix longissima, Thalassionema elegans* and *Pseudoeunotia* sp., that have already been documented for the Equatorial Pacific by Guillard and Kilham (1977). Occasional occurrences of

some emblematic species of oligotrophic regions were also observed, such as *Chaetoceros dadayi*, *C. peruvianus, C. tetrastichon* or *Planktoniella sol*. It can be noted that radiolarians were also more abundant and more diverse in the ultra-oligtrophic SPG during OUTPACE than in the MA, while unfortunately no information regarding radiolarians is available for the BIOSOPE cruise.

5.3 Evidence for active Si uptake in the pico-planktonic size-fraction in the South Tropical Pacific

The pico-size fraction (<2-3 µm) represented on average 11% of BSi stocks during BIOSOPE, and 26% of BSi stocks during OUTPACE (Fig. 6), which is a non-negligible contribution. ~~If the importance of~~The significant contribution of the pico-size fraction ~~in~~to the BSi stocks during both cruises could be explained by the presence of detrital components, however its contribution to $Si(OH)_4$ uptake during BIOSOPE was really surprising but c~~ould~~an be explained in the light of new findings. Indeed, recent studies have evidenced that the pico-phytoplanktonic cyanobacteria *Synechococcus* can assimilate Si (Baines et al., 2012; Ohnemus et al., 2016; Krause et al., 2017; Brzezinski et al., 2017), which could explain why Si stocks were detected in this size fraction. The first hypothesis was to consider broken fragments of siliceous cells passing through the filter or interferences ~~with~~by lithogenic silica, but these hypotheses were invalidated during BIOSOPE when Si uptake measurements using ^{32}Si were also carried out on this pico-size fraction and revealed a non-negligible uptake, mainly in the Chilean upwelling systems (Fig. 7). ~~It is also excluded that some broken parts of active nano-planktonic diatoms labelled with ^{32}Si could have passed through the filters because of breakage during filtration, as a kinetic type response was observed in most samples (Fig. 8), implying truly active organisms in the 0.2-2 µm size fraction.~~ Our results are thus in line with previous findings, as no other organisms below 2-3 µm are known to assimilate Si, except some small size Parmales, a poorly described siliceous armored planktonic group which span over the 2-10 µm size class, such as *Tetraparma* sp. (Ichinomiya, 2016), or small nano-planktonic diatoms such as *Minidiscus* (Leblanc et al., 2018), close to the 2 µm limit (Fig. 11 a,b). The latter two species could occur in the 2-3 µm size-fraction, but are very easily missed in light microscopy and require SEM imaging or molecular work for correct identification. Presence of Parmales or nano-planktonic diatoms may explain the measurement of BSi in this 0.4 – 3 µm size-class for the OUTPACE cruise, but can be excluded as responsible for the Si uptake measured during BIOSOPE on filters below 2 µm. Rather, during OUTPACE,

NanoSIMS imaging revealed that cytometrically sorted *Synechococcus* cells accumulated Si (Fig. 11c), confirming their potential role in the Si cycle in the South Tropical Gyre.

According to Baines et al. (2012), the Si content of *Synechococcus*, in some cases, could exceed that of diatoms, but these authors suggested that they might exert a larger control on the Si cycle in nutrient-poor waters where these organisms are dominant. In the present study, the largest contribution of the pico-size fraction to absolute ΣρSi uptake rates occurred at both ends of the transect in the Peru-Chile upwelling region and at the MAR station (Table 1), locations which also corresponded to the highest concentrations of *Synechococcus* observed (Grob et al., 2007). However, compared to diatoms, this only represented 1 to 5 % of total ΣρSi uptake, which is probably not likely to drive the Si drawdown in this environment. This low relative contribution to ΣρSi was similarly found at the other end of the transect at HNL and MAR station, but where absolute uptake rates were moderate. The largest contribution of the pico-size fraction was measured in the SPG (GYR and EGY sites), where despite very low ρSi values, the relative ΣρSi uptake between 0.2 and 2 µm reached 16 to 25 %. Station GYR as well as stations 13 to 15 are areas that are highly depleted in orthosilicic acid, with concentrations <1 µM from the surface to as deep as 240 m. Hence, it is probable that *Synechococcus* could play a ~~major~~ role in depleting the Si of surface waters in this area, which are devoid of diatoms.

During the OUTPACE cruise, there were no clear correlations between *Synechococcus* distributions and the measured 0.4-3 µm BSi concentrations. This could be explained by the extremely wide range of individual cellular Si quotas estimated to vary between 1 and 4700 amol Si $cell^{-1}$ (with an average value of 43) from cells collected in the North Western Atlantic (Ohnemus et al., 2016), where *Synechococcus* contributed up to 23.5 % of ΣBSi (Krause et al., 2017). In the latter study, a first-order estimate of the contribution of *Synechococcus* to the global annual Si production flux amounted to 0.7-3.5%, which is certainly low, but comparable to some other important input or output fluxes of Si (Tréguer and De la Rocha, 2013). Using the range of measured Si cellular content per *Synechococcus* cells given in Ohnemus et al. (2016) of 14 to 64 amol Si $cell^{-1}$ and *Synechococcoccus* abundance data from the same casts obtained in flow cytometry (data courtesy of S. Duhamel, Lamont Doherty, NY), this yields a potential contribution of 3 to 14 % of *Synechococcus* to the small BSi fraction, which is close to the previous estimates.

6 Conclusion

The Sargasso Sea (BATS) and the North Tropical Pacific Ocean (ALOHA) were until now the only two subtropical gyres where the Si cycle was fully investigated during time-series surveys. In this paper, we provide the first ~~complementary~~ data from two cruises documenting production, biomass and export fluxes from the oligotrophic to ultra-oligotrophic conditions in the South Tropical Pacific Gyre, which may lower the estimates of diatom contribution to primary productivity and export fluxes for the Pacific Ocean and for mid-ocean gyres in general. The mid-ocean gyres (representing 1/3 of the global ocean) are severely under-sampled regarding the Si cycle, and may encompass very different situations, in particular in the vicinity of Islands and archipelagos with reduced bathymetry, and nutrient-fertilized surface waters, to HNLC waters and even HNLSiLC along the equatorial divergence (Dugdale and Wilkerson, 1998). The mid-ocean gyres contribution to Si production was recently revised down to 5-7% of the total by Brzezinski et al. (2011) building on estimates from the North Subtropical Pacific Gyre. The present study points to even lower values for the South Pacific Gyre, confirming its ultra-oligotrophic nature, and should further decrease this estimate. These findings underscore the differences in functionning of different subtropical oligotrophic gyres between the North Atlantic, North Pacific and South Pacific and clearly warrant for improved coverage of these areas and for more complete elemental studies (from Si production to export).

Diatom community structure and contribution to total biomass could be summarized by differentiating 3 main ecosystems: (i) the eutrophic Peru-Chile coastal upwelling, where colonial neritic centric diatoms such as *Skeletonema* sp., *Chaetoceros* sp. and *Thalassiosira* sp. contributed to elevated abundances (>100,000 cells L^{-1}) and very high Si uptake rates; (ii) the HNLC region off the Marquesas Islands and the nutrient depleted but Fe-fertilized region of the Melanesian Archipelago, where a distinct community largely dominated by small and medium-sized pennates such as *Cylindrotheca closterium* and *Pseudo-nitzschia delicatissima* developed to moderate levels (<30,000 cells L^{-1}), while Fe levels in the MA further stimulated diazotrophs and DDAs which could have stimulated diatom growth through secondary N release; (iii) the SPG, characterized by ultra-oligotrophic conditions and Fe-limitation, where diatoms reached negligible abundances (<200 cells L^{-1}) with species typical of oligotrophic regions, such as *Nitzschia bicapitata*, *Mastogloia woodiana*, *Planktoniella sol* as well as radiolarians.

Finally, thanks to both size-fractionated biomass and Si uptake measurements, we were able to confirm a potential role for *Synechococcus* cells in Si uptake in all environments, which may be of importance relative to diatoms in oligotrophic regions, but probably negligible in highly productive regions such as coastal upwellings. Mechanisms linked to Si uptake in *Synechococcus* and its ecological function still need to be elucidated, and further attention to the Si cycle needs to be placed on this elusive pico- and nano-sized fraction.

7 Data availability

All data is available upon request through both cruises databases, for BIOSOPE (http://www.obs-vlfr.fr/proof/vt/op/ec/biosope/bio.htm) and OUTPACE (http://www.obs-vlfr.fr/proof/php/outpace/outpace.php). For the Si stocks and flux data for the OUTPACE cruise, see http://www.seanoe.org/data/00446/55743/. For the BIOSOPE cruise, see http://www.seanoe.org/data/00446/55722/.

8 Author contribution

KL treated all data and wrote the paper. BQ and PR sampled on board and analyzed Si data from the BIOSOPE cruise. SH-N and O.G. collected nutrient samples on board and analyzed nutrient data from the OUTPACE cruise. VC sampled for all BSi data and diatom diversity on board, and analyzed plankton net samples on the OUTPACE cruise. CB analyzed all Si data and ran diatom cell counts during her Masters thesis. HC and JR were in charge of all pigment data for both cruises. NL collected and analyzed Si export flux data from the OUTPACE drifting sediment traps.

9 Competing interests

The authors declare that they have no conflict of interest.

10 Special Issue Statement

This article is part of the special issue "Interactions between planktonic organisms and biogeochemical cycles across trophic and N_2 fixation gradients in the western tropical South Pacific Ocean: a multidisciplinary approach (OUTPACE experiment)"

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13 Figure Legend

Figure 1: Bathymetric map of the stations sampled in the South Pacific Ocean during the OUTPACE cruise (Feb.-Apr. 2015) and the BIOSOPE cruise (Oct.-Nov. 2004). Short-term duration stations are indicated in white, and long-term duration stations (typically 2-3d) in black.

Figure 2: Nutrient distribution (a. orthosilicic acid, b. nitrate, c. phosphate, in µ—M) along the OUTPACE cruise transect and potential density (in kg m^{-3}) as white isolines overlay.~~.~~

Figure 3: Nutrient distribution (a. orthosilicic acid, b. nitrate, c. phosphate, in µ—M) along the BIOSOPE cruise transect and potential density (in kg m^{-3}) as white isolines overlay.~~.~~

Figure 4 : ~~Top panel:~~a. TChl*a* distribution during the OUTPACE cruise in the SW Pacific (in µg L^{-1}) with fucoxanthin overlay lines in white (in ng L^{-1}). b. ~~Lower panel:~~ TChl*a* distribution during the BIOSOPE cruise in the SW Pacific (in µg L^{-1}) with fucoxanthin overlay lines in white (in ng L^{-1}). Black dots indicated the Ze depth.

Figure 5: a.c Biogenic silica (BSi) and b.d. Lithogenic Silica (LSi) distribution during the OUTPACE and BIOSOPE cruises respectively (in µmol L^{-1}).

Figure 6: a.b Size-fractionated integrated Biogenic silica (ΣBSi) standing stocks (0-125 m) during the BIOSOPE cruise. UPW1 stations was only integrated over 50 m and UPX1 and UPX2 over 100 m. The b panel shows a zoom over the central section where integrated BSi stocks are an order of magnitude lower than at the two extremities of the transect. Grey bars indicate that no size-fractionation was conducted and represent the total ΣBSi. C. Size-fractionated integrated Biogenic silica (ΣBSi) standing stocks (0-125 m) during the OUTPACE cruise.

Figure 7: a. Total absolute Si uptake rates (ρSi) vertical profiles (in µmol L^{-1} d^{-1}) at the LD stations MAR, HNL, GYR, EGY, UPX and UPW. b. ρSi in the 0.2 - 2 µm size fraction at the same sites. X-axis is in log scale to better show low production profile.

Figure 8: ~~Si uptake kinetic experiments conducted at the LD stations MAR, HNL, GYR, EGY, UPX at various euphotic depths. Specific Si uptake rates (in d^{-1}) are plotted vs $Si(OH)_4$ increasing concentrations. Data was adjusted with hyperbolic curves when statistically relevant and V_{max} and K_S values indicated below each curve~~Diatom doubling times k (in d^{-1}) as tukey box-plot of all data available per vertical profile for each station of the BIOSOPE cruise.

Figure 9: Diatoms cellular concentrations (cells L^{-1}) derived from a. Niskin cell counts, b. number of taxa and c. relative contribution to POC biomass (%) at the surface and DCM levels during the OUTPACE cruise.

Figure 10: Diatoms cellular concentrations (cells L^{-1}) derived from Niskin cell counts at several depths during the BIOSOPE cruise (data from Gomez et al. 2007).

Figure 11: Potential siliceous organisms in the picoplanktonic (<2-3 µm) size fraction. a.Siliceous scale-bearing Parmale (*Tetraparma pelagica* in SEM, photo courtesy of Dr. J. Young), b. centric diatom (*Minidiscus trioculatus*), c. *Synechoccocus* cell showing Si assimilation in red (^{28}Si) in NanoSIMS (photo courtesy of M. Caffin).

14 Tables

Table 1: Size-fractionated integrated Si production rates in mmol Si m^{-2} d^{-1} in the SEP (BIOSOPE). Integrated Si production was measured over the 0-1% light depth range for each site (in parenthesis in column 5), and normalized over 100 m considering a zero production at 100 m in the last column.

Stations	ΣρSi <2µm	ΣρSi 2-10 µm	ΣρSi >10µm	Total ΣρSi	Total ΣρSi over 0-100 m
MAR1	0.15	0.51	4.37	5.02 (50 m)	5.87
HNL1	0.05	0.12	0.58	0.75 (80 m)	0.77
GYR2	0.01	0.01	0.02	0.04 (110 m)	0.04
EGY	0.03	0.07	0.09	0.19 (100 m)	0.19
UPW2	0.62	2.88	39.66	43.16 (35 m)	52.36
UPX1	1.07	5.90	13.49	20.46 (30 m)	42.46

Table 2: Dominant diatom species in each main system of the BIOSOPE and OUTPACE cruises. Taxonomic information for the OUTPACE cruise are derived from discrete samplings at the surface and DCM and phytoplankton nets, while information for the BIOSOPE cruise were obtained through an average of six discrete samples over the euphotic layer (see Gomez et al., 2007).

Cruise	Oceanic system	Dominant diatom species
OUTPACE	Melanesian Archipelago	*Pseudo-nitzschia spp. & Pseudo-nitzschia delicatissima, Cylindrotheca closterium, Mastogloia woodiana, Leptocylindrus mediterraneus, Hemiaulus membranaceus, Chaetoceros spp. (hyalochaete), Pseudosolenia calcar-avis, Climacodium frauenfeldianum, Planktoniella sol*
	South Pacific Gyre	*Climacodium frauenfeldianum, Pseudo-nitzschia spp., Chaetoceros spp. (hyalochaete), Pseudo-nitzschia delicatissima, Mastogloia woodiana*
BIOSOPE	Western HNLC area (Marquesas)	*Pseudo-nitzschia delicatissima, Rhizosolenia bergonii, Thalassiothrix longissima, Plagiotropis spp., Pseudo-nitzschia pungens, P. subpacifica*
	South Tropical Pacific	*Nitzschia bicapitata species complex, Nitzschia sp., Thalassiothrix longissima, Pseudo-nitzschia delicatissima*
	South Pacific Gyre	*Hemiaulus hauckii, Chaetoceros curvisetus, Bacteriastrum cf. comosum*
	Eastern Gyre	*Pseudo-nitzschia cf. delicatissima, Pseudo-nitzschia cf. subpacifica, Pseudoeunotia sp.*
	Peru-Chile Upwelling	*Chaetoceros compressus, Bacteriastrum sp., Thalassiosira subtilis, Chaetoceros cf. diadema, Skeletonema sp., Pseudo-nitzschia sp.*

1008 **Table 3: Particulate biogenic and lithogenic (BSi and LSi) Silica in drifting sediment traps at each long duration station**
1009 **during OUTPACE cruise, at 153, 328 and 519 m depth.**

1010

	Trap depth	BSi	LSi
	m	μmol Si m^{-2} d^{-1}	μmol Si m^{-2} d^{-1}
A	153	0.5	23.1
	328	0.2	4.6
	519	0.1	5.2
B	153	2.6	0.4
	328	2.9	0.6
	519	4.8	1.1
C	153	1.8	0.5
	328	0.5	0.2

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1019 **Table 4: Integrated Si production rates in various systems for comparison with our study from direct ^{32}Si uptake**
1020 **measurements or from indirect silicate utilization (ΔSiO_4) estimates (*).**

Region	Integrated Si production rate ΣρSi (mmol m^{-2} d^{-1})	References
Coastal upwellings		
BIOSOPE: Peru-Chile upwelling	**42 – 52 (UPW)**	***This study***
Baja California	89	Nelson and Goering, 1978
Monterey Bay	70	Brzezinski et al., 1997
Peru	27	Nelson et al., 1981
Southern California Current coastal waters	1.7 – 5.6	Krause et al., 2015
Oceanic area		
BIOSOPE: South Eastern Pacific (HNLC)	**0.8 – 5.6 (HNL – MAR)**	***This study***
Gulf Stream warm rings	6.4	Brzezinski and Nelson, 1989
Central Equatorial Pacific (HNLC)	3.9	Blain et al., 1997
North Pacific (OSP)	5.1	Wong and Matear, 1999*
North Atlantic (POMME)	1.7	Leblanc et al., 2005b
North Atlantic (Bengal)	0.9	Ragueneau et al., 2000
Mediterranean Sea (SOFI)	0.8	Leblanc et al., 2003
Oligotrophic area		
BIOSOPE: South Eastern Pacific Gyre	**0.04 (GYR) – 0.2 (EGY)**	***This study***
Central Equatorial Pacific	0.8 – 2.1	Blain et al., 1997
Eastern Equatorial Pacific	0.2 – 2.5	Leynaert et al., 2001 ; Adjou et al., 2011 ; Krause et al., 2011, Demarest et al., 2011
Central North Pacific	0.5 – 2.9	Brzezinski et al., 1998
North Pacific Subtropical Gyre	0.1 – 1.7	Krause et al., 2013
North Pacific Subtropical Gyre (ALOHA)	0.1 – 0.5	Brzezinski et al., 2011
Sargasso Sea	0.5	Brzezinski and Nelson, 1995
Sargasso Sea (BATS)	0.1 – 0.9	Brzezinski and Kosman, 1996 (1996), Nelson and Brzezinski, 1997

Table 5: Summary of ΣBSi stocks in mmol Si m^{-2} for the OUTPACE and BIOSOPE and other oceanic and oligotrophic systems.

Region	Average Integrated Si biomass ΣρSi (mmol m^{-2})	References
Coastal upwellings		
BIOSOPE: Peru-Chile upwelling	**65.7 ± 53.8**	***This study***
Southern California Current coastal waters	53.2 ± 39.3	Krause et al., 2015
Oceanic area		
Southern California Current oceanic waters	1.6 ± 0.3	Krause et al., 2015
BIOSOPE: South Eastern Pacific (HNLC)	**11.9 ± 10.9**	***This study***
Oligotrophic area		
Mediterranean Sea (BOUM)	1.1 – 28.2	Crombet et al., 2011
Sargasso Sea (BATS)	4.0 ± 6.8	Nelson et al., 1995
Sargasso Sea	0.9 – 6.1	Krause et al., 2017
North Pacific Subtropical Gyre	1.6 – 12.8	Krause et al., 2013
North Pacific Subtropical Gyre (ALOHA)	3.0 ± 1.1	Brzezinski et al., 2011
Central North Pacific	7.1 ± 3.0	Brzezinski et al., 1998
Eastern Equatorial Pacific	3.8 – 18.0	Krause et al., 2011
BIOSOPE: South Eastern Pacific Gyre	**1.1 ± 1.1**	***This study***
OUTPACE: South Western Pacific Gyre	**1.0 ± 0.2**	***This study***
OUTPACE: Melanesian Archipalago	**2.4 ± 1.0**	***This study***

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1037 **Table 6: Summary of Si export fluxes in sediment traps at various depths in µmol Si m^{-2} d^{-1}**
1038 **for the OUTPACE cruise compared to other studies.**

Region	Sediment trap depth (m)	Average Si export fluxes (µmol m^{-2} d^{-1})	References
Coastal upwellings			
Southern California Current coastal waters	100	8,000 ± 5,760	Krause et al., 2015
Oceanic area			
North Atlantic (NABE)	400	10 – 145	Honjo and Manganini, 1993
North Atlantic (POMME)	400	2 - 316	Mosseri et al., 2005 ; Leblanc et al., 2005b
North Pacific Subtropical Gyre (ALOHA)	150	14 - 300	Brzezinski et al., 2011
Oligotrophic area			
Sargasso Sea (BATS)	150	17 - 700	Nelson et al., 1995
Sargasso Sea (BATS)	150	130	Brzezinski and Nelson, 1995
	200	113	
	300	85	
OUTPACE: South Western Pacific Gyre	153	**1.8**	***This study***
	328	**0.5**	
OUTPACE: Melanesian Archipelago	153	**1.6**	***This study***
	328	**1.6**	
	519	**2.5**	

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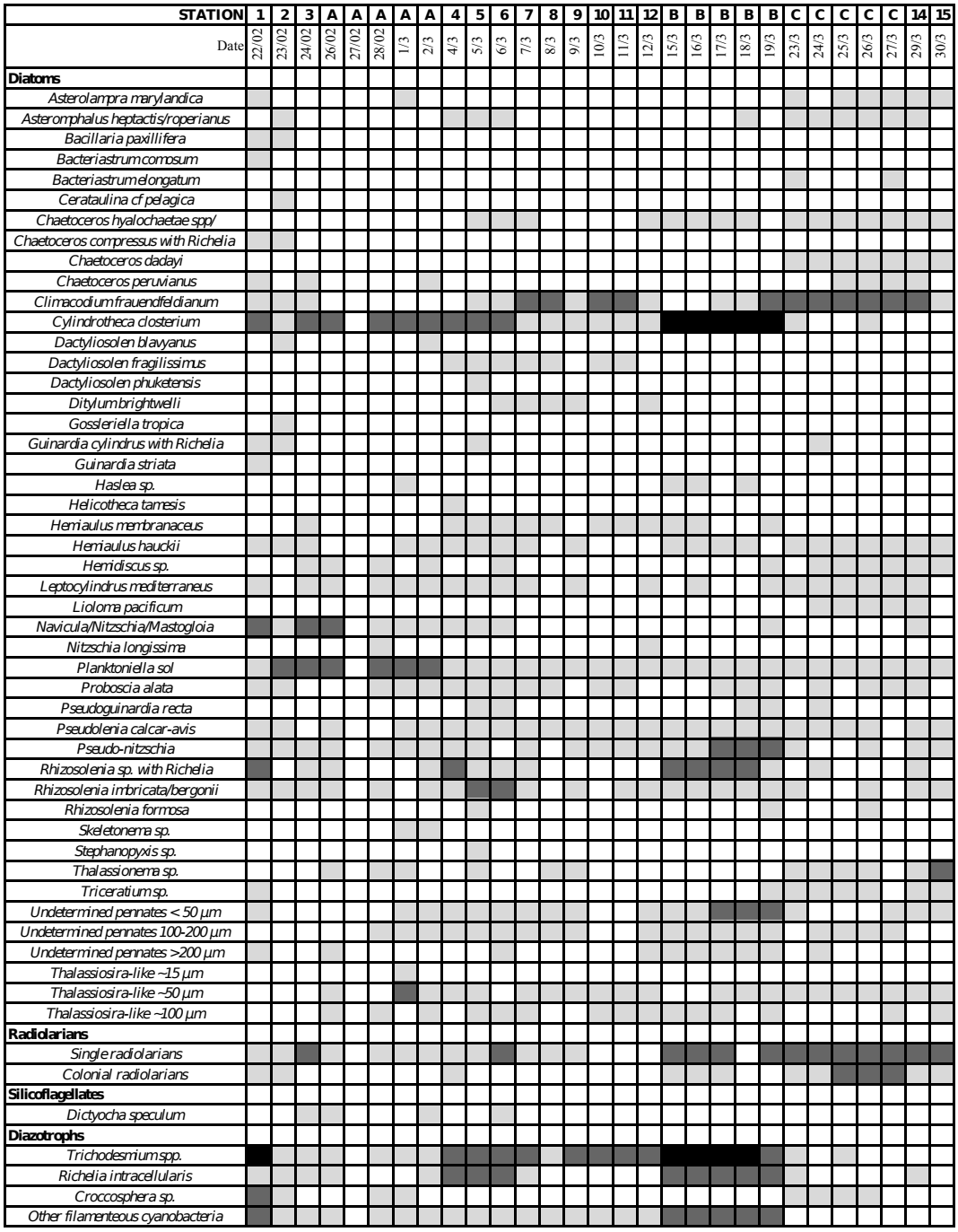
15 Appendices

Stations	ΣBSi 0.2-2 µm (mmol m^{-2})	ΣBSi 2-10 µm (mmol m^{-2})	ΣBSi >10 µm (mmol m^{-2})	Total ΣBSi (mmol m^{-2})
MAR1	0.36	3.49	20.28	24.12
NUK1	0.34	0.66	2.40	3.40
HNL1	0.20	2.34	5.54	8.09
1				3.79
2				0.40
3				0.48
4				0.31
5				0.20
6				0.18
7				0.20
8				0.49
GYR2	0.30	0.37	0.55	1.23
GYR5	0.13	0.24	0.39	0.75
11				0.42
12				0.82
13				0.16
14				0.47
15				1.03
EGY2	0.29	0.45	0.87	1.60
EGY4	0.15	0.25	0.65	1.05
17				2.36
18				2.47
19				0.45
20				1.50
21				3.48
UPW1*	1.27	5.36	55.43	62.05
UPW2	3.75	15.28	124.10	142.81
UPX1**	7.66	9.80	14.64	32.00
UPX2**	2.27	8.12	15.49	25.88

Appendix 1: Integrated size-fractionated Biogenic Silica concentrations (ΣBSi) in the South Eastern Pacific (BIOSOPE cruise) over 0-125 m. 0-50 m for * and 0-100 m for **.

Stations	ΣBSi 0.4-3 µm (mmol m^{-2})	ΣBSi > 3 µm (mmol m^{-2})	Total ΣBSi (mmol m^{-2})
1	1.24	2.52	3.76
2	0.39	3.56	3.95
3	0.43	1.83	2.26
A	0.26	1.83	2.09
4	1.06	2.24	3.30
5	0.51	3.60	4.11
6	0.70	1.80	2.49
7	0.39	1.95	2.34
8	0.39	1.12	1.51
9	0.50	1.45	1.96
10	0.77	0.98	1.75
11	0.24	1.00	1.24
12	0.17	1.29	1.46
B	0.30	1.60	1.89
13	0.17	0.96	1.13
C*	0.50	0.93	1.43
C*	0.59	1.03	1.61
14*	0.68	1.02	1.70
15*	0.76	1.38	2.14

Appendix 2: Integrated size-fractionated Biogenic Silica concentrations (ΣBSi) in the South Western Pacific (OUTPACE cruise) over 0-125 m and 0-200 m for *.



Appendix 3: Semi-quantitative contribution of siliceous plankton (diatoms, radiolarians, silicoflagellates) and diazotrophs in plankton nets hauls of 35 µm mesh size (over 0-150 m at all sites except but over 0-200 m at stations 14 and 15) during the OUTPACE cruise. Long duration stations were sampled every day. Light grey, medium grey and dark grey correspond to minor, common and dominant abundances respectively.

Figure 1

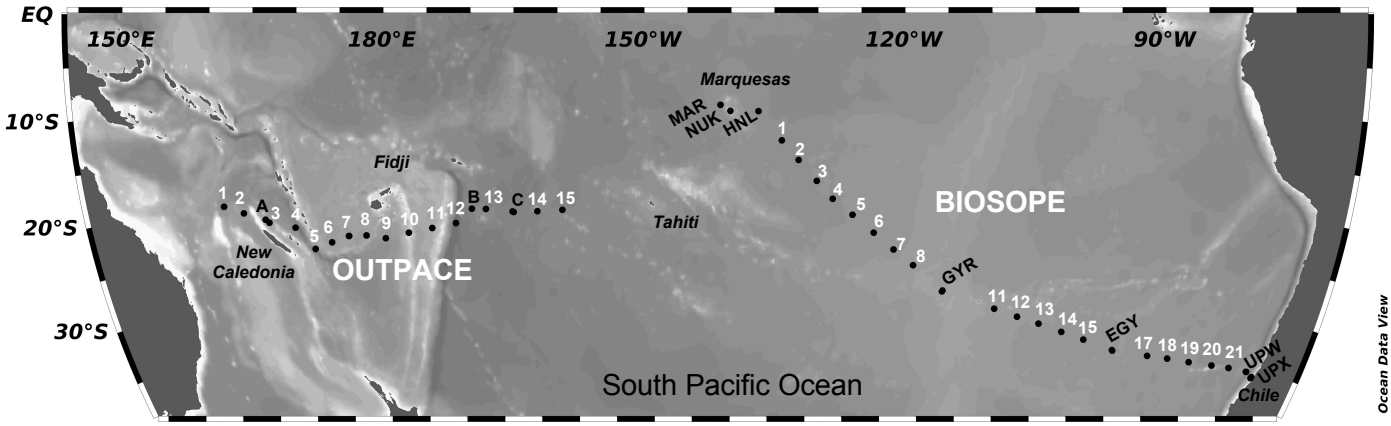

EQ
150°E
180°E
150°W
120°W
90°W
10°S
20°S
30°S
Marquesas
MAR
NUK
HNL
Fidji
Tahiti
New Caledonia
OUTPACE
BIOSOPE
GYR
EGY
UPW
UPX
Chile
South Pacific Ocean
Ocean Data View

Figure 2

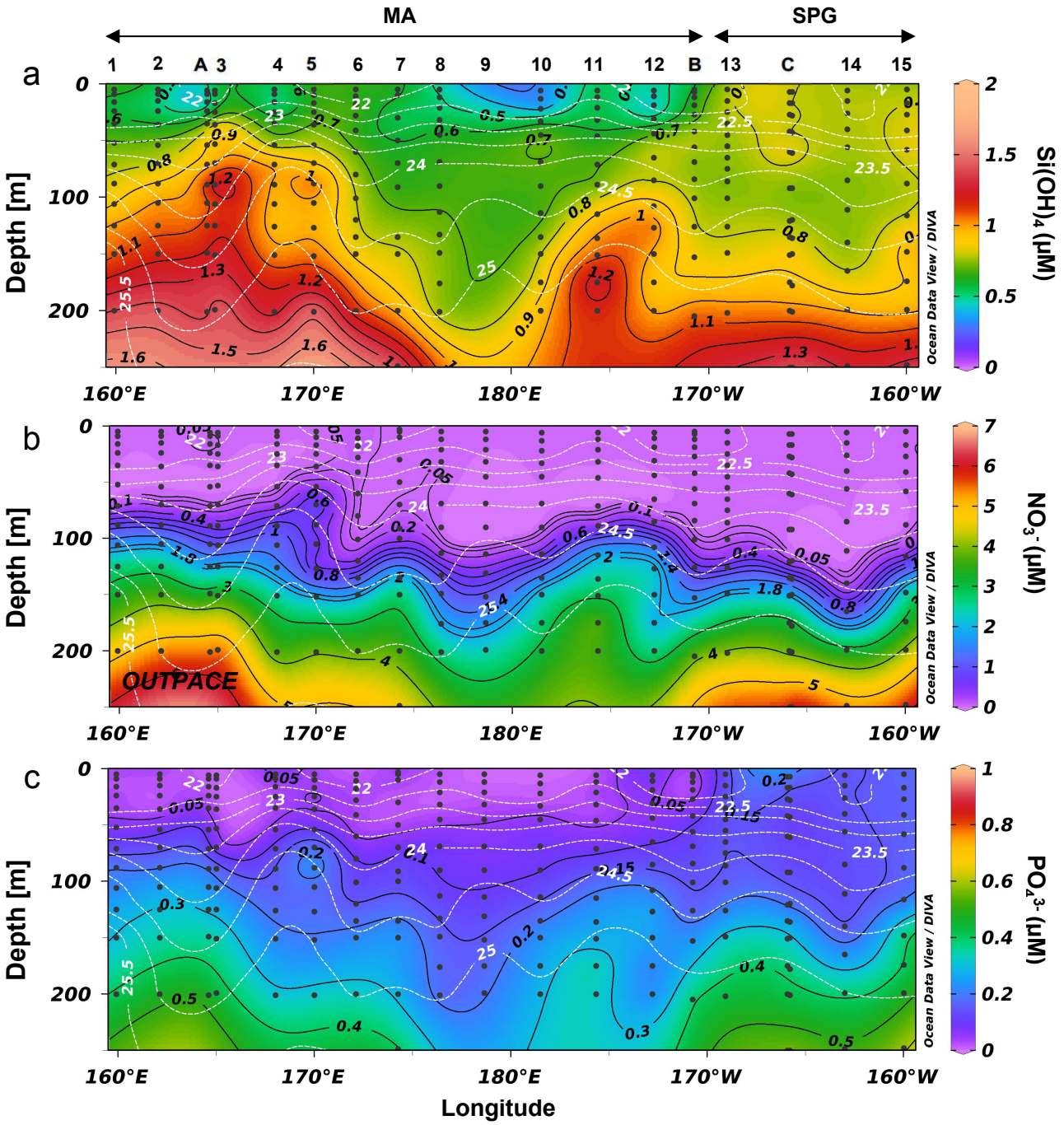

MA
SPG
1 2 A 3 4 5 6 7 8 9 10 11 12 B 13 C 14 15
a
b
c
Depth [m]
0
100
200
160°E
170°E
180°E
170°W
160°W
Longitude
OUTPACE
Ocean Data View / DIVA
Si(OH)4 (µM)
NO3- (µM)
PO43- (µM)

Figure 3

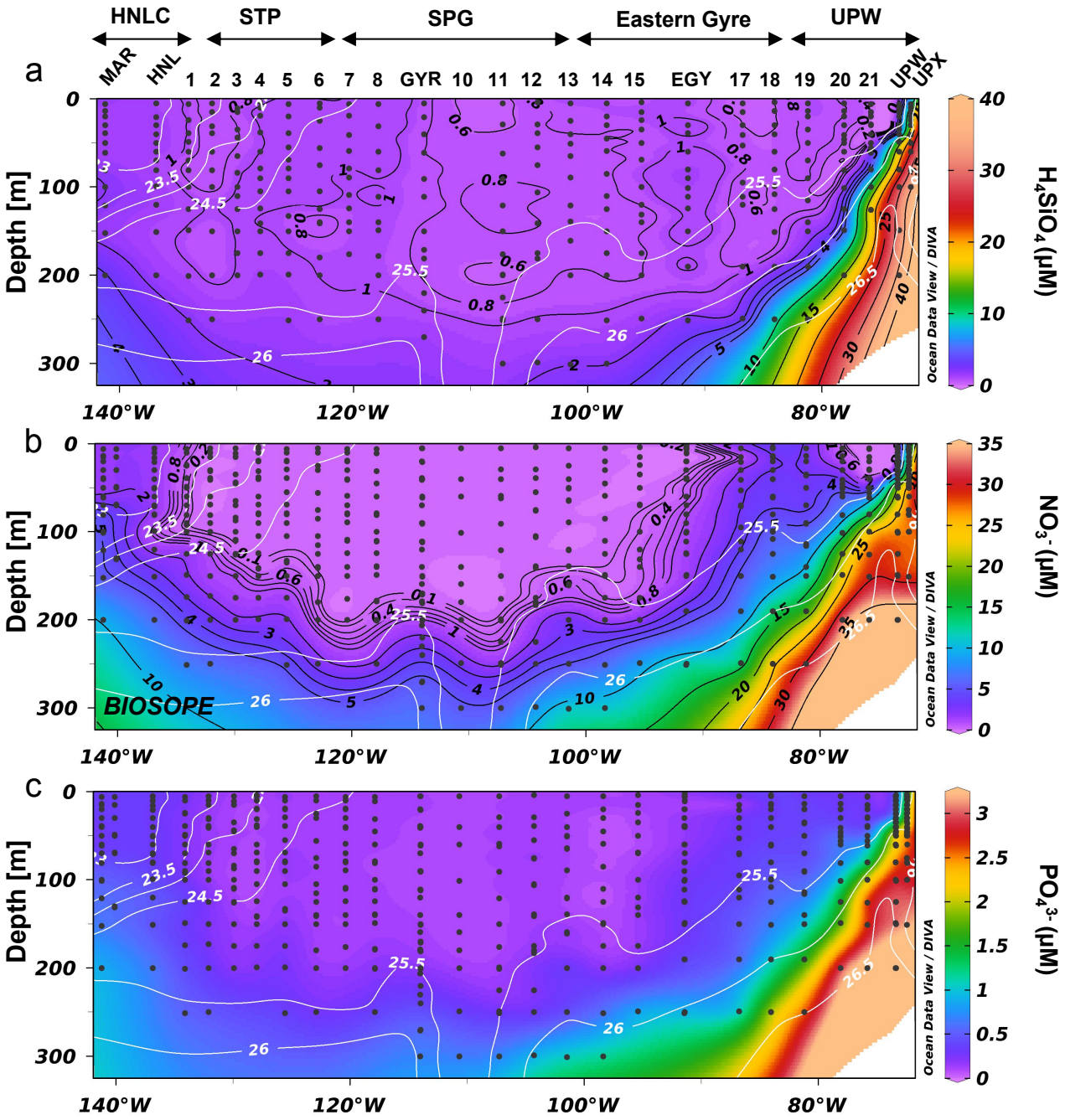

HNLC
STP
SPG
Eastern Gyre
UPW
a
MAR
HNL
1 2 3 4 5 6 7 8 GYR 10 11 12 13 14 15 EGY 17 18 19 20 21
UPW
UPX
Depth [m]
0
100
200
300
140°W
120°W
100°W
80°W
Ocean Data View / DIVA
H4SiO4 (µM)
40
30
20
10
0
b
BIOSOPE
NO3- (µM)
35
30
25
20
15
10
5
0
c
PO43- (µM)
3
2.5
2
1.5
1
0.5
0

Figure 4

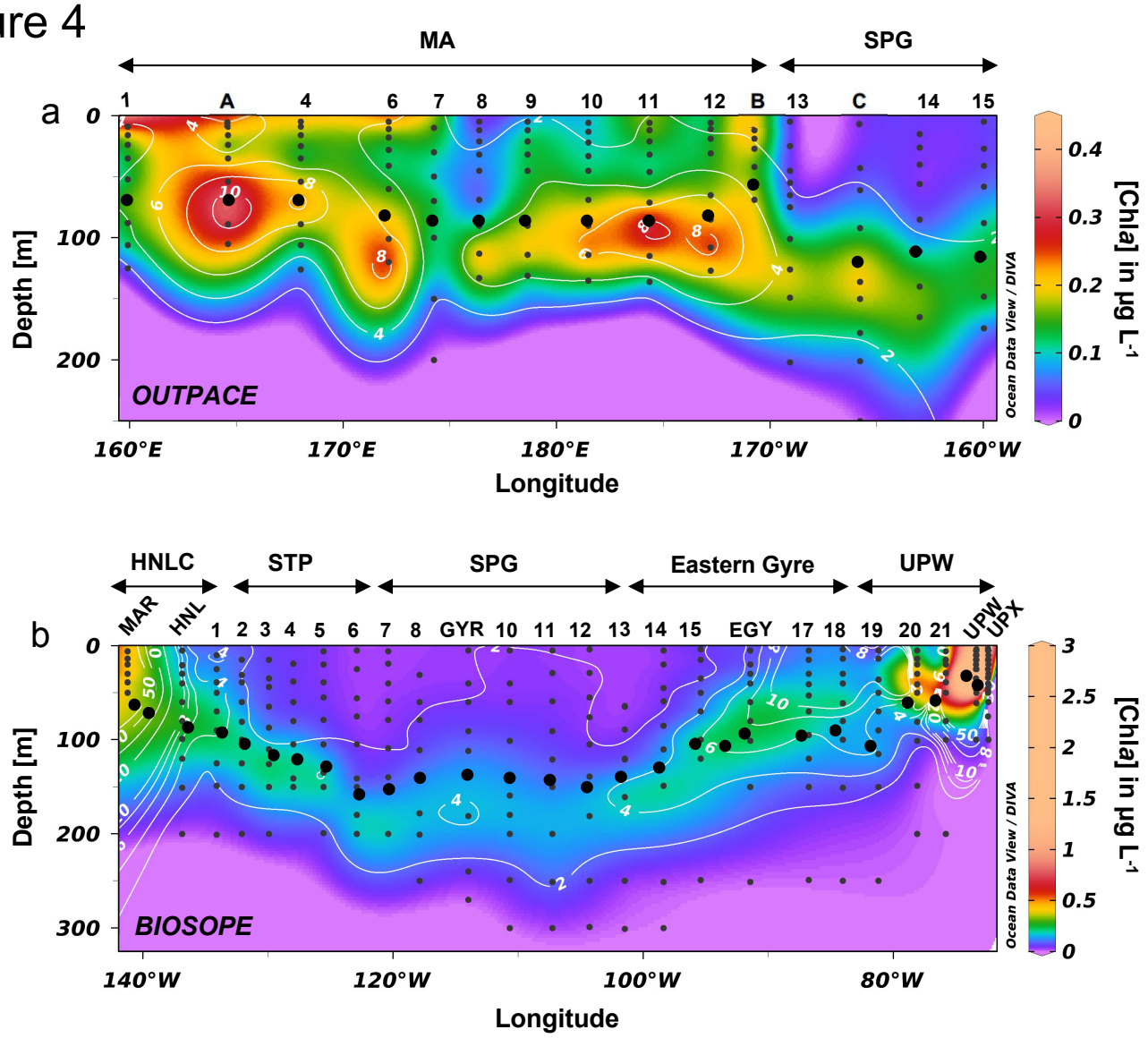
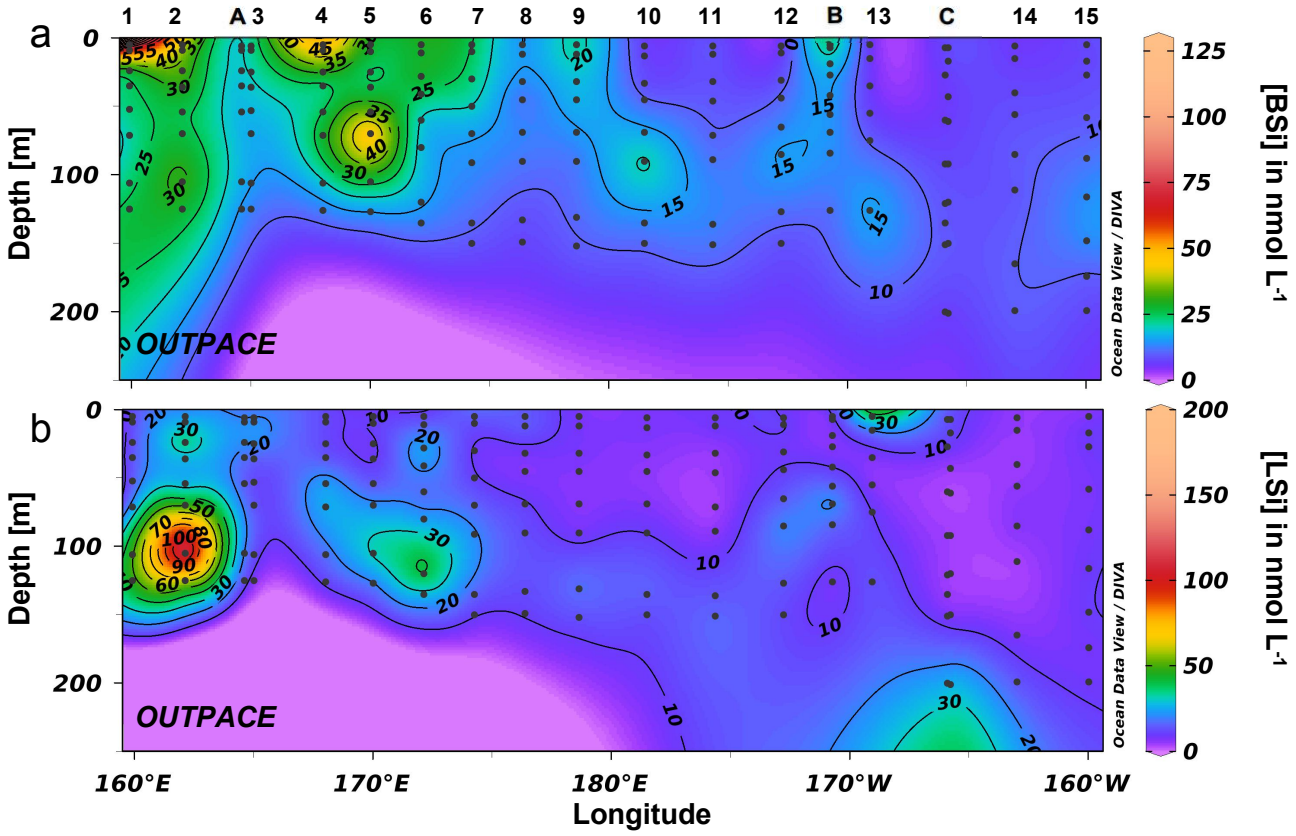

a
MA
SPG
1
A
4
6
7
8
9
10
11
12
B
13
C
14
15
0
100
200
Depth [m]
OUTPACE
160°E
170°E
180°E
170°W
160°W
Longitude
Ocean Data View / DIVA
0.4
0.3
0.2
0.1
0
[Chla] in µg L-1
b
HNLC
STP
SPG
Eastern Gyre
UPW
MAR
HNL
1
2
3
4
5
6
7
8
GYR
10
11
12
13
14
15
EGY
17
18
19
20
21
UPW
UPX
0
100
200
300
Depth [m]
BIOSOPE
140°W
120°W
100°W
80°W
Longitude
Ocean Data View / DIVA
3
2.5
2
1.5
1
0.5
0
[Chla] in µg L-1

Figure 5


a
b
1 2 A 3 4 5 6 7 8 9 10 11 12 B 13 C 14 15
Depth [m]
0
100
200
OUTPACE
Ocean Data View / DIVA
[BSi] in nmol L-1
125
100
75
50
25
0
[LSi] in nmol L-1
200
150
100
50
160°E
170°E
180°E
170°W
160°W
Longitude

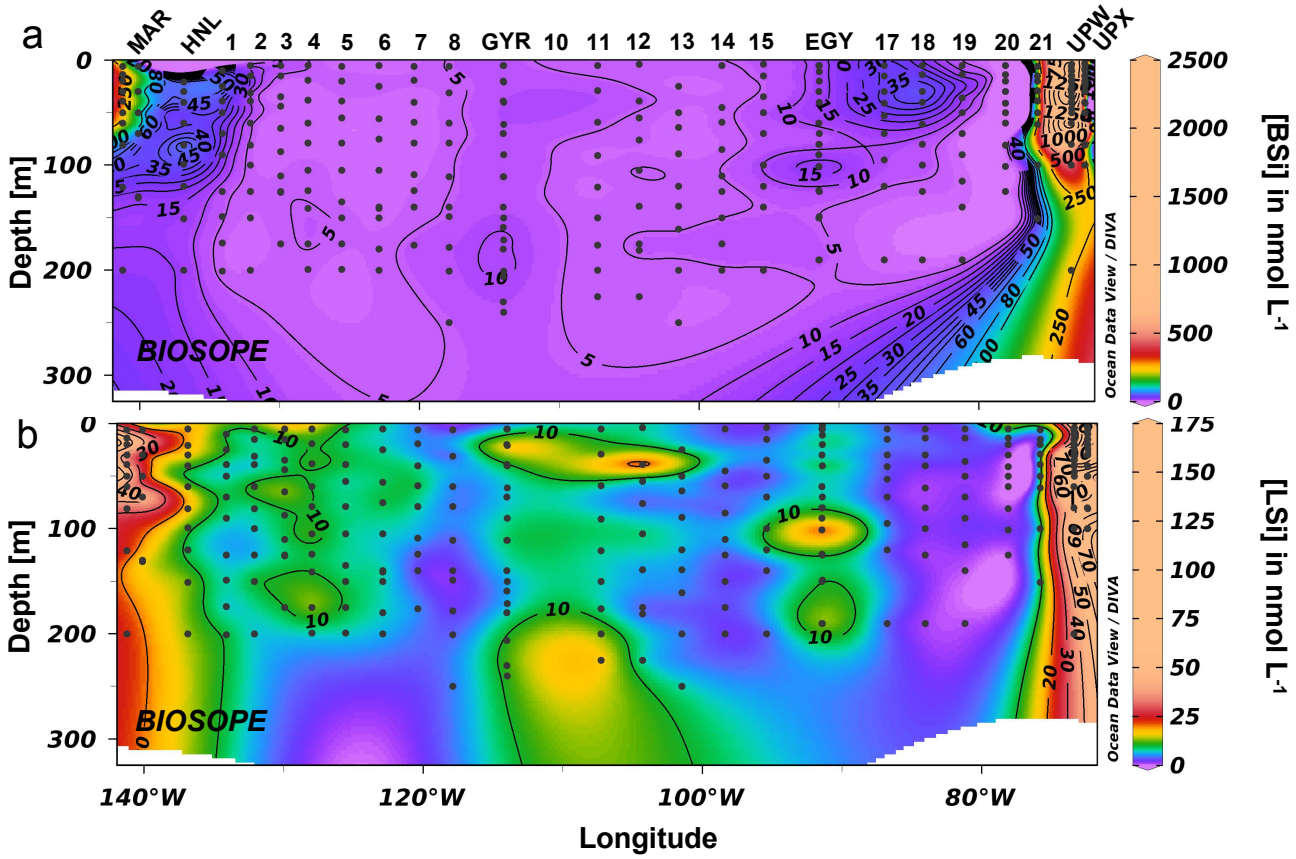

a
b
MAR HNL 1 2 3 4 5 6 7 8 GYR 10 11 12 13 14 15 EGY 17 18 19 20 21 UPW UPX
Depth [m]
0
100
200
300
BIOSOPE
Ocean Data View / DIVA
[BSi] in nmol L-1
2500
2000
1500
1000
500
0
[LSi] in nmol L-1
175
150
125
100
75
50
25
140°W
120°W
100°W
80°W
Longitude

Figure 6

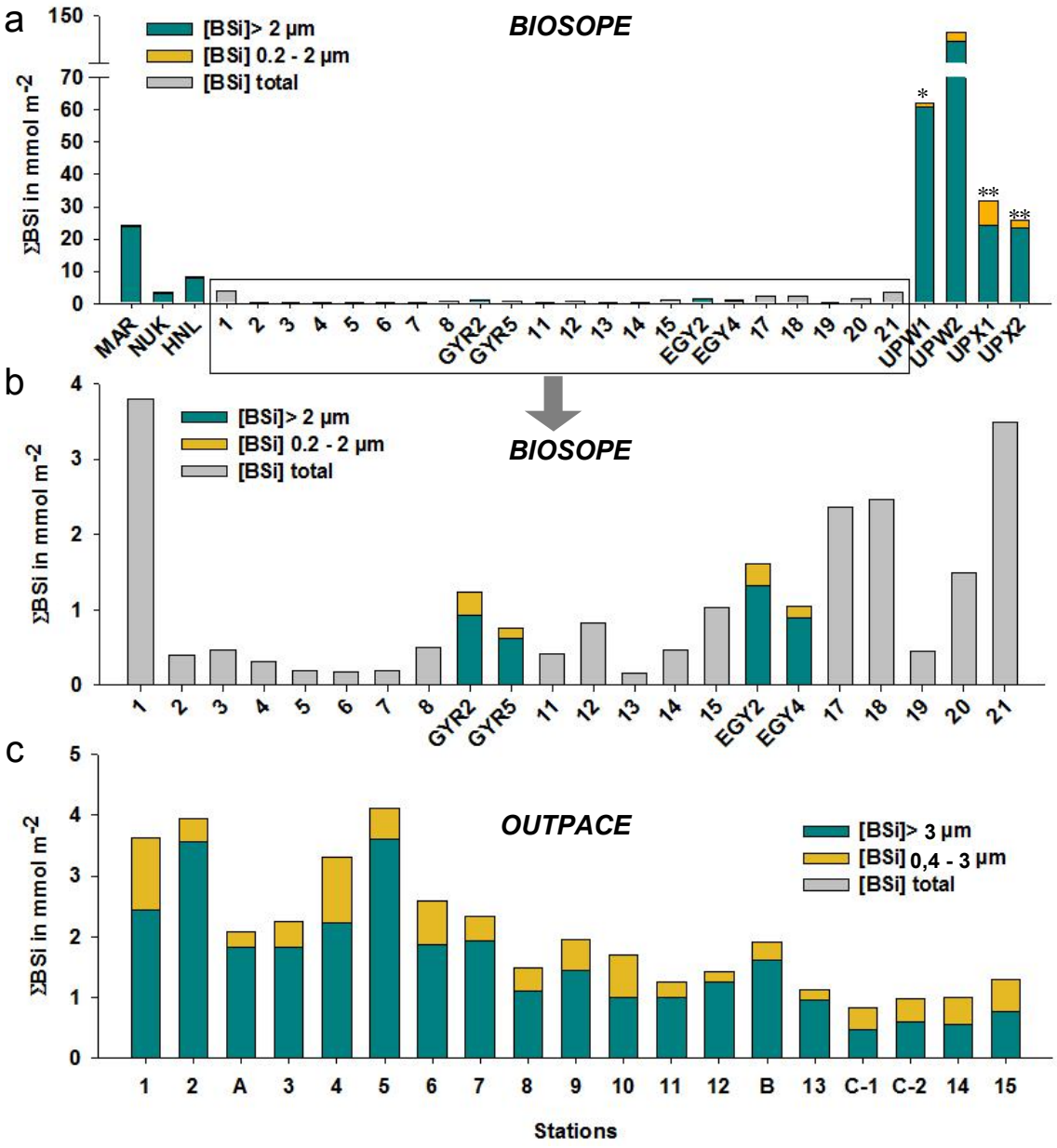

a
[BSi]> 2 µm
[BSi] 0.2 - 2 µm
[BSi] total
BIOSOPE
ΣBSi in mmol m-2
MAR
NUK
HNL
1
2
3
4
5
6
7
8
GYR2
GYR5
11
12
13
14
15
EGY2
EGY4
17
18
19
20
21
UPW1
UPW2
UPX1
UPX2
b
[BSi]> 2 µm
[BSi] 0.2 - 2 µm
[BSi] total
BIOSOPE
ΣBSi in mmol m-2
c
OUTPACE
[BSi]> 3 µm
[BSi] 0,4 - 3 µm
[BSi] total
ΣBSi in mmol m-2
1
2
A
3
4
5
6
7
8
9
10
11
12
B
13
C-1
C-2
14
15
Stations

Figure 7

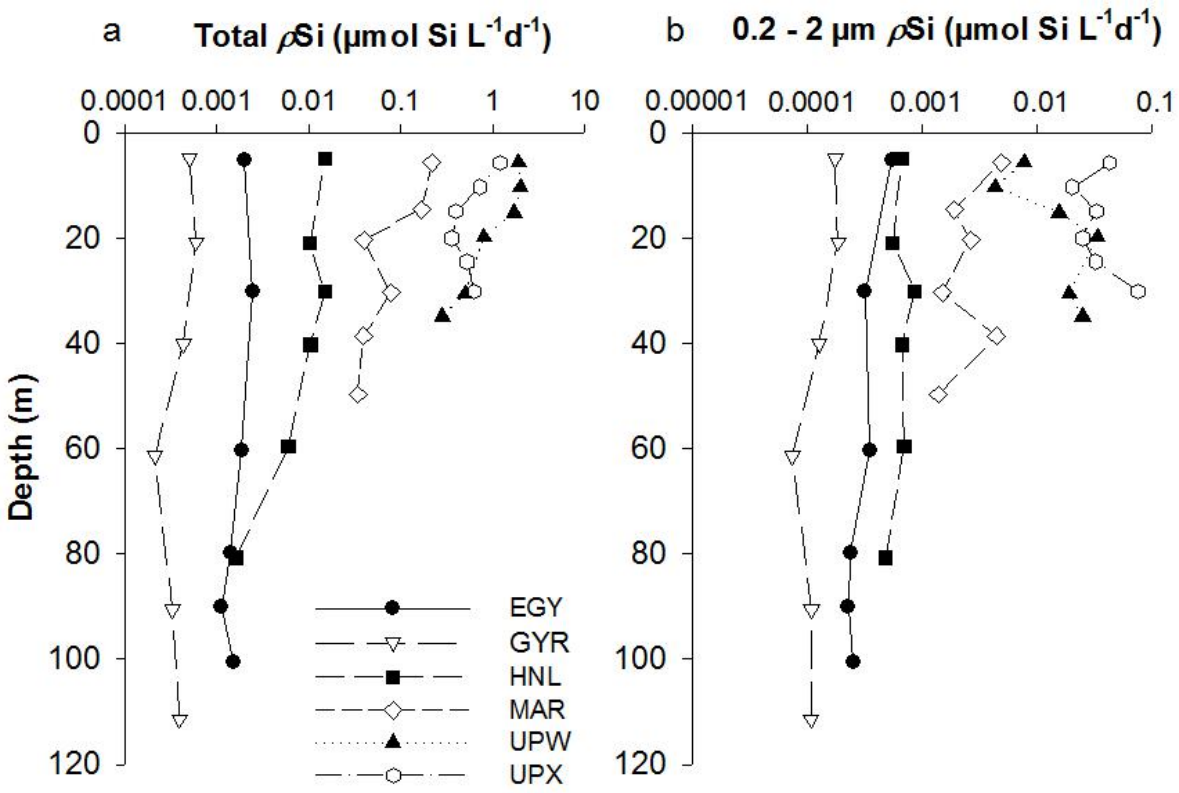

a
Total ρSi (µmol Si L-1d-1)
0.0001
0.001
0.01
0.1
1
10
b
0.2 - 2 µm ρSi (µmol Si L-1d-1)
0.00001
0.0001
0.001
0.01
0.1
Depth (m)
0
20
40
60
80
100
120
EGY
GYR
HNL
MAR
UPW
UPX

Figure 8

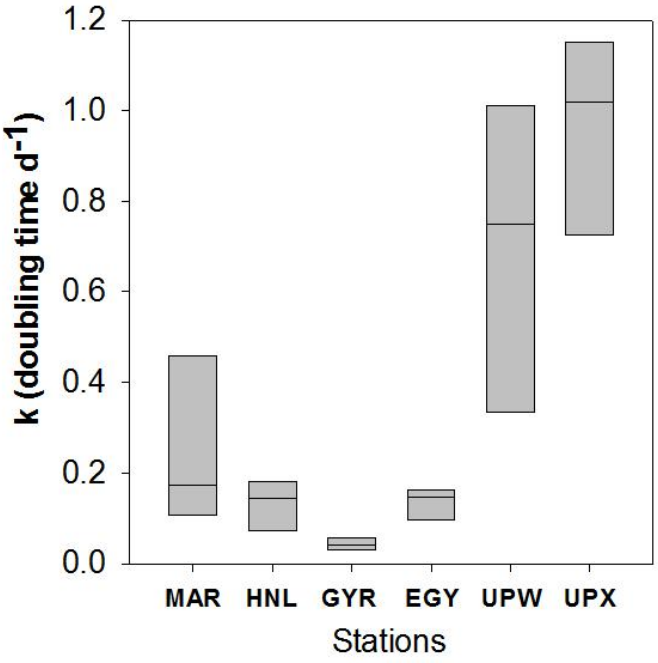

1.2
1.0
0.8
0.6
0.4
0.2
0.0
k (doubling time d-1)
MAR
HNL
GYR
EGY
UPW
UPX
Stations

Figure 9

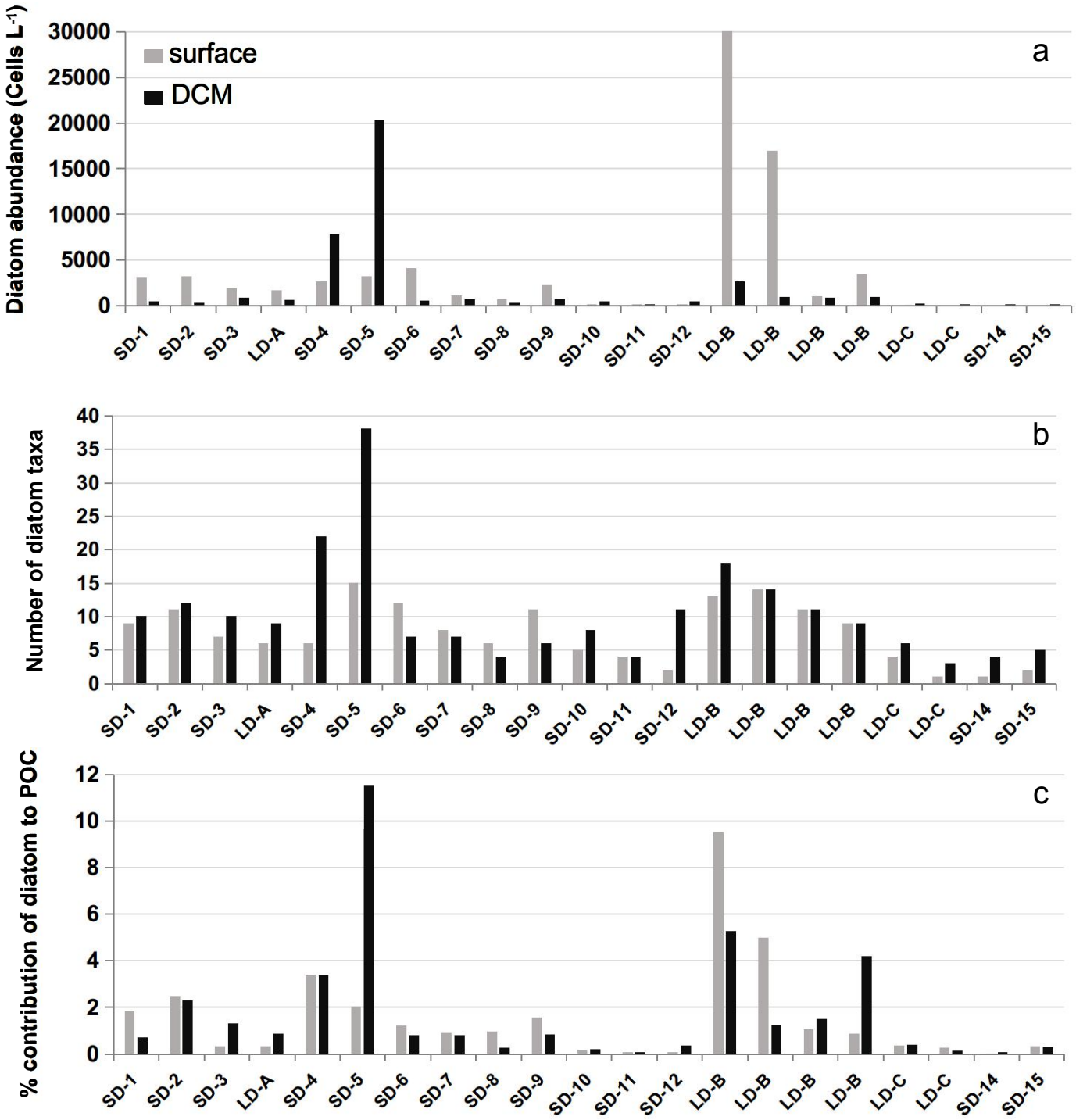

Diatom abundance (Cells L-1)
surface
DCM
a
Number of diatom taxa
b
% contribution of diatom to POC
c
SD-1
SD-2
SD-3
LD-A
SD-4
SD-5
SD-6
SD-7
SD-8
SD-9
SD-10
SD-11
SD-12
LD-B
LD-B
LD-B
LD-B
LD-C
LD-C
SD-14
SD-15

Figure 10

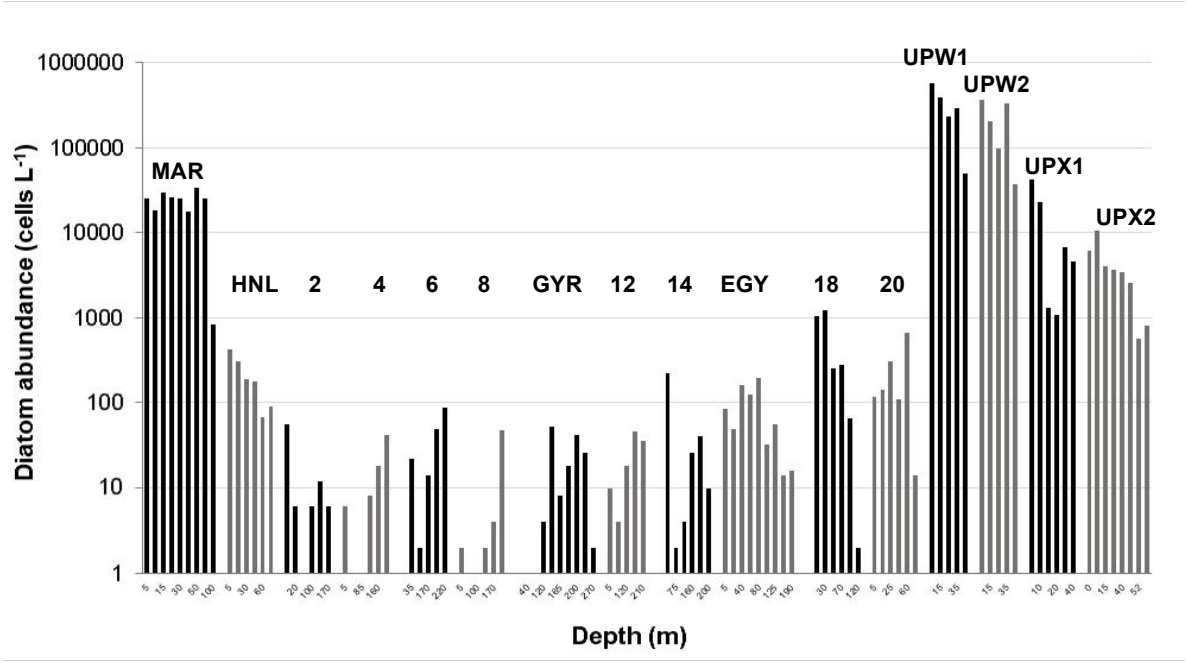
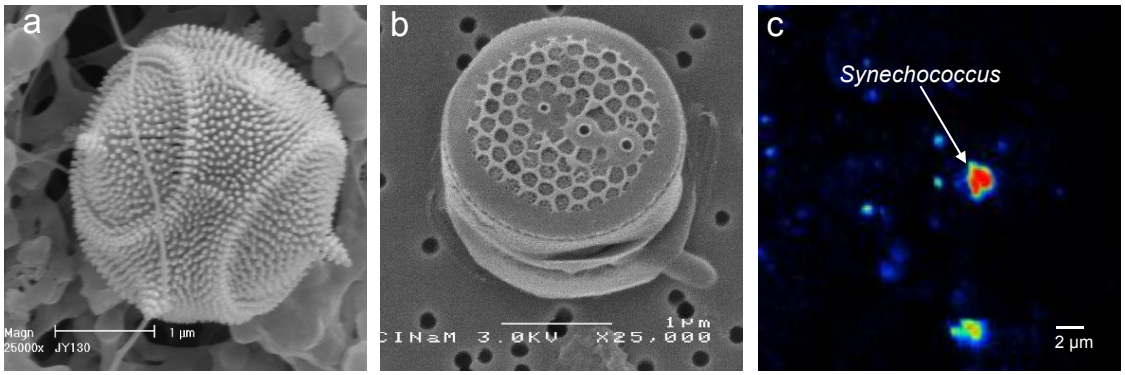

Diatom abundance (cells L-1)
1000000
100000
10000
1000
100
10
1
MAR
HNL
2
4
6
8
GYR
12
14
EGY
18
20
UPW1
UPW2
UPX1
UPX2
Depth (m)

Figure 11


a
Magn
25000x JY130
1 µm
b
1µm
CINaM 3.0KV X25,000
c
Synechococcus
2 µm