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Interactive comment on "*Trichodesmium* and nitrogen fixation in the Kuroshio" *by* T. Shiozaki et al.

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Anonymous Referee #2 General Comments: The main question posed in this manuscript seems to be whether observations support the hypothesis that nutrient supply through transport from the Ryukyu Islands fuels growth of Trichodesmium in the Kuroshio. The authors do not find evidence of a gradient in phosphorus and iron between the Islands and the Kuroshio. They do find elevated Trichodesmium abundances near the Ryukyu Islands and conclude that Trichodesmium grows in that region and is transported downstream to the Kuroshio. This is an interesting and significant result. However, the major evidence presented in support of this process is a series of numerical simulations demonstrating advection of particles from the Islands to the Kuroshio. Quantitative analysis of the simulations is not presented. Since this piece of evidence

is so crucial to the paper, it should be evaluated and presented more thoroughly and quantitatively. The nutrient dynamics of the region and potential nutrient supply mechanisms could also be treated more thoroughly. Additionally, the manuscript would benefit from further revisions to improve organization, clarity, and flow. I have included some specific detailed comments below.

We have calculated the ratio of particles delivered to the Kuroshio to total released particles in the revised manuscript. In 2003–2009, 13–56% (30 $\pm$ 16%) of particles released from the Miyako Islands were delivered to the Kuroshio and passed the Tokara Strait. (L356-359) It should be noted that our numerical experiments contained the following two uncertainties. First, the distribution of Trichodesmium around the islands, which strongly influences the destinations of particles, was not able to be determined in advance. Trichodesmium is known to aggregate and not to occur uniformly in the ocean (Capone et al., 1997). Second, the model cannot reproduce the current very close to the islands. If a water mass very near the islands was delivered to the open ocean by tide and/or river plumes that were not considered in the model, seaward dispersions of particles was likely underestimated. We have added these statements and results in L235-243. In addition, we have examined the particle tracks depending on the start time. When the start time was changed to June 1, 11, and 21, and July 1 in 2009, the particle tracks largely varied (Fig.S5). The ratio particles delivered to the Kuroshio varied from 6.2–38% (22 $\pm$ 13%) on day 120. (L361-364)

We have also mentioned about phosphorus limitation for nitrogen fixation and N/P ratio in each area in the revised manuscript. We have replied in detail below.

Specific Comments: Abstract: The major conclusion seems to be that Trichodesmium may be advected into the Kuroshio from the Ryukyu Islands, but this is not clear from the abstract.

We have changed the last sentence in the Abstract as follows. (L34-35) "Our results indicate that Trichodesmium growing around the Ryukyu Islands could be advected

into the Kuroshio"

Introduction: p.11063 lines 1-8: What is the relevance to the present study? This section could be shortened.

We have deleted these sentences from the revised manuscript.

p.11063 lines 28-29: "Phosphorus would ultimately limit diazotrophy because phosphorus in oligotrophic regions is consumed by diazotrophs, and is thus depleted." This sentence seems inaccurate, or at best, poorly worded, and could be removed. The discussion of previous findings related to the distribution of phosphorus in the region could be expanded.

We have revised the sentence as follows. "As for phosphorus limitation, iron-enhanced nitrogen fixation causes phosphorus depletion, and is consequently limited by phosphorus (Mather et al., 2008)."

Materials and Methods: p. 11067 lines 26-28: The distribution of Trichodesmium with depth can vary significantly. Perhaps the data from all depths could be presented where available.

We have added the figure of vertical distribution of Trichodesmium spp. abundance (Fig. S3).

p.11068 Section 2.3: Please provide more details on the methods used for the numerical experiments. What particle-tracking methods were used?

Numerical particle-tracking experiments were conducted to investigate the transport of water masses at the surface from areas around the Miyako Islands in the summer season from 2003 to 2009. Surface velocity data were derived from the FRA-JCOPE2 reanalysis product (Miyazawa et al., 2009), which is an eddy-resolving (1/12°) ocean model combined with three-dimensional variational data assimilation (satellites, ARGO floats, and shipboard observations), and is one of the most reliable models for the region around Japan for the above time period. The method of tracking particles was

basically the same as in Itoh et al. (2009), but we did not include the random walk for simplicity. We have added these statements at L218-226.

p.11068 lines12-13: "The particle distribution at the surface was fixed throughout the experiment." What does this mean?

This means the particle does not sink from the surface during the experiments. We have revised the sentences as follows. (L226-228) "The release points of particles were selected at the surface of the model grid points around the coastal waters of the Miyako Islands. We assumed that the particles did not increase, die, or sink from the surface during the experiments."

Results: p.11068 line 24-p.11069 line 1: "The algal bloom frequency was consistently > 10% in the west of the main stream of the Kuroshio because the average chl a was > 0.15 mg/m-3." Please clarify.

We have revised the sentence as follows. (L253-255) "In the west of the main stream of the Kuroshio, because the average chl a was over 0.15 mg m-3 (Fig. S2), the frequency of chl a values >0.15 mg m-3 was high (Fig. 1b)."

p. 11070 lines 3-8: Can the authors provide further justification for the basis of the analysis on surface Trichodesmium abundance? Perhaps a plot of depth-integrated vs. surface Trichodesmium abundance could be included.

The vertical distribution of Trichodesmium spp. abundance has been shown in Fig. S3. The abundance of Trichodesmium spp. was highest at the surface at almost all of the stations. Furthermore, the surface Trichodesmium spp. abundances were positively correlated with the depth-integrated abundances ($p < 0.05$, t-test) (Fig. 6a). (L291-293)

p. 11070 lines 25-27: Can the direction of the currents be verified with data?

The model data we assimilated satellite altimetry data, which means that satellite-based surface velocity field was reflected to the model outputs. Although shipboard

ADCP recorded vertical velocity profiles along the ship track, it is difficult to eliminate tidal components that may change direction even within the same day.

p. 11071 lines 24-28: Quantitative analysis could strengthen the manuscript. For instance, what is the likelihood a trajectory starting in the island region will end up in the Kuroshio, based on the simulations? Also, to what extent does the start time influence the results?

We have calculated the ratio of particles delivered to the Kuroshio to total released particles in the revised manuscript. As the Kuroshio generally flows along the continental slope north of the Miyako Islands (Fig. 1b), particles around the Miyako Islands were not transported along the typical path of the Kuroshio to the northeast, especially at their initial stages (Fig. 7a). Some particles migrated around the Miyako Islands, or turned south after they passed the Tokara Strait. Nevertheless, the particles delivered to Area K east of the Tokara Strait increased as time elapsed, and the ratio of particles delivered to Area K to the total released particles ranged from 13–56% (30 $\pm$ 16%) by day 120 in 2003–2009 (Fig. 7b). The year-to-year variations in the ratio are mainly due to influences of mesoscale eddies as partly seen in the particle trajectories in Fig. 7a, and likely occurred over relatively short time scales (shorter than the seasonal time scale). This is supported by another series of experiments in which particles were released on June 1, 11, and 21, and July 1 in 2009, which yielded ratios of 6.2–38% (22 $\pm$ 13%) by day 120 (Fig. S5). (L352-364)

p.11073 line 17-p.11074 line 2: Please reword for clarity. Also, here iron is referred to as "the limiting nutrient", but phosphorus may also play a role.

We have added the sentences as follows. (L427-431) Furthermore, the iron-enhanced active nitrogen fixation causes phosphorus depletion, and is consequently limited by phosphorus (Mather et al., 2008). No significant differences in surface iron and phosphate were observed among the study areas, which cannot explain the distribution of Trichodesmium spp. and nitrogen fixation in the study region.

p.11074 lines 13-15: This doesn't make sense. Do you mean "contribute to" rather than "be attributed to"?

Yes. We have changed to "contribute to". (L444)

p.11074 lines 15-22: The conclusion that "physical conditions" were similar in all regions based on consistent MLDs seems like a bit of a stretch. Perhaps the authors could reword this to make a more precise statement. Also, was there variation in N:P ratio among the regions analyzed?

We have changed "physical conditions" to "vertical mixing conditions". (L450) The surface N/P (=N+N/phosphate) at each station has been shown in Table S1, respectively. The N/P (=N+N/phosphate) ratio at the surface varied from 0.28 to 6.40 except St. T0904 (N/P=16.3), and no significant difference was observed among the four areas ($p > 0.05$, Tukey's HSD test). (L279-281)

p.11074 line 27 - p. 11075 line 1: What is the "inconsistency" between Trichodesmium abundance and iron and phosphate concentrations and how is it explained by the preceding part of the sentence?

This means why the Trichodesmium distribution in this region was not estimated from iron and phosphate concentrations. We have change the wording in L457-458. We described the inconsistency in L429-431.

p. 11075 lines 4-7: delete "This is because"

We have deleted as suggested.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/12/C6914/2015/bgd-12-C6914-2015-supplement.pdf

Interactive comment on Biogeosciences Discuss., 12, 11061, 2015.

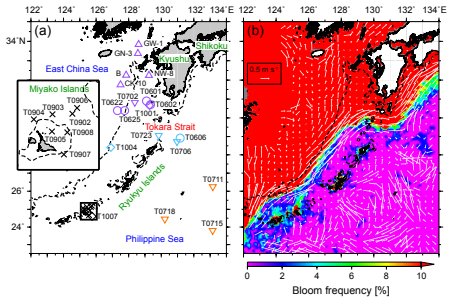

Fig 1 Shiozaki et al.

Fig. 1. (a) Sampling stations and (b) climatological surface current fields

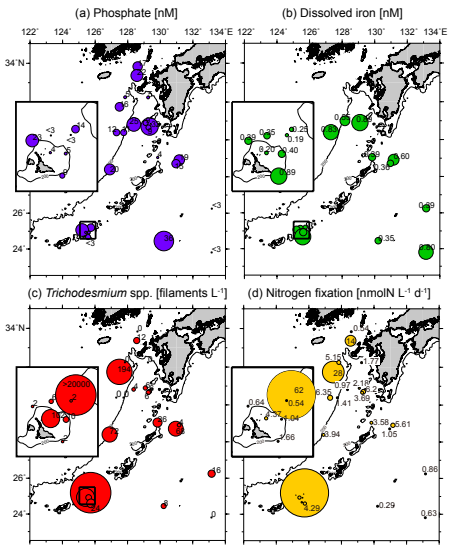

Fig 2 Shiozaki et al.

Fig. 2. Distribution of (a) phosphate, (b) dissolved iron, (c) Trichodesmium spp., and (d) nitrogen fixation at the surface.

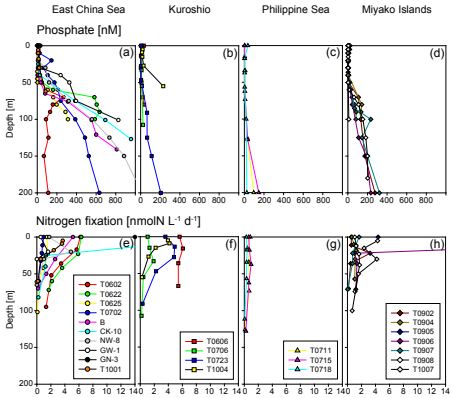

Fig 3 Shiozaki et al.

Fig. 3. Vertical profiles of phosphate and nitrogen fixation in the East China Sea (a and e), the Kuroshio (b and f), the Philippine Sea (c and g), and the Miyako Islands (d and h).

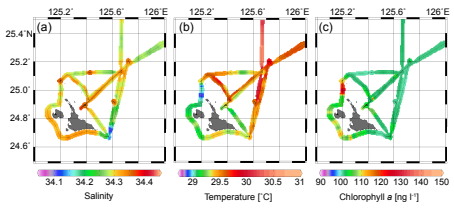

Fig 4 Shiozaki et al.

Fig. 4. Surface (a) salinity, (b) temperature, and (c) chlorophyll a during the KT-09-17 cruise.

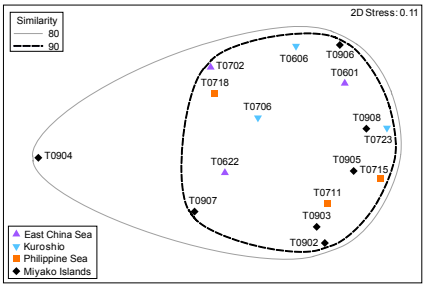

Fig 5 Shiozaki et al.

Fig. 5. nMDS ordination of sampling stations with environmental variables

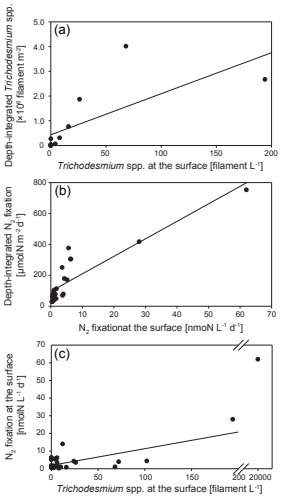

Fig 6 Shiozaki et al.

Fig. 6. Relationships (a) between surface and depth-integrated Trichodesmium spp. , (b) between surface and depth-integrated N2 fixation, and (c) between Trichodesmium spp. and N2 fixation at the surface.

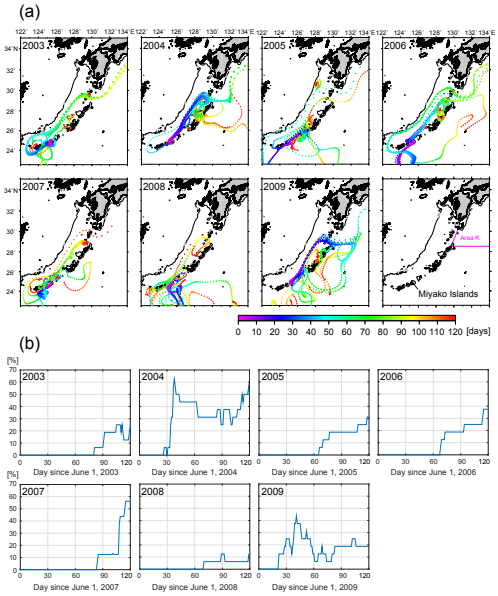

Fig 7 Shiozaki et al.

Fig. 7. (a) Trajectories of particles released from points around the Miyako Islands on June 1, 2003–2009. (b) The ratio of particles delivered to Area K to the total released particles.