Impact of air emissions from shipping on marine phytoplankton growth

Zhang, Chao; Shi, Zongbo; Zhao, Junri; Zhang, Yan; Yu, Yang; Mu, Yingchun; Yao, Xiaohong; Feng, Limin; Zhang, Fan; Chen, Yingjun; Liu, Xiaohuan; Shi, Jinhui; Gao, Huiwang

DOI:
10.1016/j.scitotenv.2021.145488

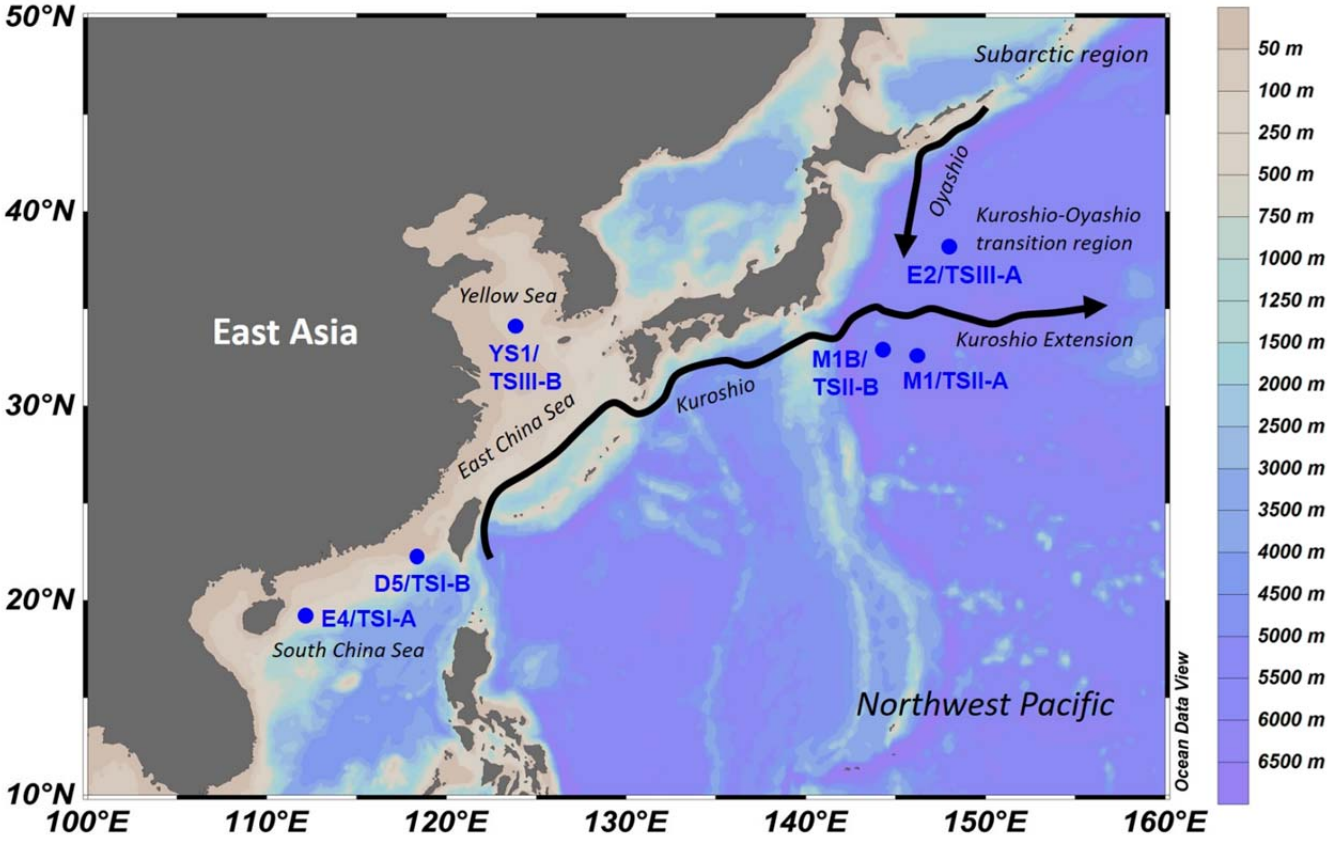

Figure 1. Locations of the sampling stations where the onboard microcosm experiments were performed. The base map reflects water depths of the ocean

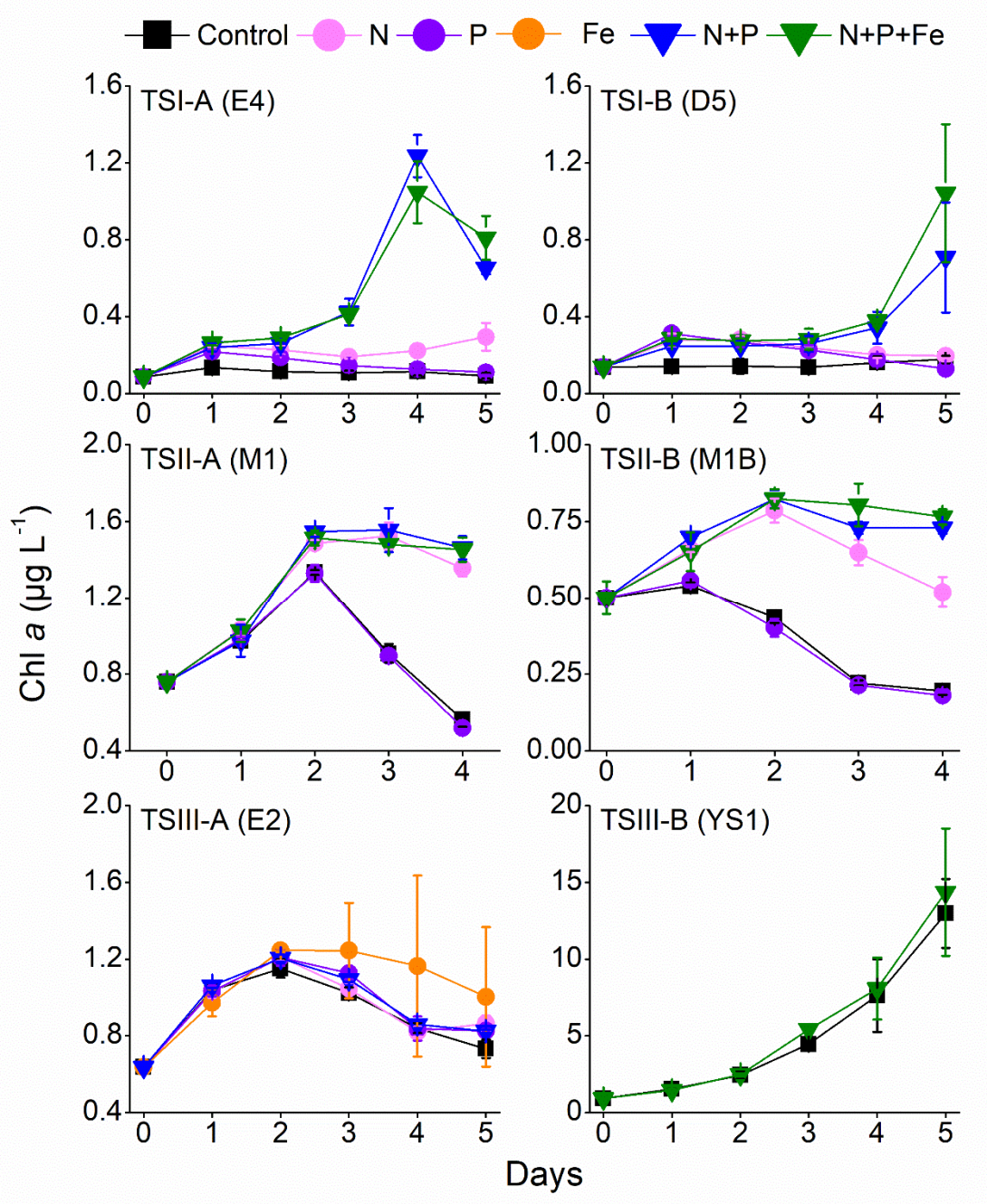

Figure 2. Responses of Chl *a* concentrations to various nutrient additions over the duration of the incubation experiments. "Control", "N", "P", "Fe", "N+P", and "N+P+Fe" in this figure indicate the control, N, P, Fe, N+P, and N+P+Fe treatments, respectively.

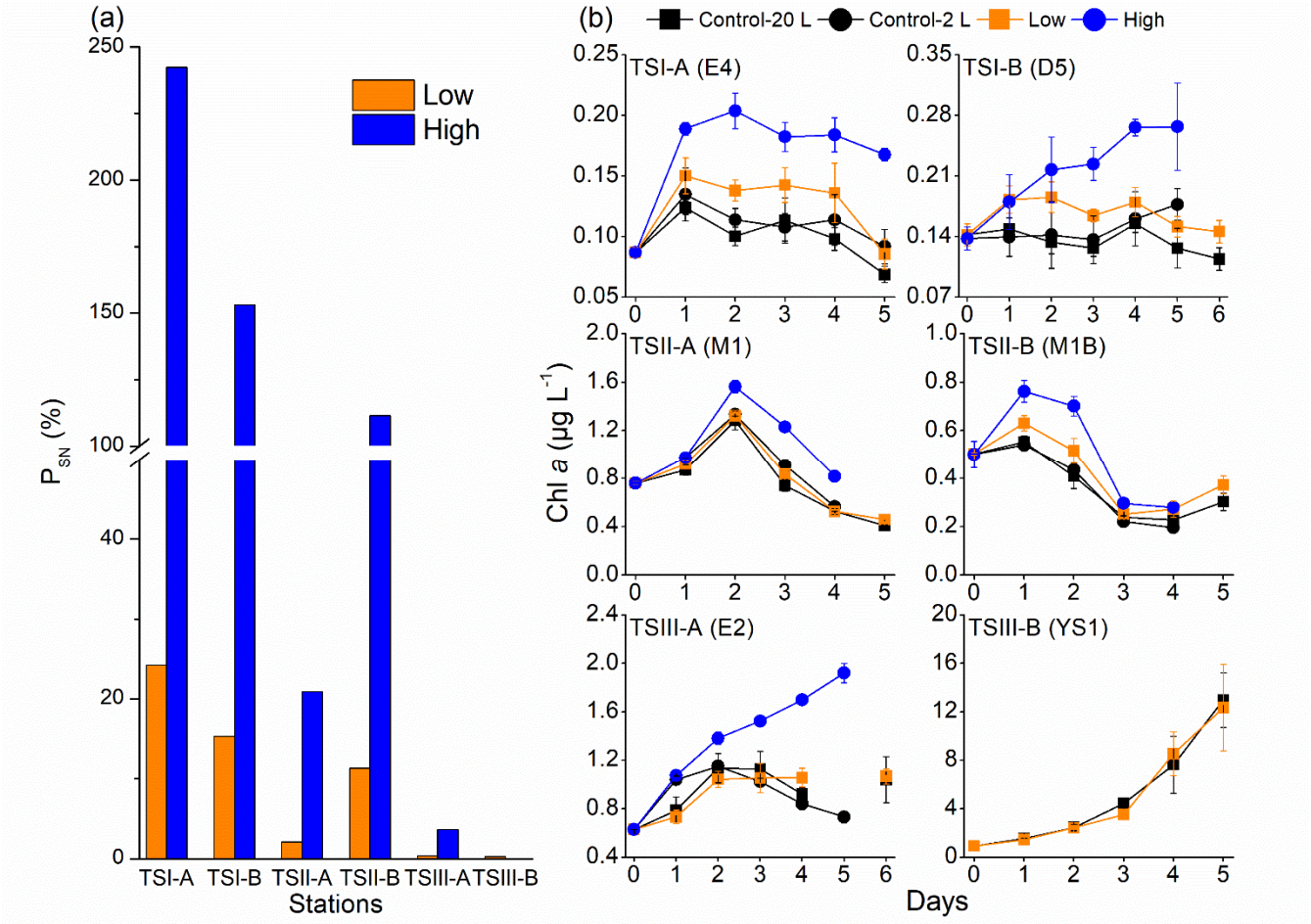

Figure 3. (a) Proportion of N supplied by ship-emitted particles (SEPs) relative to N stocks in the baseline seawater (P_{SN}=[N supplied by SEP additions/N stocks in the baseline seawater]×100) for low and high SEP treatments at the sampling stations**.** (b) Responses of total Chl *a* to low and high SEP additions during the incubation experiments. "Control-20 L" and "Control-2 L" indicate the control treatments for 20 L and 2 L incubation bottles, respectively. "Low" and "High" indicate low-SEP treatments and high-SEP treatments, respectively.

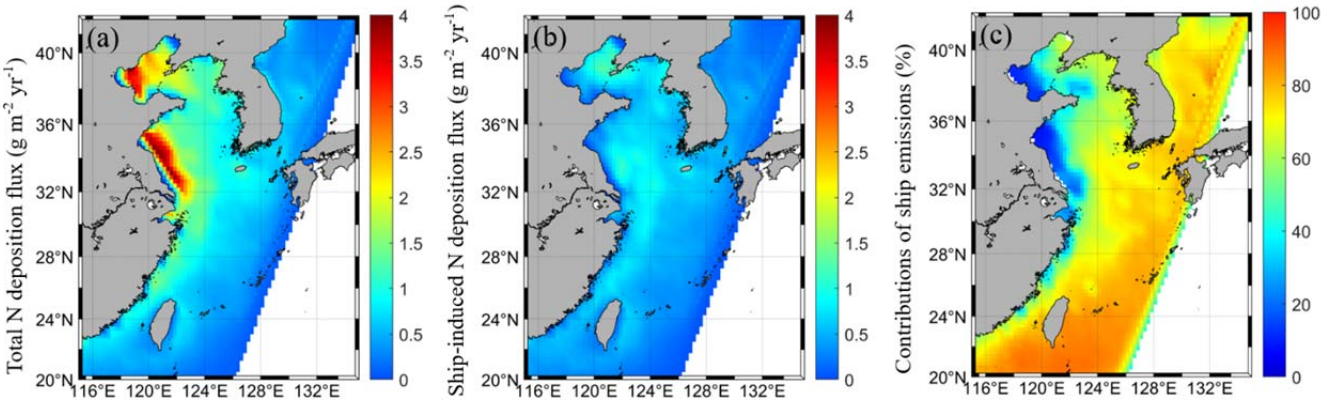

Figure 4. Annual N (including oxidised N and reduced N) deposition fluxes in the northwest Pacific Ocean from (a) all anthropogenic sources, (b) ship emissions, and (c) contributions of ship emissions to the annual N deposition fluxes

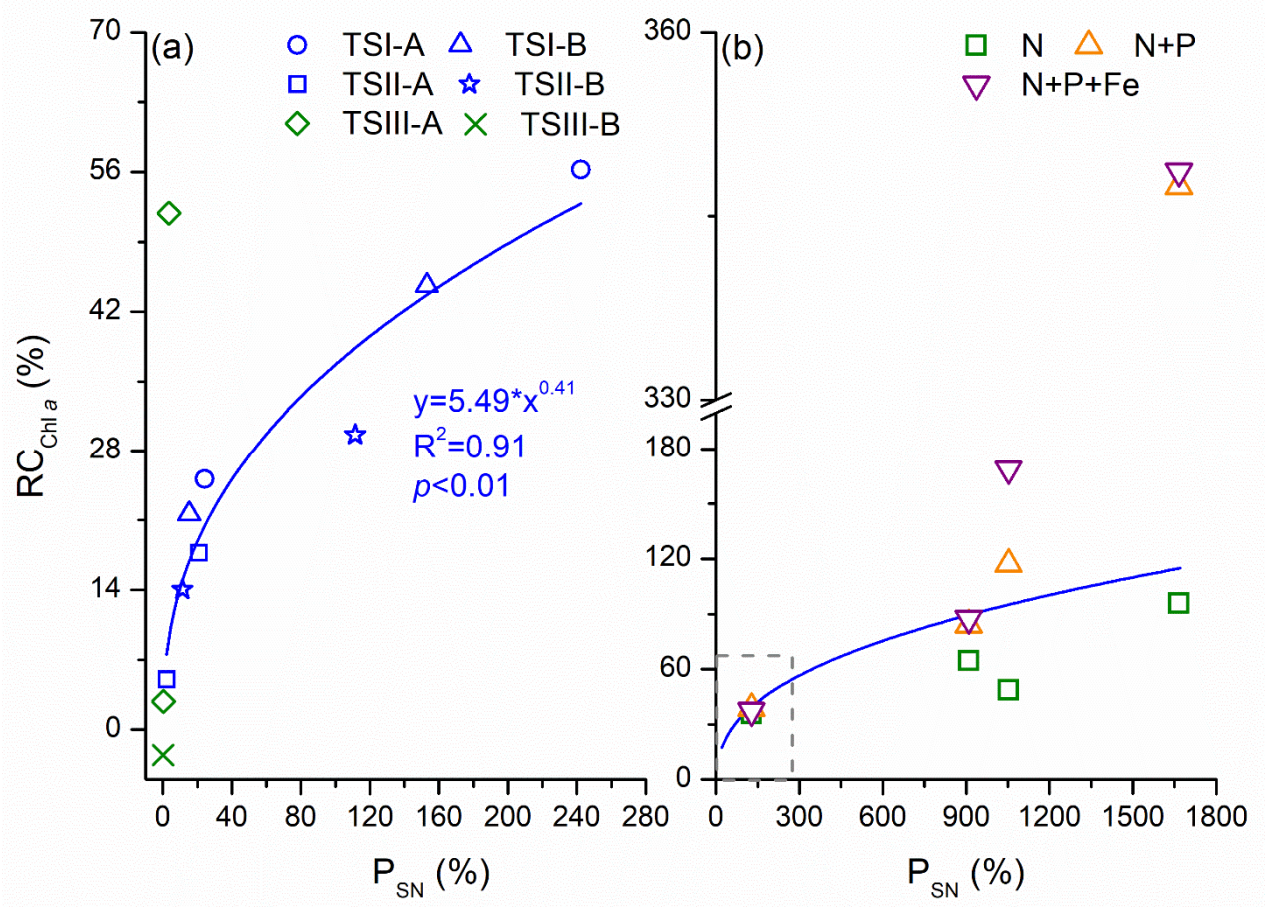

Figure 5. Relationships between relative change in Chl *a* ($RC_{Chl\ a}$, ([Mean in the ship emitted particle (SEP) treatments-Mean in the control]/Mean in the control)×100) and proportion of N supplied by SEPs relative to N stocks in the baseline seawater (P_{SN}, [N supplied by SEP additions/N stocks in the baseline seawater]×100) for (a) SEP and (b) nutrient (N, N+P, and N+P+Fe) treatments. The olive open symbols in Fig. (a) were obtained from SEP treatments at TSIII-A (E2, Fe limitation) and TSIII-B (YS1, no limitation of N, P, Fe), which were not used to fit the curve. In (b), the dashed panel region corresponds to the fitted curve in (a), and the line out of the dashed panel was extended from the fitted curve (a). The P_{SN} (x-axis) in (b) corresponds, in increasing order, to stations TSII-A (M1), TSII-B (M1B), TSI-B (D5), and TSI-A (E4)

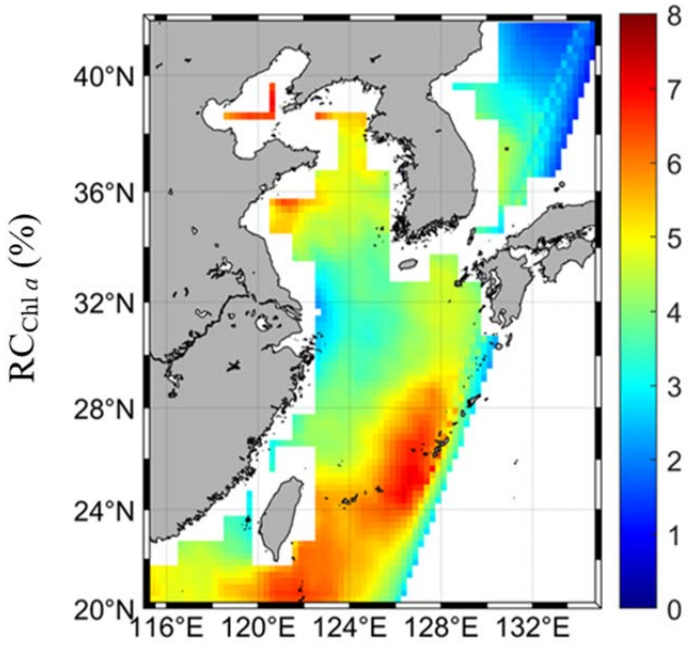

Figure 6. Relative change in Chl *a* ($RC_{Chl\,a}$) in surface seawater owing to ship-induced N deposition. $RC_{Chl\,a}$ was based on the empirical equation obtained from the incubation experiments as shown in Fig. 5a. The results in this figure were obtained by excluding the area where N:P ratios in the surface seawater exceeded 16:1 according to the World Ocean Atlas 2013 nutrient dataset.