1   **Contrasting responses of phytoplankton productivity between coastal and offshore**

2   **surface waters in the Taiwan Strait and the South China Sea to future CO_2-induced**

3   **acidification**

4

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14 **Abstract**

15 Future CO_2-induced ocean acidification (OA) has been documented to either inhibit or

16 enhance or result in no effect on marine primary productivity (PP). In order to examine

17 effects of OA under multiple drivers, we investigated the influences of OA (a decrease of

18 0.4 pH_{total} units with corresponding CO_2 concentrations ranged 22.0-39.7 μM) on PP

19 through deck-incubation experiments at 101 stations in the Taiwan Strait and the South

20 China Sea (SCS), including the coastal zone, the continental shelf and slope, as well as

21 deep-water basin. The daily net primary productivities in surface seawater under incident

22 solar radiation ranged from 17-306 μg C (μg Chl a)$^{-1}$ d^{-1}, with the responses of PP to OA

23 being region-dependent and the OA-induced changes varying from -88.03% (inhibition)

24 to 56.87% (enhancement). The OA-treatment stimulated PP in surface waters of coastal,

25 estuarine and shelf waters, but suppressed it in the South China Sea basin. Such

26 OA-induced changes in PP were significantly related to NO_X (the sum of NO_3^- and NO_2^-)

27 availability, in situ pH and solar radiation in surface seawater, but negatively related to

28 salinity changes. Our results indicate that phytoplankton cells are more vulnerable to pH

29 drop in oligotrophic waters. Considering high nutrient and low salinity in coastal waters

30 and reduced nutrient availability in pelagic zones with the progressive stratification

31 associated with ocean warming, our results imply that future OA will enhance PP in

32 coastal waters but decrease it in pelagic oligotrophic zones.

33 **Keywords:** CO_2; Taiwan Strait; ocean acidification; photosynthesis; primary productivity;

34   South China Sea

1 Introduction

36   The oceans have absorbed about one-third of anthropogenically released CO_2, which

37   increased dissolved CO_2 and decreased pH of seawater (Gattuso et al., 2015), leading to

38   ocean acidification (OA). OA has been shown to result in profound influences on marine

39   ecosystems (see the reviews and literature therein, Mostofa et al., 2016; Doney et al.,

40   2020). Marine photosynthetic organisms, which contribute about half of the global

41   primary production, are also being affected by OA (see the reviews and literatures therein,

42   Riebesell et al., 2018; Gao et al., 2019a). It is of general concern that the oceans are going

43   to take more or less CO_2 with progressive OA, since the amount of CO_2 uptake by the

44   oceans is essential to predict global and ocean warming trends. Therefore, it is important

45   to understand the responses of the key players of marine biological CO_2 pump, the

46   phytoplankton, to OA and other climate change drivers.

47   Elevated CO_2 is well recognized to lessen the dependence of algae and

48   cyanobacteria on energy-consuming CO_2 concentrating mechanisms (CCMs) which

49   concentrate CO_2 around Rubisco, the key site for photosynthetic carbon fixation (Raven

50   & Beardall, 2014 and references therein; Hennon et al., 2015). The energy freed up from

51   the down-regulated CCMs under increased CO_2 concentrations can be applied to other

52   metabolic processes, resulting in a modest increase in algal growth (Wu et al., 2010;

53   Hopkinson et al., 2011; Xu et al., 2017). Accordingly, elevated CO_2 availability could

54   potentially enhance marine primary productivity (Schippers et al., 2004). For instance,

55   across 18 stations in the central Atlantic Ocean primary productivity was stimulated by

56   15-19% under elevated dissolved CO_2 concentrations up to 36 μM (Hein and

57   Sand-Jensen 1997). On the other hand, neutral effects of OA on growth rates of

58   phytoplankton communities were reported in five of six CO_2 manipulation experiments in

59   the coastal Pacific (Tortell et al., 2000). Furthermore, simulated future OA reduced

60   surface PP in pelagic surface waters of Northern SCS and East China Sea (Gao et al.,

61   2012). It seems that the impacts of OA on PP could be region-dependent. The varying

62   effects of OA may be related to the regulation of other factors such as light intensity (Gao

63   et al., 2012), temperature (Holding et al., 2015), nutrients (Tremblay et al., 2006) and

64   community structure (Dutkiewicz et al., 2015).

65   Taiwan Strait of the East China Sea, located between southeast Mainland China and

66   the Taiwan Island, is an important channel in transporting water and biogenic elements

67   between the East China Sea (ECS) and the South China Sea (SCS). Among the Chinese

68   coastal areas, the Taiwan Strait is distinguished by its unique location. In addition to

69   riverine inputs, it also receives nutrients from upwelling (Hong et al., 2011). Primary

70   productivity is much higher in coastal waters than that in pelagic zones due to increased

71   supply of nutrients through river runoff and upwelling (Chen, 2003; Cloern et al., 2014).

72   The South China Sea (SCS), located from the equator to 23.8 °N, from 99.1 to 121.1 °E

73   and encompassing an area of about 3.5×10^6 km^2, is one of the largest marginal seas in

74   the world. As a marginal sea of the Western Pacific Ocean, it has a deep semi-closed

75   basin (with depths > 5000 m) and wide continental shelves, characterized by a tropical

76   and subtropical climate (Jin et al., 2016). Approximately 80% of ocean organic carbon is

77   buried in the Earth's continental shelves and therefore continental margins play an

78   essential role in the ocean carbon cycle (Hedges & Keil, 1995). Investigating how ocean

79   acidification affects primary productivity in the Taiwan Strait and the SCS could help us

80   to understand the contribution of marginal seas to carbon sink under the future

81   CO_2-increased scenarios. Although small-scale studies on OA impacts have been

82   conducted in the ESC and the SCS (Gao et al., 2012, 2017), our understanding of how

83   OA affects PP in marginal seas is still fragmentary and superficial. In this study, we

84   conducted three cruises in the Taiwan Strait and the SCS, covering an area of 8.3×10^5

85   km^2, and aimed to provide in-depth insight into how OA and/or episodic pCO_2 rise

86   affects PP in marginal seas with comparisons to other types of waters.

87   **2 Materials and Methods**

88   **2.1 Investigation areas**

89   To study the impacts of projected OA (dropping by ~0.4 pH) on marine primary

90   productivity in different areas, we carried out deck-based experiments during the 3

91   cruises supported by National Natural Science Foundation of China (NSFC), which took

92   place in the Taiwan Strait (Jul 14th-25th, 2016), the South China Sea basin (Sep 6-24th,

93   2016), and the West South China Sea (Sep 14th to Oct 24th, 2017), respectively. The

94   experiments were conducted at 101 stations with coverage of 12 ^{o}N-26 ^{o}N and 110

95   ^{o}E-120 ^{o}E (Fig. 1). Investigation areas include the coastal zone (< 50 m), the continental

96   shelf (50-200 m) and the slope (200-1000 m), and the vast deep-water basin (> 1000 m).

97   **2.2 Measurements of temperature and carbonate chemistry parameters**

98   The temperature and salinity of surface seawater at each station were monitored with

99   an onboard CTD (Seabird, USA). pH_{NBS} was measured with an Orion 2-Star pH meter

100   (Thermo scientific, USA) that was calibrated with standard National Bureau of Standards

101   (NBS) buffers (pH=4.01, 7.00, and 10.01 at 25.0 ^{o}C; Thermo Fisher Scientific Inc., USA).

102   The analytical precision was ±0.001. Total alkalinity (TAlK) was determined using Gran

103   titration on a 25-mL sample with a TA analyzer (AS-ALK1, Apollo SciTech, USA) that

104   was regularly calibrated with certified reference materials supplied by A. G. Dickson at

105   the Scripps Institution of Oceanography (Gao et al., 2018a). The analytical precision was

106   ±2 μmol kg^{-1}. CO_2 concentration in seawater and the pH_{Total} (pH_T) values was calculated

107   by using CO2SYS (Pierrot et al., 2006) with the input of pH_{NBS} and TAlK data.

108   **2.3 Nutrient measurement**

109   Surface seawater was collected from the Conductivity Temperature Depth (CTD)

110   rosette/Niskin bottles with a clean 125 mL HDPE (High-Density Polyethylene) sample

111   container. The nitrate and nitrite concentrations in seawater were then measured with a

112   Technicon AA3 Auto-Analyzer (Bran-Lube, GmbH, Germany). The quantitative limits

113   for nitrate and nitrite were 0.1 μmol L^{-1} and 0.04 μmol L^{-1}, respectively. We used

114   certified reference materials (CRMS) (https://www.jamstec.go.jp/scor/) as external

115   quality checks, and the analytical precision was better than ±1% during the whole cruise.

116   Nutrient measurement was conducted in the cruise of the South China Sea basin. Due to

117   the limit of human resources, it was not conducted in the other two cruises.

118   **2.4 Solar radiation**

119   The incident solar radiation intensity during the cruises was recorded with an

120   Eldonet broadband filter radiometer (Eldonet XP, Real Time Computer, Germany). This

121   device has three channels for PAR (400–700 nm), UV-A (315–400 nm) and UV-B (280–

122   315 nm) irradiance, respectively, which records the means of solar radiations over each

123   minute. The instrument was fixed at the top layer of the ship to avoid shading.

124   **2.5 Determination of primary productivity**

125   Surface seawater (0-1m) was collected a 10 L acid-cleaned (1 M HCl) plastic bucket

126   and pre-filtered (200 μm mesh size) to remove large grazers. To prepare high CO_2 (HC)

127   seawater, CO_2-saturated seawater was added into pre-filtered seawater until a decrease of

128   ~0.4 units in pH (corresponding CO_2 concentrations being 22.0-39.7 μM) was

129   approached (Gattuso et al., 2010). The same amount of filtered seawater (0.22 μm) was

130   added into the pre-filtered seawater setting as ambient CO_2 (AC) control. Prepared AC

131   and HC seawater was allocated into 50-mL quartz tubes in triplicate, inoculated with 5

132   μCi (0.185 MBq) $NaH^{14}CO_3$ (ICN Radiochemicals, USA), and then incubated for 24 h

133   (over a day-night cycle) under 100 % incident solar irradiances in a water bath for

134   temperature control by running through surface seawater. After the incubation, the cells

135   were filtered onto GF/F filters (Whatman) and immediately frozen at −20 °C for later

136   analysis. In the laboratory, the frozen filters were transferred to 20 mL scintillation vials,

137   thawed and exposed to HCl fumes for 12 h, and dried (55 ℃, 6 h) to expel non-fixed ^{14}C,

138   as previously reported (Gao et al., 2017). Then 3 mL scintillation cocktail (Perkin

139   Elmer®, OptiPhase HiSafe) was added to each vial. After 2 h of reaction, the

140   incorporated radioactivity was counted by a liquid scintillation counting (LS 6500,

141   Beckman Coulter, USA). The carbon fixation for 24 h incubation was taken as

142   chlorophyll (Chl) a-normalized daily net primary productivity (PP, μg C (μg Chl a)$^{-1}$)

143   (Gao et al., 2017). The changes (%) of PP induced by ocean acidification were expressed

144   as (PP$_{HC}$-PP$_{AC}$)/PP$_{AC}$×100, where PP$_{HC}$ and PP$_{AC}$ are the net daily primary productivity

145   under HC and AC, respectively.

146   **2.6 Chl a measurement**

147   Pre-filtered (200 μm mesh size) surface seawater (500-2000 mL) at each station was

148   filtered onto GF/F filter (25 mm, Whatman) and then stored at -80 °C. After returning to

149   laboratory, phytoplankton cells on the GF/F filter were extracted overnight in absolute

150   methanol at 4 °C in darkness. After centrifugation (5000 g for 10 min), the absorption

151   values of the supernatants were analyzed by a UV–VIS spectrophotometer (DU800,

152   Beckman, Fullerton, California, USA). The concentration of chlorophylls a (Chl a) was

153   calculated according to Porra (2002).

154 **2.7 Data analysis**

155   The data of environmental parameters were expressed in raw and the data of PP were

156 the means of triplicate incubations. Two-way analysis of variance (ANOVA) was used to

157 analyze the effects of OA and location on PP. Least significant difference (LSD) was used

158 to for *post hoc* analysis. Linear fitting analysis was conducted with Pearson correlation

159 analysis to assess the relationship between PP and environmental factors. A 95%

160 confidence level was used in all analyses.

161 **3 Results**

162   During the cruises, surface temperature ranged from 25.0 to 29.9 ^{o}C in the Taiwan

163 Strait and from 27.1 to 30.2 ^{o}C in the South China Sea (Fig. 2a). Surface salinity ranged

164 from 30.0 to 34.0 in the Taiwan Strait and from 31.0 to 34.3 in the South China Sea (Fig.

165 2b). The lower salinities were found in the estuaries of Minjiang and Jiulong Rivers as

166 well as Mekong River-induced Rip current. High salinities were found in the SCS basin.

167 Surface pH_T changed between 7.91-8.20 in the Taiwan Strait with the higher values in the

168 estuary of Minjiang River (Fig. 2c). On the contrary, surface pH had a narrower range

169 (8.06-8.23) in the South China Sea and the lower values occurred near the islands in the

170 Philippines. TAlK ranged from 2100 to 2359 μmol L^{-1} in the Taiwan Strait and 2126 to

171 2369 μmol L^{-1} in the South China Sea (Fig. 2d). The lowest value occurred in the estuary

172 of Minjiang River. CO_2 concentration in surface seawater changed from 6.4-15.9 μM kg^{-1}

173 SW in the Taiwan Strait, and 9.3-14.3 μM kg^{-1} SW in the SCS (Fig. 1e). It showed an

174   opposite pattern to surface pH, with the lowest value in the estuary of Minjiang River in

175   the Taiwan Strait and highest value in near the islands in the Philippines in the South

176   China Sea. During the PP investigation period, the daytime mean PAR intensity ranged

177   from 126.6 to 145.2 W m^{-2} s^{-1} in the Taiwan Strait and 37.3 to 150.0 W m^{-2} s^{-1} in the SCS

178   (Fig. 2f).

179   The concentration of Chl a ranged from 0.11 to 12.13 μg L^{-1} in the Taiwan Strait (Fig.

180   3). The highest concentration occurred in the estuary of the Minjiang River. The

181   concentration of Chl a in the SCS ranged from 0.037 to 7.43 μg L^{-1}. The highest

182   concentration was found in the coastal areas of Guangdong province in China. For both

183   the Taiwan Strait and the SCS, there were high Chl a concentrations (> 1.0 μg L^{-1}) in

184   coastal areas, particularly in the estuaries of the Minjing River, Jiulong River and Pearl

185   River. On the contrary, Chl a concentrations in offshore areas were lower than 0.2 μg L^{-1}.

186   Surface primary productivity changed from 99-302 μg C (μg Chl $a)^{-1}$ d^{-1} in the

187   Taiwan Strait, and from 17-306 μg C (μg Chl $a)^{-1}$ d^{-1} in the South China Sea (Fig. 4).

188   High surface primary productivity (> 200 μg C (μg Chl $a)^{-1}$ d^{-1}) was found in the

189   estuaries of the Minjing River, Jiulong River, and Pearl River and areas near the East of

190   Vietnam. In pelagic zones, the surface primary productivity was usually lower than 100

191   μg C (μg Chl $a)^{-1}$ d^{-1}.

192   Through a series of onboard CO_2-enrich experiments we observed that effects of the

193   elevated pCO_2 on primary productivity of surface phytoplankton community ranged from

194   -88.03% (inhibition) to 56.87% (promotion), revealing significant regional differences

195   (ANOVA, $F_{(100, 404)} = 4.103$, $p < 0.001$, Fig. 5). Among 101 stations, 70 stations showed

196   insignificant OA effects. OA increased PP at 6 stations and reduced PP at 25 stations.

197   Positive effects of OA on surface primary productivity was observed in the Taiwan Strait

198   and the western SCS (Fig. 5, red-yellow shading areas), with the maximal enhancement

199   of 56.9% in the station approaching Mekong River plume (LSD, $p < 0.001$). Reduction in

200   PP induced by the elevated CO_2 was mainly found in the central SCS basin within the

201   latitudes of 10 ^{o}N to14 ^{o}N and the longitudes of 114.5 ^{o}E to 118 ^{o}E (Fig. 5, blue-purple

202   shading areas), with inhibition rates ranging from 24.02% to 88.03% (Fig. 5, LSD, $p <$

203   0.05). These results showed a region-related effect of OA on photosynthetic carbon

204   fixation of surface phytoplankton assemblages. Overall, the elevated pCO_2 had neutral or

205   positive effects on primary productivity in nearshore waters, while having adverse effects

206   in pelagic waters.

207   By analyzing the correlations between OA-induced PP changes and regional

208   environmental parameters, we found that OA-induced changes in phytoplankton primary

209   productivity was significantly positively related with $in\ situ$ pH ($p < 0.001$, $r = 0.379$),

210   NOx availability (the concentrations of NO_3^- + NO_2^- at the bottom of upper mixing layers

211   as they were unmeasurable in the surface water, $p = 0.002$, $r = 0.727$), PAR density ($p =$

212   0.002, $r = 0.311$) and primary productivity ($p = 0.004$, $r = 0.284$) (Fig. 6 and Table S1).

213   On the other hand, the influence induced by OA was negatively related to salinity that

214   ranged from 30.00 to 34.28 ($p < 0.001$, $r = -0.418$).

4 Discussion

216   In the present study, we found that the elevated pCO_2 and associated pH drop

217   increased or did not affect PP in coastal waters but reduced it in pelagic waters. Our

218   results suggested that the enhanced effects of the OA treatment on photosynthetic carbon

219   fixation depend on regions of different physicochemical conditions. Higher levels of

220   nutrients due to runoffs or upwellings should be mainly responsible for the enhancement.

221   On the other hand, such stimulation could be related to higher UV-attenuation in these

222   coastal waters that contain more organic matters (Hader et al., 2015), since we employed

223   UV-transparent vessels for the incubations. In addition, coastal diatoms appear to benefit

224   more from OA than pelagic ones (Li et al., 2016). Therefore, community structure

225   differences might also be responsible for the differences of the short-term high

226   CO_2-induced acidification between coastal and pelagic waters.

227   OA is deemed to have two kinds of effects at least (Xu et al., 2017; Shi et al., 2019).

228   The first one is the enrichment of CO_2, which is usually beneficial for photosynthetic

229   carbon fixation and growth of algae because insufficient ambient CO_2 limits algal

230   photosynthesis (Hein & Sand-Jensen, 1997; Bach & Taucher, 2019). The other effect is

231   the decreased pH which could be harmful because it disturbs the acid-base balance

232   between extracellular and intracellular environments. For instance, the decreased pH

233   projected for future OA was shown to reduce the growth of the diazotroph

234   *Trichodesmium* (Hong et al., 2017), decrease PSII activity by reducing removal rate of

235   PsbD (D2) (Gao et al., 2018b) and increase mitochondrial and photo-respirations in

236   diatoms and phytoplankton assemblages (Yang and Gao 2012, Jin et al., 2015). In

237   addition, OA could reduce the RuBisCO transcription of diatoms, which also contributed

238   to the decreased growth (Endo et al., 2015). Therefore, the net impact of OA depends on

239   the balance between its positive and negative effects, leading to enhanced, inhibited or

240   neutral influences, as reported in diatoms (Gao et al., 2012, Li et al., 2021) and

241   phytoplankton assemblages in the Arctic and subarctic shelf seas (Hoppe et al., 2018), the

242   North Sea (Eberlein et al., 2017) and the South China Sea (Wu and Gao 2010, Gao et al.,

243   2012).

244   In the present study, OA increased or did not affect PP in coastal waters but reduced

245   it in offshore waters. This is significantly related to nutrient availability (Fig. 6d), with

246   that the inhibitory effect was minimized when NOx availability increased. Riverine

247   inputs, including the Minjiang River, Jiulong River, Pearl River, and Mekong River, are

248   the primary source of nutrients in the coastal and shelf zones, resulting in higher

249   concentrations of nutrients and lower salinity in these waters (Xiao et al., 2018). It was

250   reported that elevated pCO_2 decreased net organic carbon production of

251   natural plankton community in nutrient-depleted waters (Yoshimura et al., 2010).

252   Furthermore, OA did not affect the specific growth rate of a diatom under N-replete

253   condition but reduced it under N-limited condition (Li et al., 2018). The alleviating effect

254   of nutrient enrichment on OA-induced stress could be multifaceted. Firstly, algae could

255   cope with the acid-base perturbation caused by OA through active proton pumps

256   (McNicholl et al., 2019). The operation of such proton pumps need some essential

257   proteins, such as plasma membrane H^+-ATPase, whose synthesis is nutrient-dependent

258   (Taylor et al., 2012; Xu et al., 2017). Secondly, it has been shown that nutrient

259   enrichment could accelerate the repair rate of PSII via synthesizing the key proteins such

260   as PsbA (D1), and PsbD (D2) (Geider et al., 1993; Li et al., 2015). Thirdly, nitrogen

261   enrichment could significantly increase the synthesis and content of photosynthetic

262   pigments including Chl *a*, phycocyanin, and phycoerythrin (Johnson & Carpenter, 2018;

263   Gao et al., 2019b), contributing to high photosynthetic activity under stressful

264   environmental conditions. Negative correlation between OA-induced changes of PP and

265   salinity was found in this study. While little has been documented on the relationship

266   between salinity and OA (Wulff et al., 2018; Sugie et al., 2020; Xu et al., 2020), lowered

267   salinity has been shown to alleviate the impact of OA on a coccolithorphorid (Xu et al.,

268   2020). Nevertheless, we presume the enhanced PP could mainly be related to nutrient

269   availability because lower salinity in coastal waters usually companies with high nutrient

270   levels (Li et al., 2011). In addition, local pH may be another factor that affects the

271   impacts of OA. There are diurnal and seasonal fluctuations of pH in coastal waters and

272   phytoplankton that adapt well to the fluctuant pH environments would be tolerant to the

273   decreased pH caused by OA (Flynn et al., 2012, Li et al., 2016). On the other hand, the

274   surface pH in the ocean basin is relatively stable, with a varied range of only ~0.024 over

275   a month (Hofmann et al., 2011). Therefore, the phytoplankton cells living in these

276   environments could be more sensitive to pH drop due to elevated pCO_2 (Li et al., 2016).

277   The specific environmental conditions have profound effects on shaping diverse

278   dominant phytoplankton groups (Boyd et al., 2010). Larger eukaryotic groups (especially

279   diatoms) usually dominate the complex coastal regions, while picophytoplankton

280   (*Prochlorococcus* and *Synechococcus*), characterizing with more efficient nutrients

281   uptake, dominate the relatively stable offshore waters (Dutkiewicz et al., 2015). In

282   summer and early autumn, previous investigations demonstrated that diatoms dominated

283   in the northern waters and the Taiwan Strait (coastal and shelf regions) with the high

284   abundance of phytoplankton, which are consistent with our Chl *a* data; *Prochlorococcus*

285   and *Synechococcus* dominated in the SCS basin and the north of SCS (slope and basin

286   regions) (Xiao et al., 2018, Zhong et al., 2020). In addition, it has been reported that

287   larger cells benefit more from OA because a thicker diffusion layer around the cells limits

288   the transport of CO_2 (Feng et al., 2010; Wu et al., 2014). In contrast, a thinner diffusion

289   layer and higher surface to volume ratio in smaller phytoplankton cells can make them

290   easier to transport CO_2 near the cell surface and within the cells, and therefore

291   picophytoplankton species are less CO_2-limited (Bao and Gao, 2021). Therefore, different

292   community structures between coastal and pelagic areas could also be responsible for the

293   enhanced and inhibitory effects of OA.

Conclusions

294

295   By investigating the impacts of the elevated pCO_2 on PP in the Taiwan Strait and the

296   SCS, we demonstrated that such short OA-treatments induced changes in PP were mainly

297   related to NOx availability based on Pearson correlation coefficients, supporting the

298   hypothesis that negative impacts of OA on PP increase from coastal to pelagic waters

299   (Gao et al., 2019a). In view of ocean climate changes, strengthened stratification due to

300   global warming would reduce the upward transports of nutrients and further reduce

301   nutrient availability, consequently, leading to exacerbating impacts of OA on PP in

302   pelagic zones. Meanwhile, PP in coastal and/or upwelled waters would be stimulated or

303   non-affected by OA with continuous discharges of nutrients from terrestrial environments,

304   which may imply higher PP and enhance frequency of harmful algal blooms in future

305   oceans.

306   *Data availability.* All data are included in the article or Supplement.

307   *Author contributions.* KG and TW developed the original idea and designed research.

308   TW and JS carried out fieldwork. GG provided statistical analyses and prepared figures.

309   GG, KG, and XZ wrote the manuscript. All contributed to revising the paper.

310   *Competing interests.* The contact author has declared that neither they nor their

311   co-authors have any competing interests.

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517 **Figure captions**

518 **Fig. 1** Sampling stations for the incubation experiments in the Taiwan Strait and the

519 South China Sea during three cruises. Taiwan Strait cruise was conducted in July 2016

520 (red dots), South China Sea Basin cruise were conducted in September 2016 (blue dots)

521 and Western South China Sea cruise was conducted in September 2017 (black dots). The

522 arrows represent surface circulation fields in summer in the vicinity of Vietnam coast

523 based on Lan et al. (2006).

524 **Fig. 2** Temperature (^{o}C, panel a), salinity (panel b), pH (panel c), total alkalinity (μmol

525 L^{-1}, panel d), and CO_2 (μmol kg^{-1} SW, panel e) in surface seawater and mean PAR

526 intensity (W m^{-2} s^{-1}, panel f) during the PP incubation experiments.

527 **Fig. 3** Chl *a* concentration (μg L^{-1}) in the Taiwan Strait and the South China Sea during

528   research cruises.

529 **Fig. 4** Surface primary productivity (μg C (μg Chl *a*)$^{-1}$ d^{-1}) in the Taiwan Strait and the

530   South China Sea during research cruises.

531 **Fig. 5** Ocean acidification (pH decreases of 0.4 units) induced changes (%) of surface

532 primary productivity in the Taiwan Strait and the South China Sea. Red-yellow shading

533 represents a positive effect on PP and blue-purple shading represents a negative effect.

534 Positive effect was found in coastal waters and estuary affected waters, such as the

535 Taiwan Strait, the Pearl River plume, Mekong River induced Rip current in West China

536 Sea. Negative effect was found in surface of oligotrophic waters like SCS Basin.

Fig. 6 Ocean acidification (pH decreases of 0.4 units) induced changes (%) on surface primary productivity in the South China Sea as a function of salinity (a), PAR (b), ambient pH (c), and nitrate plus nitrite concentration (d). The dotted lines represent 95% confidence intervals.
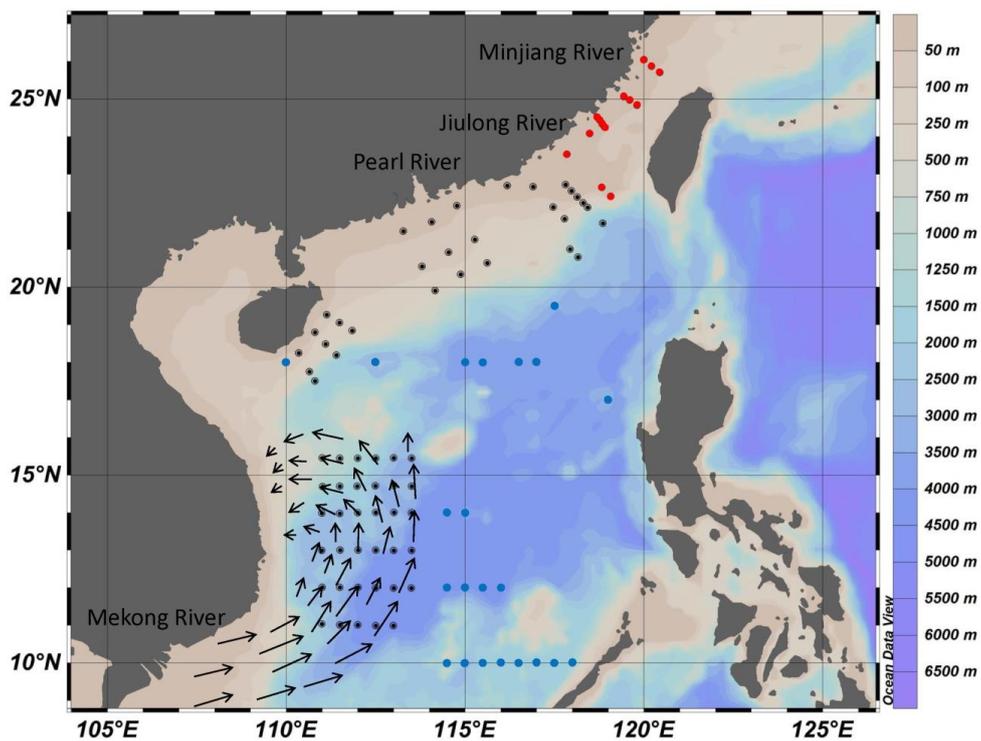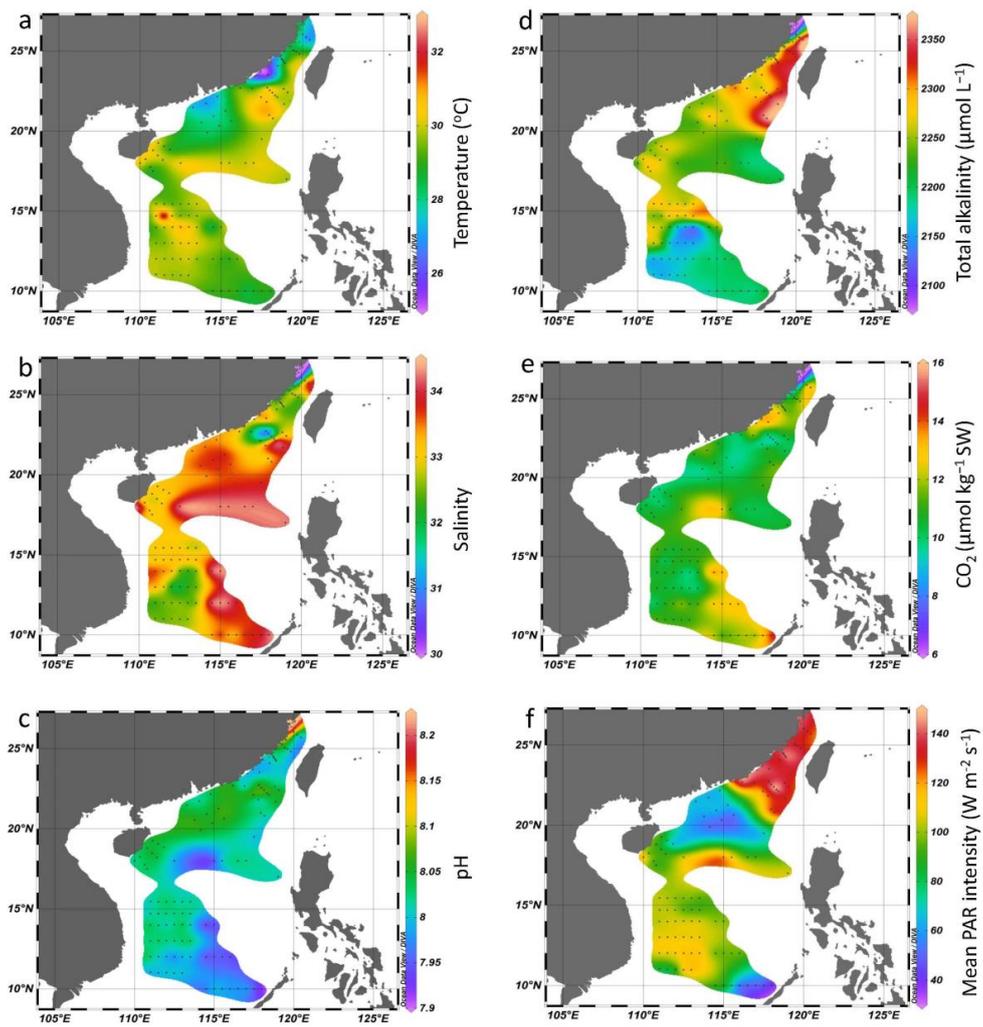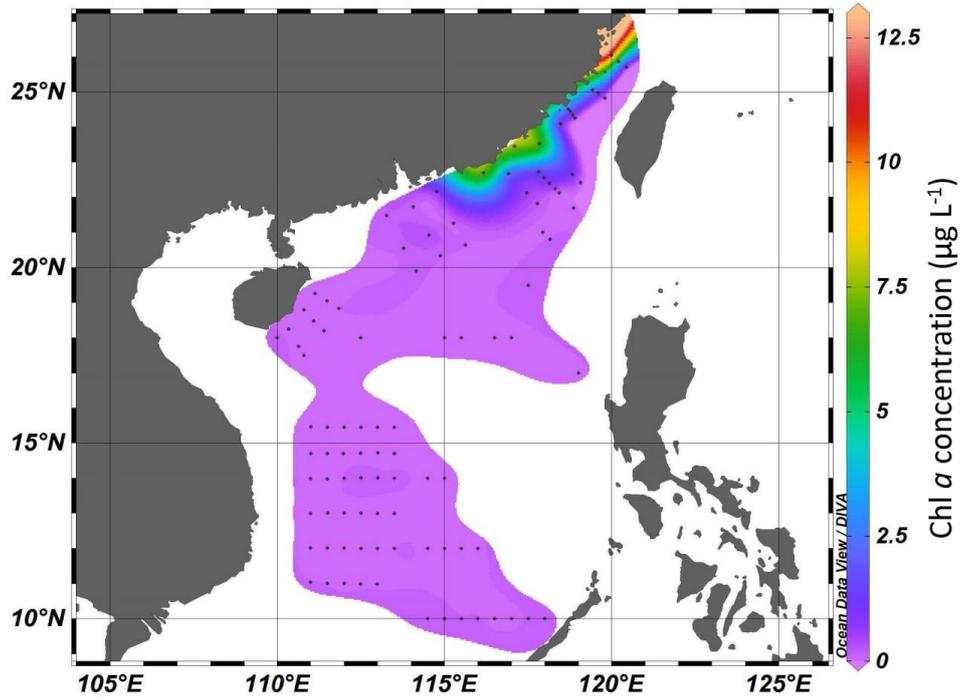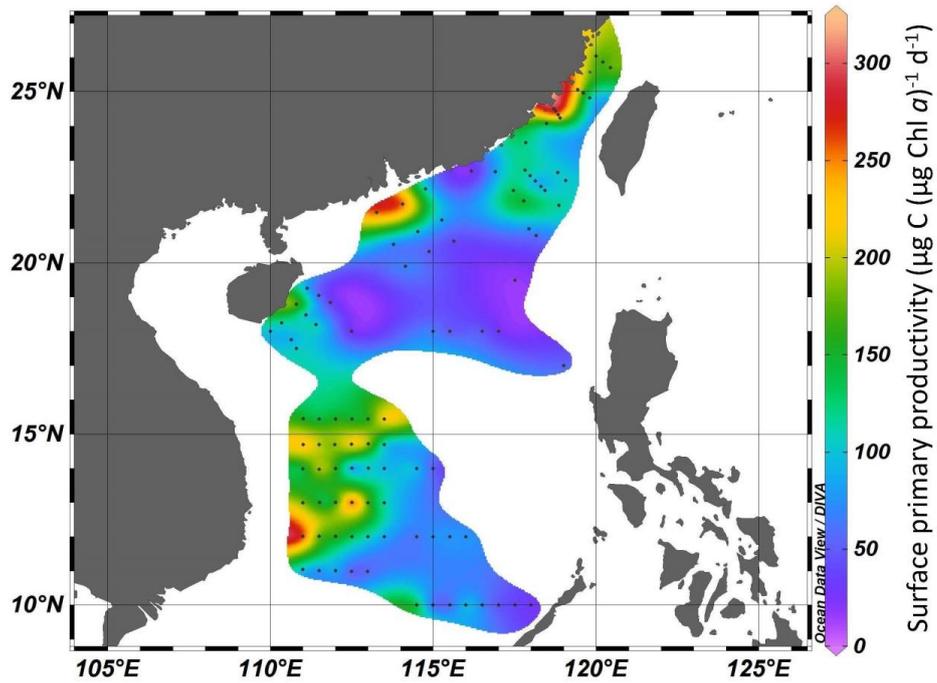
Fig. 1

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