Annual plankton community metabolism in estuarine and coastal waters in Perth (Western Australia)

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16 **Abstract**

18 The planktonic metabolic balance that is the balance between gross primary production (GPP)

19 and community respiration (CR) was determined in Matilda Bay (estuarine) and Woodman Point

20 (coastal) in Perth, Western Australia. The rates of net community production (NCP = GPP - CR)

21 and the ratio between GPP and CR (P/R) were assessed to evaluate whether the metabolic

22 balance in the two coastal locations tends to be net autotrophic (production exceeding

23 community respiration) or net heterotrophic (respiration exceeding production). We also

24 analyzed environmental variability by measuring temperature, salinity, and nutrients and

25 chlorophyll *a* concentration. Samples were collected biweekly from March 2014 to March 2015.

26 During the study period the metabolic rates were three times higher in Matilda Bay than in

27 Woodman Point. The predominant metabolism was net autotrophic at both sites with P/R ratios

28 >1 in the majority of the sampling dates. In Matilda Bay, the metabolic rates were negatively

29 correlated with salinity denoting river dynamics influence, and positively with chlorophyll *a*. In

30 Woodman Point only the GPP was positively correlated with chlorophyll *a*. The positive

31 correlation between P/R ratio and GPP in Matilda Bay and the positive correlations between the

32 metabolic rates and chlorophyll *a* suggest that factors controlling autotrophic processes are

33 modulating the planktonic metabolic balance in the coastal marine ecosystem in Perth.

34 Significant correlations were found between CR and GPP standardized to chlorophyll *a* and

35 water temperature. The net autotrophic metabolic balance indicates that in both ecosystems

36 planktonic communities are acting as a sink of CO_2 and as a source of organic matter and oxygen

37 to the system and are able to export organic matter to other ecosystems.

38

39

Introduction

41

42 Plankton metabolism is a fundamental property of marine ecosystem driving the flux of gases

43 and the transference of organic matter to the food web (Duarte et al. 2011). The metabolism of

44 plankton communities in the open ocean is in approximate balance, i.e. with gross primary

45 production (GPP) similar to community respiration (CR) and a P/R ratio close to 1.0, or

46 experiences small deviations from this balance (Williams et al. 2013, Duarte et al. 2013),

47 because deviations from such balance require external fluxes of nutrients or organic carbon,

48 which are small. In contrast, coastal plankton communities, which typically present higher

49 metabolic rates (Duarte and Agustí, 1998), may have large deviations from metabolic balance

50 with either excess respiration over production when the ecosystem receives large inputs of labile

51 organic carbon (e.g. Mediterranean coastal areas, Duarte et al., 2004, Vidussi et al., 2011) or

52 gross primary production in excess of respiration when the ecosystem receives large inputs of

53 dissolved inorganic nutrients (e.g. Agusti et al., 2004).

54

55 The metabolic balance of coastal ecosystems plays an important role in determining their role as

56 CO_2 sources or sinks (Borges 2005, Cai 2011). Recently, a contrasting role between continental

57 shelves acting as sinks and near-shore ecosystems as sources of atmospheric CO_2 was proposed

58 to reconcile opposing views on the role of coastal ecosystems as CO_2 sources or sinks (Chen and

59 Borges, 2009; Cai, 2011). In particular, inner estuaries are believed to act as sources of CO_2 to

60 the atmosphere due to a prevalence of heterotrophic ecosystem metabolic status fueled by land-

61 derived inputs of organic carbon whereas outer reaches of estuaries tend to be CO_2 sinks (Odum

62 and Hoskin, 1958; Odum and Wilson, 1962; Heip et al., 1995; Kemp et al., 1997; Gattuso et al.,

63 1998; Hopkinson and Smith, 2005).

64 However, virtually all of the results from near-shore and open coastal ecosystems thus far

65 refer to those in the northern hemisphere, particularly Europe, the USA and Asia (Borges, 2005;

66 Chen and Borges, 2009; Cai, 2011). As these typically represent highly populated areas with

67 watersheds supporting intense agricultural practices, the results may not be directly transferable

68 to coastal areas in the southern hemisphere. The metabolism of Australian coastal waters was

69 recently studied by McKinnon et al. (2013) and (2017). Autotrophic plankton metabolism

70 prevailed in the coastal zone of the Great Barrier Reef (GBR) (McKinnon et al., 2013), despite

71 being located in the wet Australian tropics with a distinct rainy season. Moreover, the inshore

72 area was even more strongly autotrophic than the offshore region of the GBR, which is in

73 contrast to the expectation that inshore coastal waters should be heterotrophic. Coastal waters

74 adjacent to Northern Australia were also predominantly autotrophic (McKinnon et al. 2017).

75 Whether autotrophic metabolism could prevalent in other regions of Australia is, thus far,

76 unresolved.

77

78 Here we report plankton metabolic rates for two contrasting coastal sites in the Perth area in

79 temperate Western Australia, Matilda Bay, an inshore-site in the Swan river estuary, and

80 Woodsman Point, an open coastal site. Specifically, we assessed biweekly during a year (March

81 2014 to March 2015) community respiration,, gross primary production and net community

82 production, along with temperature, salinity, dissolved inorganic nutrient concentration, and

83 chlorophyll *a* concentration.

84

85 **Methods**

86

87 Matilda Bay is located in the lower reaches of the Swan River. Swan is one of the main rivers in

88 Western Australia with an extension of more than 50 km and a catchment area about 190,000

89 Km^2 (Thomson, 1998). The estuary has been open to the ocean since 1987 when a rocky bar near

90 to the mouth of the estuary in Fremantle was removed. The estuary has a seasonal cycle

91 influenced by rainfall with wet and cool winters with about 90% of the annual rain and hot and

92 dry summers (Thomson, 1998; Hamilton et al., 2006). During winter most of the water body is

93 fresh because of the rainfall and runoff but the salinity increases upstream when the rainfall

94 decreases and the system receive a significant flow of oceanic waters (Thompson 1998). The

95 estuary has received anthropogenic pressure because of land clearing for agricultural purposes,

96 urbanization, dam construction and other factors (Chan et al. 2002; Thompson 1998).

97 Consequently, nutrient inputs and sedimentation rates have increased and the water quality has

98 decreased (Chan et al. 2002; Hamilton et al. 2006). Gedaria (2012) reported that salinity and

99 temperature are the main drivers of the variation in phytoplankton biomass in the Swan River

100 estuary Woodman Point is located in the Owen Anchorage in the Coast of Cockburn Sound

101 (Perth, Western Australia), and, in contrast with Matilda Bay, represents an open shoreline with

102 no direct freshwater influence. Cockburn. Sound area was a place of industrial activity reducing

103 coastal water quality in the 1950s due to phytoplankton blooms (Cambridge & McComb 1984).

104 However, the water quality has improved since the mid-1990s due to the reduction of nutrients

105 inputs from industrial activities (Kendrick et al. 2002). The coastal area of Western Australia is

106 also influenced by the Leeuwin Current, a poleward-flowing eastern boundary current

107 characterized by warm waters with low salinity and low nutrients, but weakening between

108 November and March (Cresswell & Golding 1980).

109

110 Sub-surface water samples were collected at biweekly intervals between March 2014 to March

111 2015 in Matilda Bay (-31.9904 °S, 115.8181 °E; Fig. 1) and the Ammunition Jetty, Woodman

112 Point (-32.1241 °S, 115.7586 °E; Fig. 1). The free software Ocean Data View (Schlitzer, R.,

113 Ocean Data View, http://odv.awi.de, 2016), version 4.7.10, was used to generate the study area

114 map. Samples were then transported to incubated and processed at the University of Western

115 Australia (UWA). Temperature (°C), Salinity and dissolved oxygen were measured through the

116 water column by deploying a calibrated YSI EXO1 Multi-parameter Water Quality Sonde fitted

117 with a pressure sensor (± 0.04 m), temperature (± 0.01°C), conductivity sensor, and an optode

118 dissolved oxygen sensor. In addition, surface water temperature was measured from the water

119 collected by a digital thermometer.

120

121 Net community production, gross primary production, and community respiration were

122 quantified by changes in dissolved oxygen using micro-Winkler techniques by the use of a

123 precise automatic titration based on redox potentiometric endpoint (Oudot et al., 1988). Water

124 collected in each site was siphoned into 21 calibrated glass 100 ml borosilicate Winkler bottles.

125 Seven bottles were fixed immediately to measure initial oxygen, another seven bottles were

126 incubated in the light and the last seven bottles were incubated in the dark. The incubation,

127 starting between 8 to 9 am, was run for 24 hours in situ conditions of temperature and natural

128 solar radiation in an outdoor, temperature controlled tank. After the incubation, samples were

129 fixed and the final oxygen was measured using a high-precision autotitrator (Compact Titrator

130 G20, Mettler Toledo). NCP rates were determined from the oxygen change in the clear bottles

131 (oxygen clear – initial oxygen), CR rates were determined from the oxygen change in the dark

132   bottles (Initial oxygen – dark oxygen) and GPP rates were calculated as the sum of CR and NCP

133   (Duarte et al., 2011). Model II regression was used to analyse the relationships between CR,

134   NCP, and GPP.

135

136   Aliquots of 200 ml were used for chlorophyll *a* analyses using acetone extraction and

137   fluorometric determination after Parsons et al. (1984). Subsamples were filtered through

138   Whatman grade GF/F glass microfiber filters of 25 mm diameter. Filters were placed in plastic

139   tubes of 1 ml and stored at -20°C until analysis. Filters were immersed in acetone at 90% during

140   24 hours for chlorophyll *a* extraction. After that period, chlorophyll *a* fluorescence was measured

141   by the use of a Trilogy Laboratory Fluorometer (Turner Designs) equipped with a module of

142   Chlorophyll a Non-Acidification Fluorescent Module (CHL-A NA) at UWA. The fluorometer

143   was calibrated with pure chlorophyll a (Sigma- Aldrich C6144-1mg) solution.

144

145   Samples for dissolved inorganic nutrient analyses were collected during transportation to the

146   laboratory and kept frozen until analysis in a segmented flow autoanalyzer following standard

147   procedures Samples (Hansen and Koroleff, 1999).

148

149   The temperature response of plankton communities was described by fitting, using least squares

150   regression analysis, the Arrhenius equation,

151

152    $$\mathrm{Ln}\ Y = A\ \exp^{-AE/kT}$$

153

154   where Y is the property of interest, AE is the activation energy (eV), k is the

155   Boltzmann' s constant (8.617734 10-5 eV ^{o}K^{-1}) and T is the sea-surface water temperature (^{o}K),

156   and A is a fitted intercept (Regaudie-de-Gioux and Duarte, 2012).

157

158

159   **Results**

160

161   Surface water temperature ranged from 12.0 to 27.4 ^{o}C and 15.1 to 25.0 ^{o}C (Fig. 2a) and salinity

162   ranged from 22.03 to 36.97 PSU and 31.6 to 37.1 PSU (Fig. 2b) in Matilda Bay and Woodman

163   Point, respectively. The minimum salinity was reached in late winter and spring in Matilda Bay,

164   following river discharge, and while the pattern was less clear in Woodman Point, the lowest

165   salinity was also observed in winter and early spring (Fig. 2b). Dissolved inorganic nitrogen

166   concentration was highest in winter, but phosphate concentration was highest in late summer in

167   Matilda Bay (Fig. 3a-c). In contrast, nitrate and phosphate concentrations in Woodman Point

168   were lower ($P < 0.05$) than those in Matilda Bay (Table 1) and dissolved inorganic nitrogen

169   concentration showed two maxima, winter and summer, while phosphate concentrations showed

170   a summer minima (Fig. 3a-c). Chlorophyll *a* concentration was significantly higher and more

171   variable in Matilda Bay than in Woodman Point (Table 1, Fig. 3d), and reached the highest

172   values in winter, at the time of peak nitrate concentration (Fig. 3d), as there was a significant,

173   positive, relationship between chlorophyll *a* concentration and nitrate concentration ($r = 0.67$, P

174   < 0.0001).

175

176   Respiration rates were, on average, twice as high in Matilda Bay as in Woodman Point (Table 1),

177   and increased strongly toward summer in Woodman Point whereas it showed less seasonal

178   variability in Matilda Bay (Fig. 4a). Gross primary production was also much higher in Matilda

179   Bay than in Woodman Point (Table 1), with no clear seasonal pattern at either site (Fig. 4b). The

180   communities were generally autotrophic, with GPP about twice as high as R (NCP and P/R > 1,

181   Table 1), with NCP being three times higher, on average, at Matilda Bay than at Woodman Point

182   (Table 1, Fig. 4c), and neither community displayed any clear seasonal trend in net community

183   production along the year (Fig. 4c). GPP was significantly correlated with CR ($r = 0.68$, P <

184   0.0001), but NCP increased strongly with increasing GPP (Fig. 5). Net community production

185   and gross primary production increased with increasing chlorophyll *a* concentration (NCP, R^2=

186   0.73, $P < 0.0001$; GPP, R^2= 0.69, $P < 0.0001$), with the relationship between community

187   respiration rate and chlorophyll *a* being much weaker (CR, R^2= 0.15, $P = 0.0036$) albeit also

188   significant (Fig. 6 a, b, c).

189

190   Respiration rates increased with increasing temperature, resulting in an activation energy of 0.76

191   ± 0.21 eV (Fig. 7a). GPP showed, in contrast, no significant temperature-dependence ($P > 0.05$).

192   Indeed, when standardized to chlorophyll *a*, as observed in previous studies (e.g. Regaudie de-

193   Gioux and Duarte, 2012; Garcia-Corral et al., 2017), there was a significant temperature-

194   dependence of gross primary production, with an activation energy of 0.69 ± 0.12 (Fig. 7b),

195   comparable to that of community respiration.

196

197   **Discussion**

198

199   Chlorophyll *a* values were higher in Matilda Bay than in Woodman point, but all values ranged

200   within those reported for coastal waters around Perth (Pearce et al., 2006). The highest

201   chlorophyll *a* concentration in both Matilda Bay and Woodman point occurred at the low salinity

202   winter events. Chlorophyll *a* concentration in the Swan River has been reported to vary

203   seasonally showing large interannual variability (Thompson, 1998). Both coastal ecosystems, but

204   particularly Matilda Bay, supported productive communities, as reflected in high GPP rates.

205

206   Community respiration rates were less variable than GPP, particularly at Matilda Bay, but GPP

207   sufficed to support all carbon demands from the community generating excess organic matter.

208   This resulted in the prevalence of autotrophic communities at both sites, with average P/R ratios

209   above 2.0 similar across both sites. This is expected from relatively productive sites with GPP

210   well above the threshold previously determined to delineate autotrophic from heterotrophic

211   communities (Duarte & Agustí, 1998; Duarte & Regaudie-de-Gioux, 2009). Net community

212   production was strongly correlated with chlorophyll *a* concentration, accounting for the much

213   higher NCP in productive Matilda Bay compared to Woodman Point plankton communities,

214   suggesting that the metabolic balance of plankton communities in the coast of Perth is regulated

215   by factors controlling autotrophic processes, such as nutrient inputs, salinity regimes and

216   temperature. In coastal waters of Northern Australia, McKinnon et al (2017) also observed that

217   the metabolism and community respiration were autotrophic and positively related to chlorophyll

218   *a* concentration.

219

220   The results presented here contribute to address a paucity of studies of plankton community

221   metabolism in the Indian Ocean (Regaudie-de-Gioux & Duarte, 2013). Robinson and Williams

222   (1999) studied the planktonic metabolic balance during a research cruise in the Gulf of Oman,

223   reporting P/R ratios for surface waters between 1.17 and 2.43, with the highest ratio near to the

224   Omani coast (Regaudie-de-Gioux & Duarte, 2013; Robinson & Williams, 1999). Indeed, the P/R

225   ratio of the station closer to the Omani coast, 2.43 (Robinson & Williams, 1999) was similar to

226   the P/R ratio for out study sites in the Western Australia coast. More recently, Mackinnon et al.

227   (2017) in a comprehensive study of the metabolism of planktonic communities in the North of

228   Australia, found that Indian Ocean communities from Ningaloo Reef and Exmouth Gulf (North

229   Western Australia coast) were also predominantly net autotrophic.

230

231   Our results indeed showed a prevalence of net autotrophic metabolism in plankton communities

232   of the Coast of Perth (Western Australia), both at the productive estuarine waters at Matilda Bay

233   and the open coastal Indian Ocean waters at Woodman Point. This indicates that planktonic

234   communities in these coastal locations act as strong CO_2 sinks and sources of organic matter and

235   oxygen to the system. This is in contrast to the expectation that near-shore ecosystems act as

236   sources of atmospheric CO_2, proposed to reconcile opposing views on the role of coastal

237   ecosystems as CO_2 sources or sinks (Chen & Borges, 2009; Cai, 2011). Indeed, the pattern

238   showed here, with higher net community production in the inner waters of Matilda Bay

239   compared to the more open waters at Woodman Point agree with prior findings for Australian

240   GBR where inshore areas being more strongly autotrophic than offshore waters (McKinnon et

241   al., 2013).

242

243   The plankton communities in the coastal waters of Perth showed increased metabolic rates with

244   increasing temperature, as expected from metabolic theory of ecology (Brown et al., 2004).

245   However, the activation energy for gross primary production of 0.69 ± 0.12 eV found here was

246   well below that found in previous analyses of Indian Ocean communities. Garcia-Corral et al.

247   (2017) reported for Indian Ocean open-ocean waters a gross primary production Ea (standardized

248   to chlorophyll a) of 1.70 eV. Also, whereas, consistent with other assessments (e.g. Regaudie de-

249   Gioux & Duarte 2012; Garcia-Corral et al., 2017), the activation energy for community

250   respiration was higher than that for gross primary production, this difference was small and not

251   statistically significant. This is important as it predicts that warming events, such as the heat

252   wave that impacted marine ecosystems across Western Australia in 2011 (Wernberg et al., 2016),

253   will affect gross primary production and respiration rates of plankton communities in a similar

254   way.

255

256 The net autotrophic communities encountered in the coastal system studied in Western Australia
257 suggest that these pelagic communities produce organic matter in excess, thereby exporting
258 organic matter either to the underlying benthic compartment or offshore. For instance, analysis
259 of carbon stocks in Matilda Bay sediments, which support seagrass meadows, have shown the
260 organic carbon to be partially of planktonic origin along with contributions of the seagrass
261 themselves (Rozaimi et al. 2013). Hence, both the pelagic and benthic compartments of Matilda
262 Bay appear to be autotrophic, although the contributions of the benthic compartment to
263 ecosystem metabolism were not addressed here. We, therefore, provide only one of the
264 components, pelagic metabolism, that determine ecosystem metabolic budgets, which include
265 contributions from benthic compartments as well as exchanges, either import or export, with
266 adjacent ecosystems.

267

268 **Conclusions**

269

270 Our results indicated that planktonic communities in the two coastal Western Australia locations
271 studied act as strong CO_2 sinks and sources of organic matter and oxygen to the system. The
272 plankton communities of the Coast of Perth (Western Australia) showed net autotrophic
273 metabolism both at the productive estuarine waters at Matilda Bay and the open coastal Indian
274 Ocean waters at Woodman Point. This result is in contrast to the expectation of net
275 heterotrophic balance for near-shore ecosystems, but in agreement with the few metabolic
276 balance assessments from Australian coastal waters. The thermal relationships indicated that
277 warming may decrease the strong capacity observed for CO_2 sinks. Our study is based on two
278 contrasting plankton communities in Western Australia and, while useful to address the absence
279 of reports on plankton community metabolism in the Indian Ocean coast of Australia, and the
280 paucity of reports across the Indian Ocean (Regaudie de-Gioux & Duarte 2013), a broader
281 analyses of coastal plankton communities across Western Australia is required to confirm the
282 patterns revealed here and diagnose the role of plankton communities in across Western
283 Australia in carbon fluxes and their likely response to future warming.

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289

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397

398   **Figure Headings**

399

400   **Figure 1: Map showing the study area in Western Australia.** The stations sampled in the

401   coast of Perth are marked with green (Matilda Bay) and red (Woodman Point) dots.

402

403   **Figure 2: Temporal variability in seawater temperature and salinity.** Changes in surface

404   seawater temperature (A) and salinity (B) in Matilda Bay are shown in blue line and symbols,

405   and in Woodman Point in red line and symbols, over time.

406

407   **Figure 3: Nutrients and chlorophyll *a* variability**. Changes in (A) nitrate, (B) ammonium, (C)

408   phosphate and (D) chlorophyll *a* concentration in Matilda Bay (blue line and symbols) and

409   Woodman Point (red line and symbols) over time.

410

411   **Figure 4: Planktonic metabolism.** Changes in (A) community respiration rate, (B) gross

412   primary production, and (C) net community production in Matilda Bay (blue line and symbols)

413   and Woodman Point (red line and symbols) over time.

414

415   **Figure 5. The relationship between net community production and gross primary**

416   **production.** The solid line shows the fitted regression equation: NCP (mmol O_2 m^{-3} d^{-1}) = -2.65

417   + 0.65 (± 0.05) GPP (mmol O_2 m^{-3} d^{-1}) (R^2 = 0.75, P < 0.0001). Blue symbols and red symbols

418   correspond to Matilda Bay and Woodman Point, respectively.

419

420   **Figure 6. Plankton metabolism and phytoplankton.** The relationship between (A) net

421   community production, (B) gross primary production and (C) community respiration and

422   chlorophyll *a* concentration. The solid lines show the fitted regression equations: (A) NCP

423   (mmol O_2 m^{-3} d^{-1}) = -1.54 + 2.29 (± 0.19) Chl *a* (µg Chl *a* L^{-1}) (R^2 = 0.73, P < 0.0001); (B) GPP

424   (mmol O_2 m^{-3} d^{-1}) = 2.93 + 3.03 (± 0.05) Chl *a* (µg Chl *a* L^{-1}) (R^2 = 0.69, P < 0.0001); and (C) R

425   (mmol O_2 m^{-3} d^{-1}) = 4.45 + 0.74 (± 0.24) Chl *a* (µg Chl *a* L^{-1}) (R^2 = 0.15, P =0.0036). Blue

426   symbols and red symbols correspond to Matilda Bay and Woodman Point, respectively.

427

428   **Figure 7: Thermal relationships**. Arrhenius plots showing the relationship between the natural

429   log of (A) community respiration and (B) gross primary production standardized to chlorophyll

430   *a*, and 1/kT, where k is the Boltzmann' s constant (8.617734 10-5 eV $^oK^{-1}$) and T is the sea-

431   surface water temperature (^oK) in Matilda Bay (blue symbols) and Woodman Point (red

432   symbols). The solid lines show the fitted equations: ln R (mmol O_2 mg m^{-3} d^{-1}) = 31.87 - 0.76 ($\pm$

433   0.21) 1/kT (R^2 = 0.21, P =0.0008) and ln GPP/Chl a (mmol O_2 mg Chl a^{-1} d^{-1}) = 28.8 - 0.69 ($\pm$

434   0.12) 1/kT (R^2 = 0.41, P < 0.0001).

435

Mean (±SE) of the variables measured in Matilda Bay and Woodman Point (Western Australia).

NCP = net community production, GPP = gross primary production and P/R = is the ratio of GPP over R. Asterisks denotes statistically significant difference (t-test, P<0.05).

	Matilda Bay		Woodman Point	
	Mean	± SE (N = 33)	Mean	± SE (N = 27)
Temperature (°C)	20.90	0.66	20.79	0.57
Salinity	32.09	0.95	35.13*	0.29
Ammonia (μmol N L^{-1})	2.68	0.30	2.17	0.29
Nitrate (μmol N L^{-1})	2.32	0.71	0.56*	0.08
Phosphate (μmol P L^{-1})	0.52	0.06	0.20*	0.02
Chlorophyll a (μg Chl a L^{-1})	4.05	0.47	1.68*	0.14
Respiration (μmol O$_2$ L^{-1} d^{-1})	8.81	0.76	4.33*	0.48
NCP (μmol O$_2$ L^{-1} d^{-1})	7.21	1.29	2.32*	0.61
GPP (μmol O$_2$ L^{-1} d^{-1})	16.05	1.56	6.23*	0.60
P/R	1.91	0.14	2.05	0.27

Figure 1

Map showing the study area in Western Australia.

The stations sampled in the coast of Perth are marked with green (Matilda Bay) and red (Woodman Point) dots. The free software Ocean Data View (Schlitzer, R., Ocean Data View, http://odv.awi.de , 2016), version 4.7.10, was used to generate the study area map.
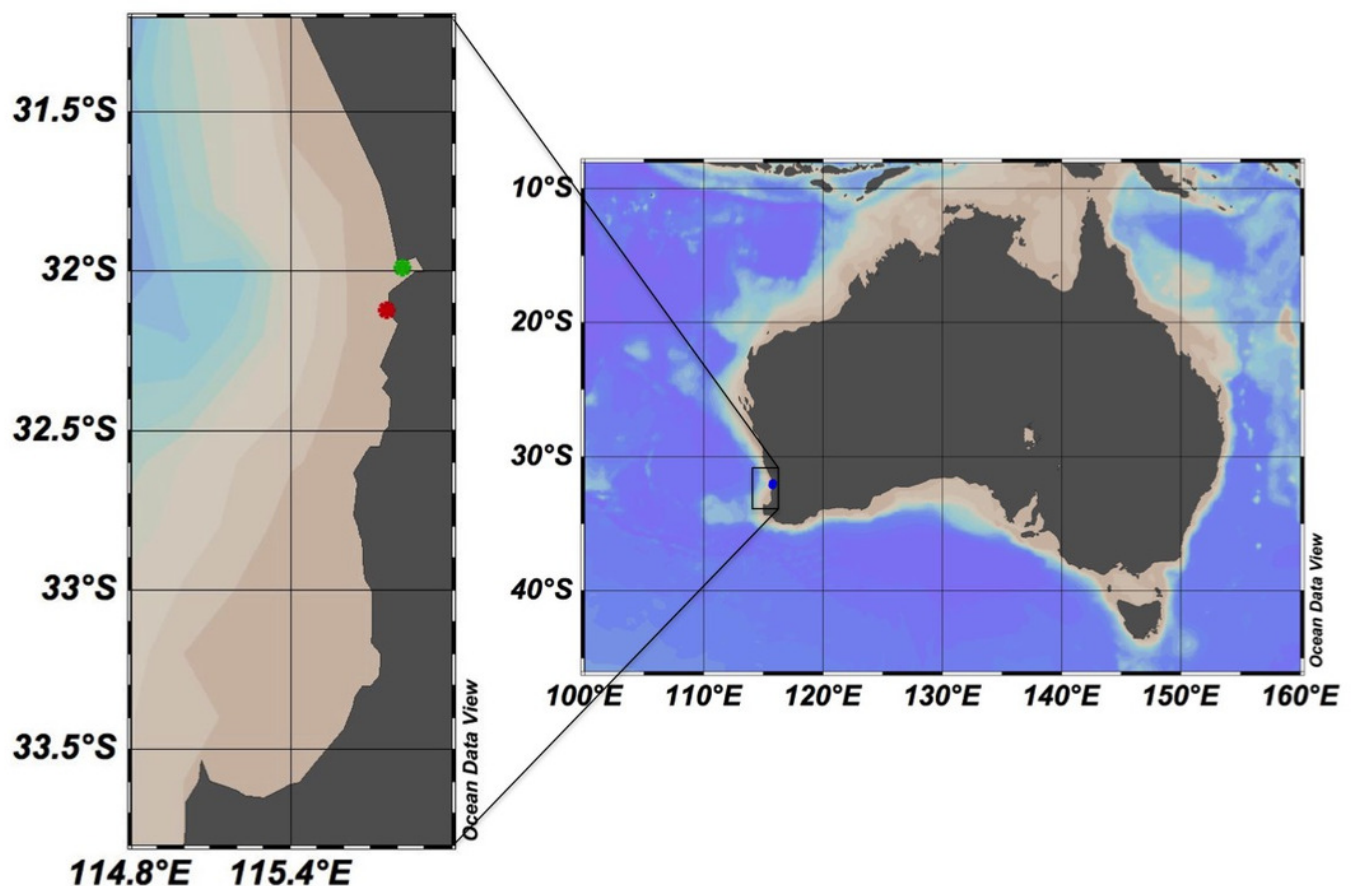
Figure 2

Temporal variability in seawater temperature and salinity.

Changes in surface seawater temperature (A) and salinity (B) in Matilda Bay are shown in blue line and symbols, and in Woodman Point in red line and symbols, over time.

A

Julian Day 2014-2015

B

Julian Day 2014-2015
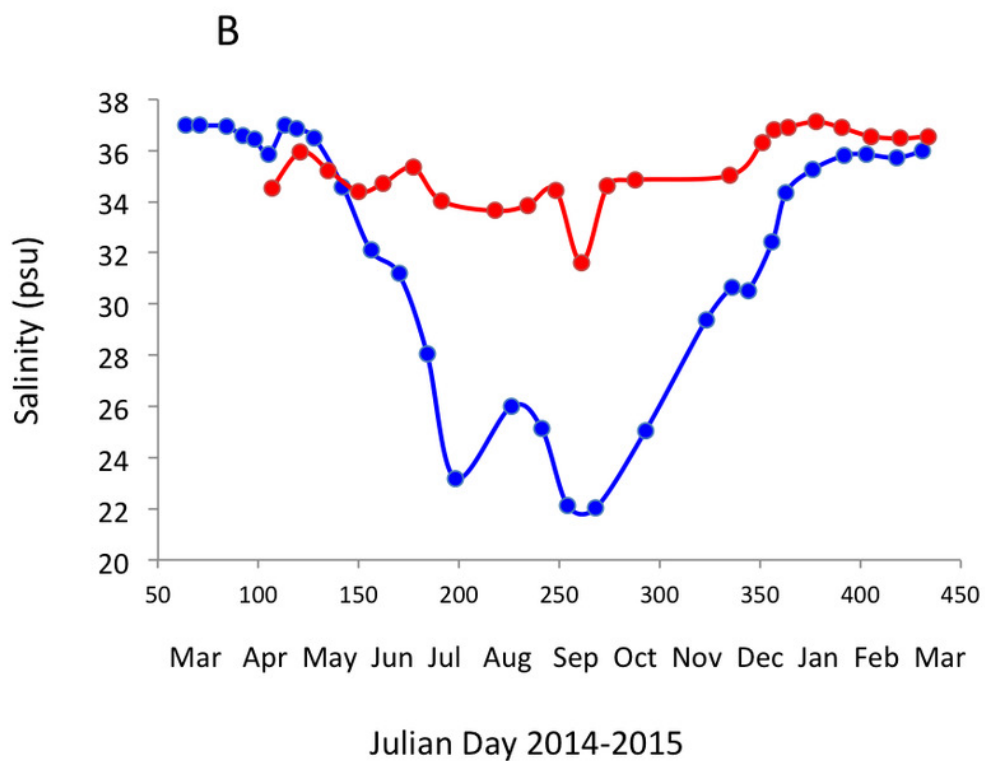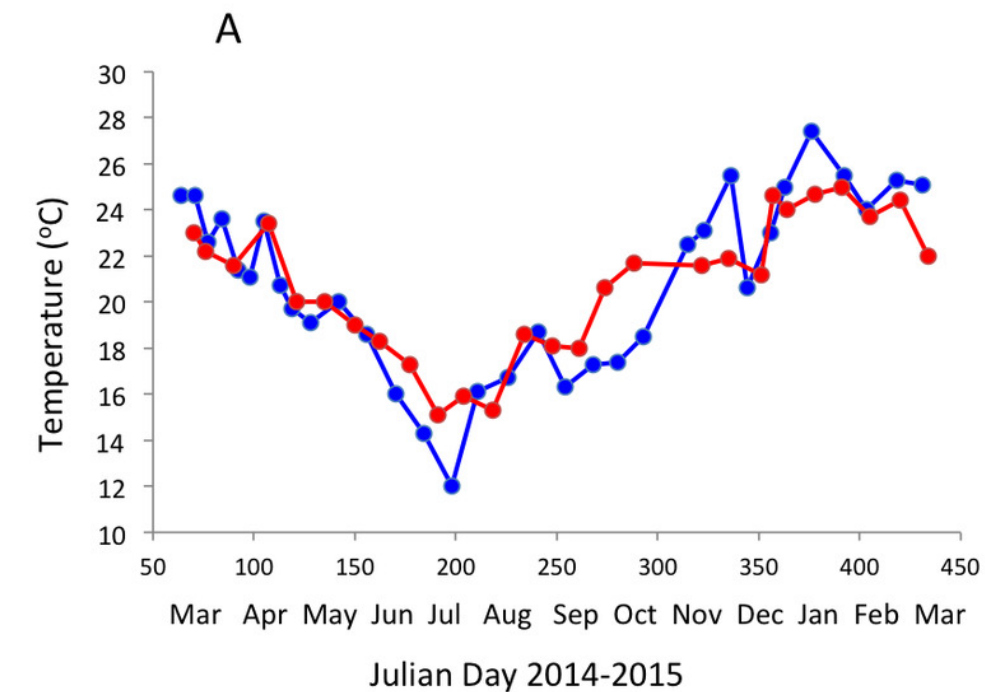
Figure 3

Nutrients and chlorophyll *a* variability.

Changes in (A) nitrate, (B) ammonium, (C) phosphate and (D) chlorophyll *a* concentration in Matilda Bay (blue line and symbols) and Woodman Point (red line and symbols) over time.
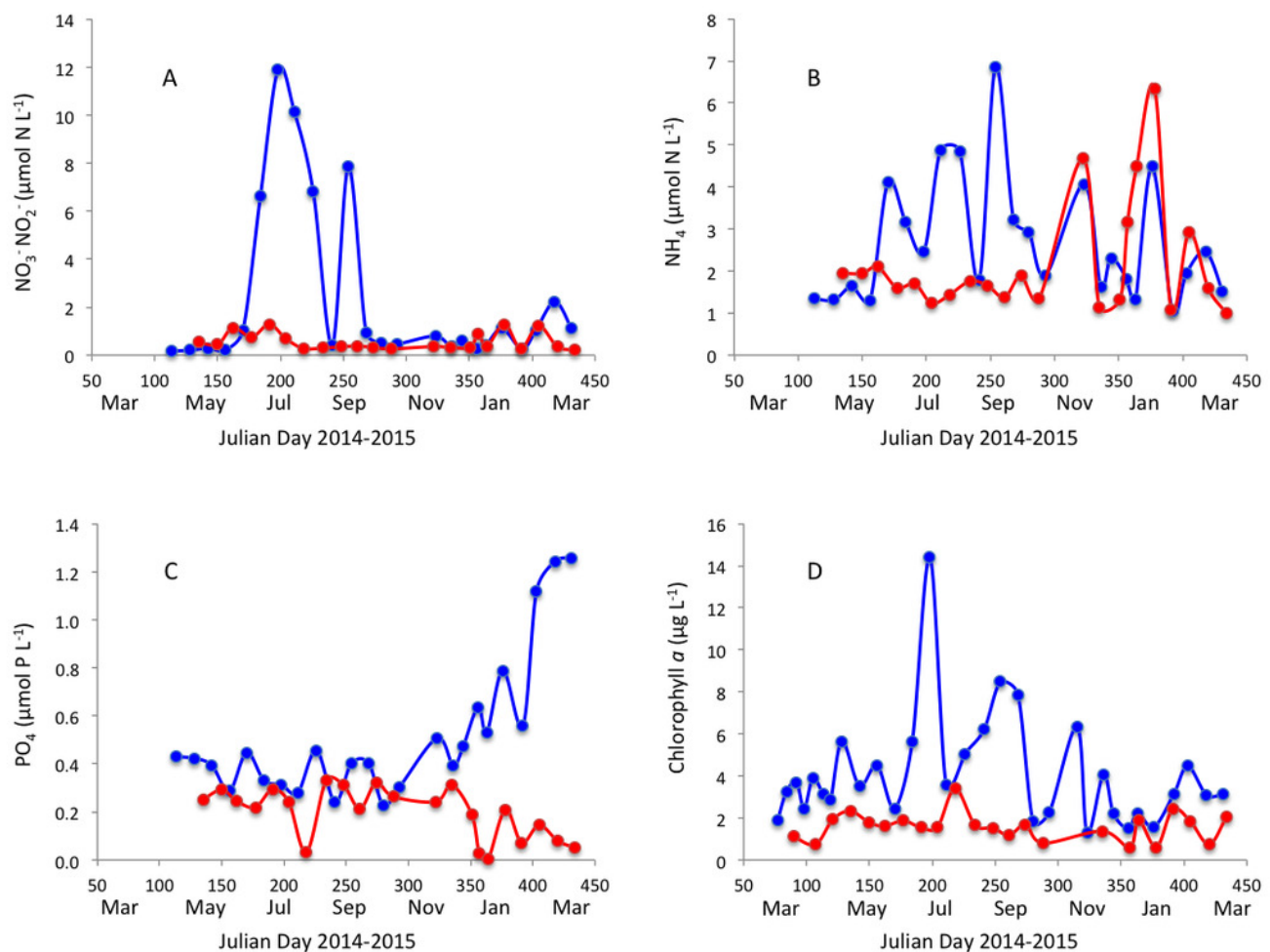
Figure 4

Planktonic metabolism.

Changes in (A) community respiration rate, (B) gross primary production, and (C) net community production in Matilda Bay (blue line and symbols) and Woodman Point (red line and symbols) over time.

Julian Day 2014-2015
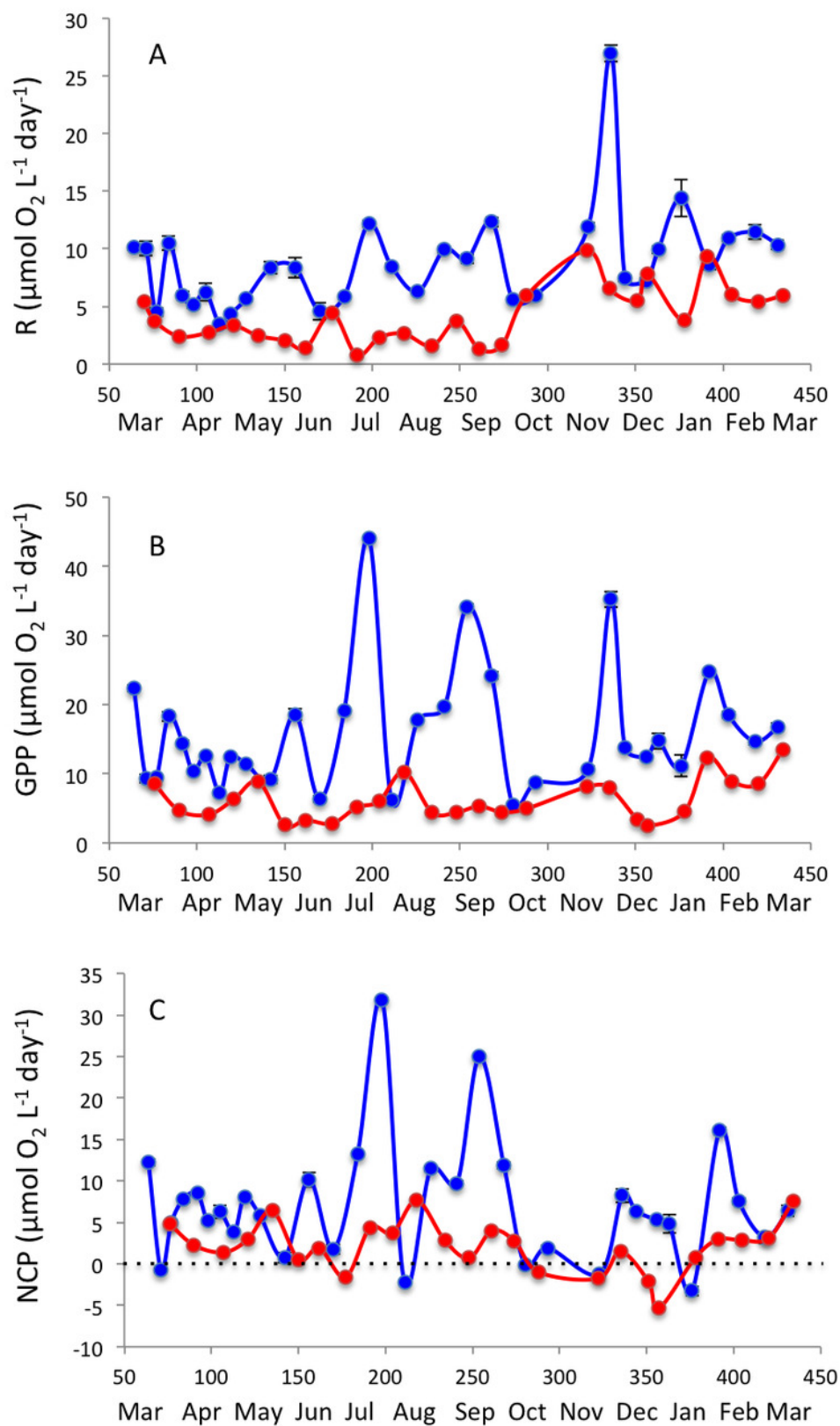
Figure 5

The relationship between net community production and gross primary production.

The solid line shows the fitted regression equation: NCP (mmol O_2 m^{-3} d^{-1}) = -2.65 + 0.65 (± 0.05) GPP (mmol O_2 m^{-3} d^{-1}) (R^2 = 0.75, P < 0.0001). Blue symbols and red symbols correspond to Matilda Bay and Woodman Point, respectively.
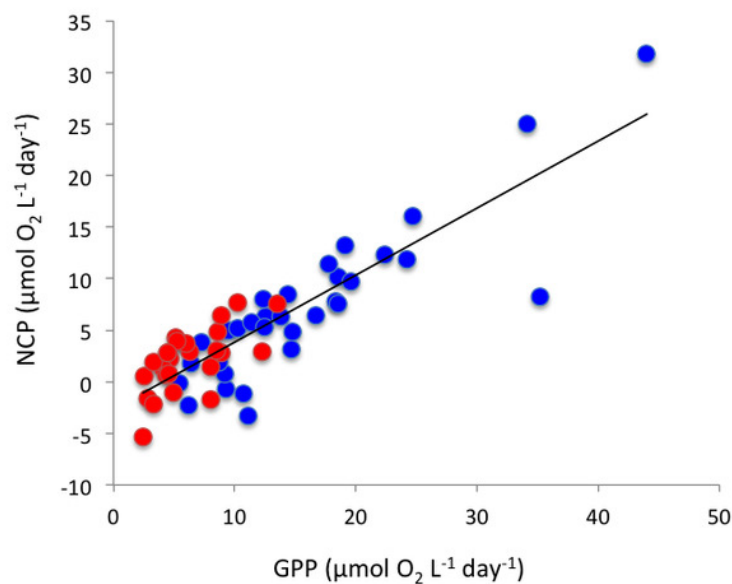
Figure 6

Plankton metabolism and phytoplankton.

The relationship between (A) net community production, (B) gross primary production and (C) community respiration and chlorophyll a concentration. The solid lines show the fitted regression equations: (A) NCP (mmol O_2 m^{-3} d^{-1}) = -1.54 + 2.29 ($\pm$ 0.19) Chl a (μg Chl a L^{-1}) (R^2 = 0.73, P < 0.0001); (B) GPP (mmol O_2 m^{-3} d^{-1}) = 2.93 + 3.03 ($\pm$ 0.05) Chl a (μg Chl a L^{-1}) (R^2 = 0.69, P < 0.0001); and (C) R (mmol O_2 m^{-3} d^{-1}) = 4.45 + 0.74 ($\pm$ 0.24) Chl a (μg Chl a L^{-1}) (R^2 = 0.15, P =0.0036). Blue symbols and red symbols correspond to Matilda Bay and Woodman Point, respectively.
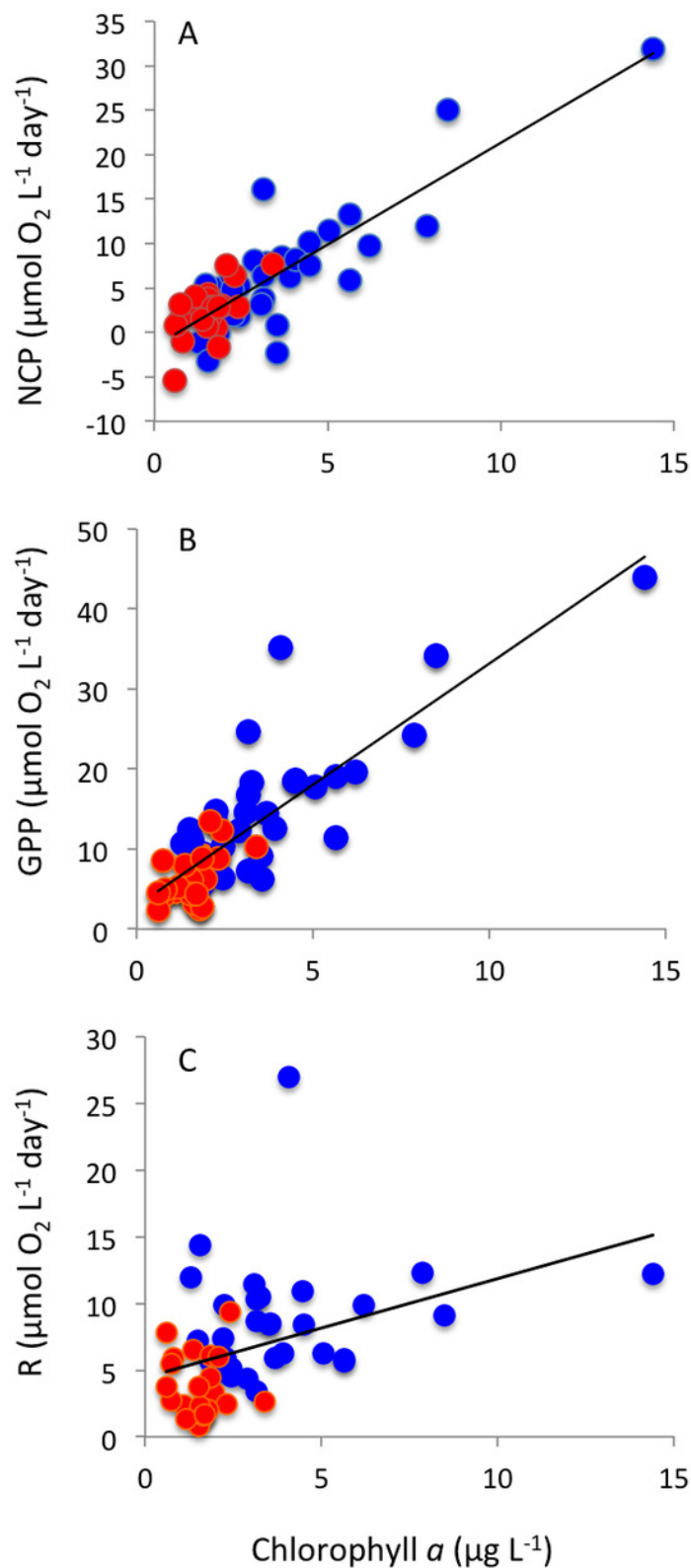
Figure 7

Thermal relationships.

Arrhenius plots showing the relationship between the natural log of (A) community respiration and (B) gross primary production standardized to chlorophyll a, and 1/kT, where k is the Boltzmann' s constant (8.617734 10-5 eV °K^{-1}) and T is the sea-surface water temperature (°K) in Matilda Bay (blue symbols) and Woodman Point (red symbols). The solid lines show the fitted equations: ln R (mmol O$_2$ mg m^{-3} d^{-1}) = 31.87 - 0.76 (± 0.21) 1/kT (R^2 = 0.21, P =0.0008) and ln GPP/Chl a (mmol O$_2$ mg Chl a^{-1} d^{-1}) = 28.8 - 0.69 (± 0.12) 1/kT (R^2 = 0.41, P < 0.0001).