2.2 Spatial and seasonal trends in net primary production

Peter Thompson[1] and Karlie McDonald[1]

[1] CSIRO Oceans and Atmosphere, Hobart, TAS, Australia

Summary

Net primary productivity varies greatly around Australia, with highest rates in coastal zones and in seas between Australia and its northern neighbours. Although there is a strong seasonal trend, increasing during spring-summer and decreasing in autumn-winter, average net primary productivity has declined in Australian waters by 12 % in the past 17 years (2002-2019). Given that primary production sets the carrying capacity of higher trophic levels (zooplankton, fish, birds and mammals), this decrease is likely to cause a reduction in the size of Australia's fisheries.

Key Data Streams

Satellite Remote Sensing

State and Trends of Australia's Ocean Report
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Rationale

Plants use sunlight to grow and this growth supports all animal life. The growth is often measured as the conversion of carbon dioxide (CO_2) into plant biomass (= primary production) per unit time. Total net primary production on Earth exceeds 100 billion tons of carbon per year and plays a profound role in the global carbon cycle. Phytoplankton in the oceans provide almost half of this productivity. Satellites have made it possible to have much more precise estimates of global primary production because of their ability to observe the entire planet every few days. The productivity of phytoplankton in our ocean pastures regulates the abundance of fish.

Methods

Although there are direct measurements of primary production from Australian waters (Everett & Doblin, 2015; Furnas & Carpenter, 2014; Jitts, 1967; Lourey et al., 2013; McLaughlin et al., 2019; Waite et al., 2007), they do not provide comprehensive spatial resolution or interannual resolution. Therefore, we are reliant on data from satellites. Converting satellite estimates of phytoplankton biomass derived from ocean colour to chlorophyll ***a*** and into primary production uses conceptual and mathematical models that originated in the 1950s (Ryther, 1956; Ryther & Yentsch, 1957; Talling, 1957). A more recent model uses satellite-based estimates of phytoplankton carbon concentration (Behrenfeld et al., 2005) derived from light scattering properties (Behrenfeld & Boss, 2003, 2006; Durand & Olson, 1996; Green & Sosik, 2004; Green et al., 2003; Loisel et al., 2001; Stramski et al., 1999) and improved information on particulate backscattering coefficients, phytoplankton pigment absorption, and coloured dissolved organic carbon absorption (Garver & Siegel, 1997; Maritorena et al., 2002; Siegel et al., 2002). We use this carbon-based approach here. Data and further description of the methods can be found at http://www.science.oregonstate.edu/ocean.productivity/.

Results and interpretation

The mean net primary production across the Australian region between 2002 and 2019 was 551 mgC m^{-2} d^{-1}. This is a relatively low productivity, typical of healthy tropical and subtropical oceanic waters. Areas of higher net primary production in the region include the coastal zone and seas between Australia and its northern neighbours (**Figure 1**).

Across the Australian region, the net primary production (NPP) varied seasonally and inter-annually (**Figure 2**). NPP was elevated during the summer of 2009-10 and reduced in the summer of 2011-12 (**Figure 2**). There was, however, a significant ($p<0.001$) negative trend in NPP across this region. From 2002 to 2019, the mean annual NPP declined 12%.

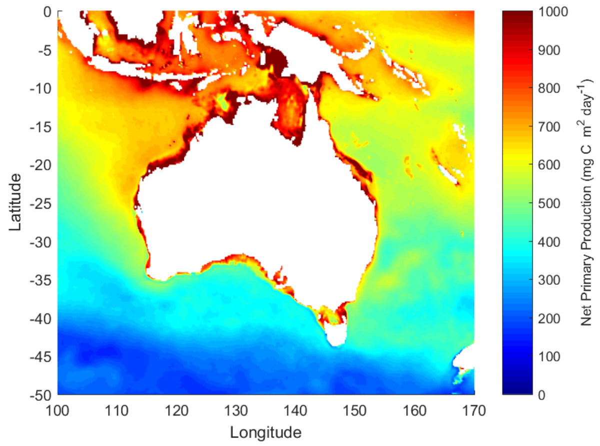

Figure 1. Estimated mean net primary production (mgC m^{-2} d^{-1}) for the Australian region (0-50°S and 100-170°E) from December 2002 to January 2019.

Within Australia's continental EEZ, the mean net primary production was 606 mgC m^{-2} d^{-1}. Net primary production was lower further south (**Figure 3**). Net primary production was greater in the coastal zone, the shallow seas between Australia and its northern neighbours, and through Bass Strait to Tasmania.

Similar to the broader regional trend, the net primary production in the Australian EEZ has declined significantly ($p<0.0009$) from 2002 to 2019 (**Figure 4**). The rate of decline was similar at 0.6% per year or ~10% over the elapsed period from 2002 to 2019. There was substantial inter-annual variation (Fig. 4). For example, summer 2009-10 was less productive than the summer of 2010-11 (**Figure 4**).

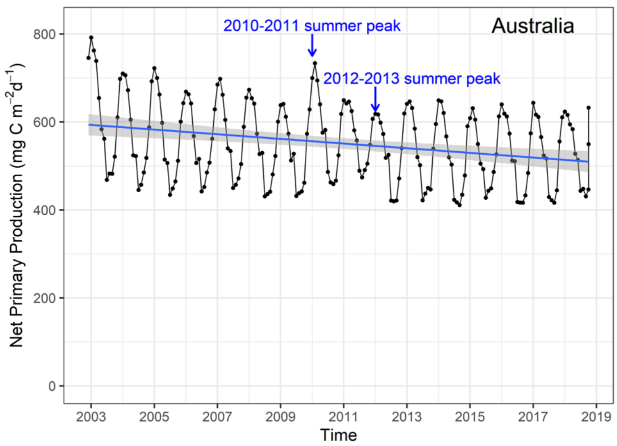

Figure 2. Estimated mean monthly net primary production (mgC m^{-2} d^{-1}) for the Australian region (0-50°S and 100-170°E) from December 2002 to January 2019. Strong seasonal, inter-annual and long-term variability are evident (grey ellipses show differences between peak primary production in 2010-11 and 2012-13), with the long-term trend estimated as significantly negative ($P<0.001$).

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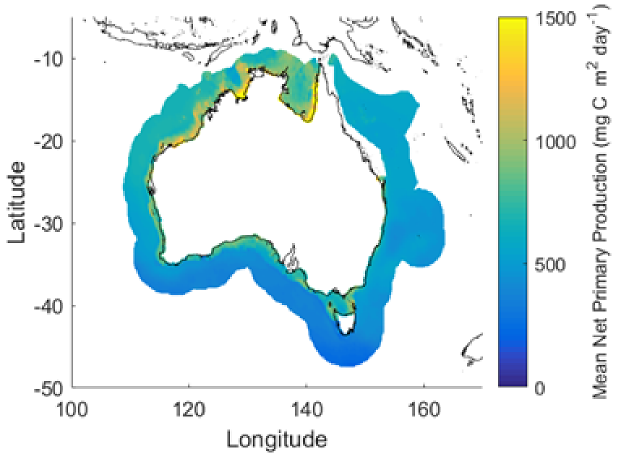

Figure 3. Estimated mean net primary production (mgC m^{-2} d^{-1}) for the Australian EEZ for December 2002 to January 2019.

All six bioregions around the coast of Australia were significantly different from each other in terms of their net primary production (p<0.001), except for the Temperate East, which was not different from the South East (**Figure 5**). The North bioregion had the greatest primary production followed by the North West and then the Coral Sea. The three bioregions further south, Temperate East, South West and South East had lower primary production. Across all bioregions, the range in estimated primary production was a factor of ~2 between the North and South East regions (**Table 1**).

All bioregions showed seasonal variability in net primary production, with largest seasonal changes in more southern bioregions (**Figure 6**). The South East bioregion had the largest seasonal variation, with a relatively high mean primary production of ~800 mgC m^{-2} d^{-1} during summer, declining to <200 mgC m^{-2} d^{-1} during winter for an annual range of 642 mgC m^{-2} d^{-1}. The smallest average annual range of only 87 mgC m^{-2} d^{-1} was in the North West bioregion, where there was a winter minimum followed by small spring and autumn increases in primary production.

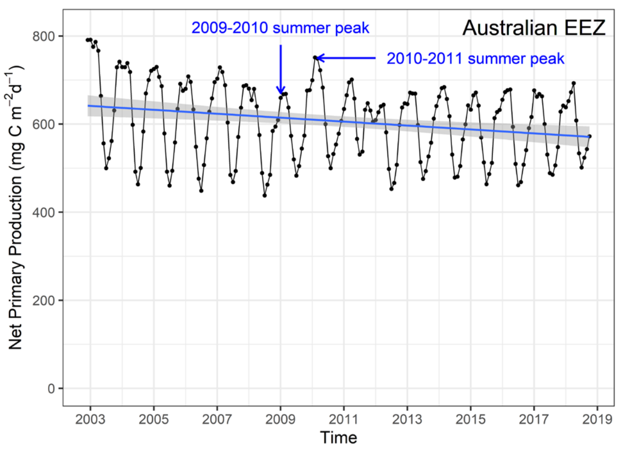

Figure 4. Estimated mean monthly net primary production (mgC m^{-2} d^{-1}) for the Australian EEZ for December 2002 to January 2019. Strong seasonal, inter-annual and long-term variability are evident (grey ellipses show differences between peak primary production in 2009-10 and 2010-11) with the long-term trend estimated as significantly negative (P<0.0009).

Table 1. Mean 2003-2018 daily net primary production in each bioregion (mgC m^{-2} d^{-1}), its overall decline, and the probability the rate of decline is zero (p). SD = Standard Deviation

Bioregion	Mean	SD	Standard error of the mean	% decline 2003 to 2018	p
North	888	43	11	-7.1%	0.074
Temperate East	510	28	7	-12.9%	0.001
North West	758	36	9	-10.2%	0.004
South West	491	25	6	-8.6%	0.032
South East	423	28	7	-7.6%	0.158

Trends in net primary production from 2002 to 2019 were negative in each of the six bioregions, although only statistically significant for four (the Coral Sea, Temperate East, South West, North West bioregions, **Table 1**). Rates of decline in net primary production ranged from 7-13% over 15 years across the 6 bioregions and averaged 9% overall or 0.6% per year across all bioregions. The rate of decline as a percent of total net primary production was greatest in the Temperate East and least in the North (**Table 1**).

Although there are few net primary production estimates in the Australian region, the North bioregion has been relatively well studied using conventional ^{14}C measurements for primary production (Furnas & Carpenter 2016). These data, collected between 1990 and 2013, had a mean of 1048 ± 109 mgC m^{-2} d^{-1} (mean ± 95% CI). Based on our results, the estimated mean for the entire region between 1990 and 2013 was 924 mgC m^{-2} d^{-1}, with monthly means that varied from 684 to 1165 mgC m^{-2} d^{-1}. Thus, estimates here from satellite and observed point estimates from ^{14}C measurements are in reasonable agreement, given differences in spatial-temporal sampling.

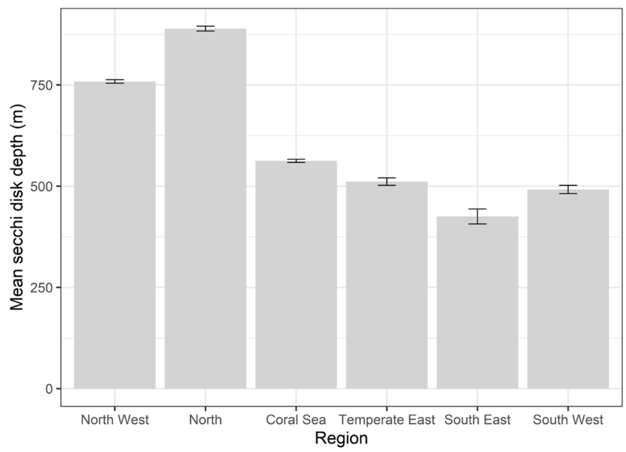

Figure 5. Estimated mean annual net primary production for the six bioregions around Australia (mean ± standard error).

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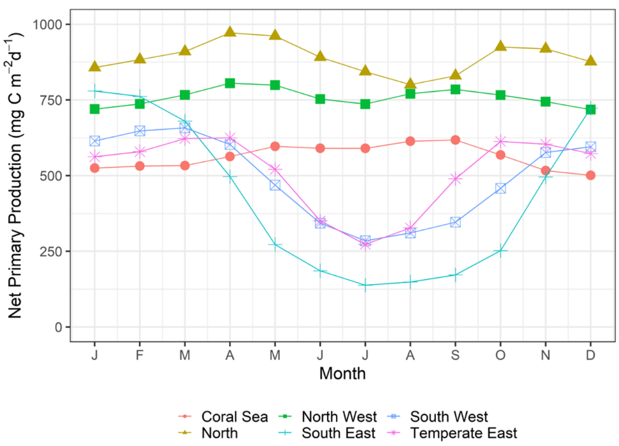

Figure 6. The average monthly net primary production for the six bioregions around Australia.

Implications for people and ecosystems

From 2002 to 2019, there was a significant decline in net primary production in the continental EEZ and four of the six bioregions. Both the carbon-based model and the ocean colour-based model of primary production are likely to indicate significant declines in primary production. These downwards trends in primary production are also similar to those observed elsewhere using other observational methods such as long-term measurements by Secchi Disk (e.g. Falkowski & Wilson, 1992). This decline in primary production is consistent with the observed declines in chlorophyll ***a*** (see State and Trends of Australia's Ocean Report 2.1: Spatial and seasonal trends in Chlorophyll a), phytoplankton abundance and phytoplankton biovolume (see State and Trends of Australia's Ocean Report 2.3: Contrasting trends of Australia's plankton communities).

The conventional understanding of primary production around Australia has changed dramatically in the last decade. Early estimates based on ocean colour from the coastal zone colour scanner, the SeaWiFs, and MODIS satellites e.g. (Behrenfeld & Falkowski, 1997) indicated that the greatest primary production was in the Tasman Sea (**Figure 7**). These early models have been widely used to estimate global primary production (e.g. (Field, Behrenfeld, Randerson, & Falkowski, 1998). Here net primary production was calculated based on the satellite-derived measures of phytoplankton carbon. This carbon-based approach is considered an improvement (Behrenfeld & Boss, 2003, 2006) . Using the new temperature-corrected and carbon-based model suggests northern Australian waters are more productive than previously thought (**Figure 7**). The new approach estimates the North bioregion has the greatest annual primary production at 324 gC m^{-2} y^{-1} and Southeast bioregion with the least at only 154 gC m^{-2} y^{-1} (Table 1).

All the Australian bioregions had estimated primary production values within ±100 gC m^{-2} d^{-1} of the global mean of measurements from 131 coastal or estuarine water bodies of 252 gC m^{-2} d^{-1} (Cloern et al., 2014). The relatively high measured values of primary production using ^{14}C from the North (e.g. Furnas & Carpenter, 2014) would suggest that newer carbon-based models (Behrenfeld & Boss, 2003, 2006) provide better estimates of primary production in our northern waters than models based on ocean colour. At this time there are no data to substantiate whether these new models are also better for the Tasman Sea.

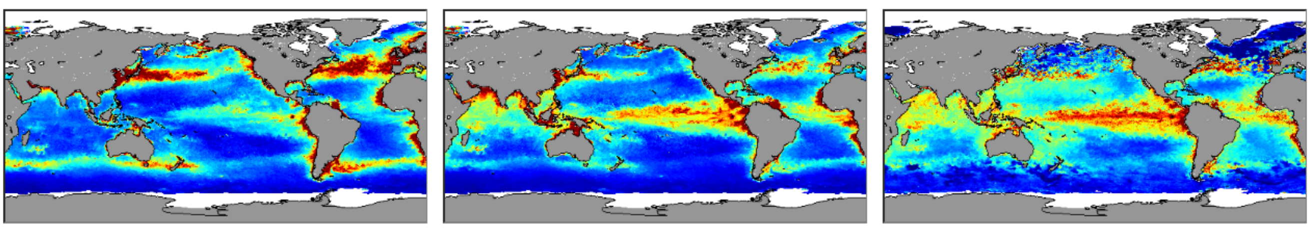

Figure 7. Modified from **http://www.science.oregonstate.edu/ocean.productivity/custom.php**. (accessed May 17 2019). All panels show estimated net primary production (NPP) with blue (= low) to red (= high) derived from MODIS satellite data. The Left panel shows conventional NPP, the centre panel shows temperature adjusted NPP, the right panel is NPP from a spectral and depth resolved carbon-based model.

Data Sources

Oregon State University

http://sites.science.oregonstate.edu/ocean.productivity/

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