Spatial and Temporal Variation in Primary and Secondary Productivity in the Eastern Great Australian Bight

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Summary

The Great Australian Bight (GAB) was for many years thought to be an area of limited biological productivity due to a perceived lack of nutrient enrichment processes. These conclusions, however, were based on data from few studies in the western GAB which were assumed to reflect conditions throughout the entire GAB. More recent studies have reported the occurrence of coastal upwelling in the eastern GAB (EGAB) during summer/autumn (November-April), characterized by low sea surface temperatures and elevated concentrations of chlorophyll *a*, which suggests that certain areas of the GAB may be highly productive during certain times of the year.

The eastern Great Australian Bight (EGAB) forms part of the Southern and Indian Oceans and is an area of high ecological and economic importance. Although it supports the largest fishery in Australia (the South Australian Sardine fishery, annual catches since 2004 ~ 25,000 to 42,500 t), quantitative estimates of the primary productivity underlying this industry are open to debate. Estimates range from < 100 mg C m^{-2} day^{-1} to > 500 mg C m^{-2} day^{-1}. Part of this variation may be due to the unique upwelling circulation of shelf waters in summer/autumn (November-April), which shares some similarities with highly productive eastern boundary current upwelling systems, but differs due to the influence of a northern boundary current, the Flinders current, and a wide continental shelf. Shelf waters encompass an area of ~115,000 km^2, and the diverse coastal topography forms part of one of the longest stretches of southward facing coastline in the world. In summer-autumn, winds are upwelling favourable, and the Flinders current running along the continental slope causes the upwelling of the deep permanent thermocline from around 600 m depth

(dynamic uplift), allowing nutrient rich cold water to entrain onto the shelf. In winter-spring, the EGAB is dominated by westerly downwelling-favourable winds, and upwelling via the Flinders current is suppressed. Thus, the area is highly dynamic, with significant spatial and temporal variations in meteorology and oceanography which may drive variations in nutrient enrichment and productivity. This study represents the first intensive investigation of the primary and secondary productivity of the EGAB, and was designed to evaluate the general hypothesis that spatial and temporal variations in meteorology and oceanography in the EGAB will drive spatial and temporal variations in phytoplankton size structure, and primary and secondary productivity. It examines variations in primary and secondary productivity in the EGAB during the upwelling and downwelling seasons of 2004, and the upwelling seasons of 2005 and 2006.

Daily integral productivity calculated using the vertically generalised production model (VGPM) showed a high degree of spatial variation. Productivity was low (<800 mg C m^{-2} day^{-1}) in offshore central and western regions of the EGAB. High productivities (1600-3900 mg C m^{-2} day^{-1}) were restricted to hotspots in the east that were influenced by the upwelled water mass. There was a strong correlation between the depth of the euphotic zone and the depth of the mixed layer that suggested that ~50% of the euphotic zone lay below the mixed layer depth. As a result, high rates of primary productivity did not require upwelled water to reach the surface. A significant proportion of total productivity in the euphotic zone (57% in 2005 and 65% in 2006) occurred in the upwelled water mass below the surface mixed layer. This result has implications for daily integral productivities modelled with the VGPM, which uses surface measures of phytoplankton biomass to calculate productivity. Macro nutrient concentrations could not be used to explain the difference in the low and high productivities (silica >1 μmol L^{-1}, nitrate/nitrite >0.4 μmol L^{-1}, phosphate >0.1 μmol L^{-1}). Mixing patterns or micro-nutrient concentrations are possible explanations for spatial variations in primary productivity in the EGAB. On a global scale, daily rates of primary productivity of the EGAB lie between the highly productive eastern boundary current upwelling systems, and less productive coastal regions of western and south eastern Australia, and the oligotrophic ocean. However, daily productivity rates in the upwelling hotspots of the EGAB rival productivities in Benguela and Humbolt currents.

Temporal variation in mixing and primary productivity was examined in upwelling influenced nearshore waters off south western Eyre Peninsula (SWEP) in the EGAB. Mixing/stratification in the region was highly temporally variable due to the unique upwelling circulation in summer/autumn, and downwelling through winter/spring. Highest productivity was associated with upwelled/stratified water (up to 2958 mg C m^{-2} d^{-1}), with low productivity during periods of downwelling and mixing (~300-550 mg C m^{-2} d^{-1}), yet no major variations in macro-nutrient concentrations were detected between upwelling and downwelling events (silica >1 μmol L^{-1}, nitrate/nitrite >0.4 μmol L^{-1}, phosphate >0.1 μmol L^{-1}). We hypothesise that upwelling enriches the region with micro-nutrients. High productivity off SWEP appears to be driven by a shallowing of mixed layer depth due to the injection of upwelled waters above Z_{cr}. Low productivity follows the suppression of enrichment during downwelling/mixing events, and is exacerbated in winter/spring by low irradiances and short daylengths.

Phytoplankton abundance and community composition was also examined in the shelf waters of the EGAB. Phytoplankton abundances were generally higher in near shore waters compared with offshore waters, and during the summer/autumn upwelling season compared with the winter/spring downwelling season. Three distinctly different phytoplankton communities were present in the region during the upwelling and downwelling seasons of 2004, and the upwelling season of 2005, with distinctions manifest in variations in the abundance of dominant types of phytoplankton, and differences in average cell sizes. In summer/autumn, waters influenced by upwelling were characterised by high phytoplankton abundances (particularly diatoms) and larger average cell sizes, while the warmer high-nutrient-low-chlorophyll (HNLC) waters in the region had lower phytoplankton abundances and smaller average cell sizes. The winter/spring community was made up of low abundances of relatively large cells. Diatoms always dominated, but evidence of Si limitation of further diatom growth suggests there may be an upper limit to diatom productivity in the region. The maximum observed diatom concentration of ~164,000 cells L^{-1} occurred in February/March 2004, in an area influenced by the upwelled water mass. Variations in phytoplankton biodiversity in the shelf waters of southern Australia appear to be related to variations in the influence of upwelling in the region.

Meso-zooplankton abundance and community composition was examined in the coastal upwelling system of the EGAB. Spatial and temporal variations were influenced by variations in primary productivity and phytoplankton abundance and community composition, which were driven by variations in the influence of upwelling in the region. Peak meso-zooplankton abundances and biomass occurred in the highly productive upwelling influenced nearshore waters of the EGAB. However, abundances were highly variable between regions and years, reflecting the high spatial and temporal variations in primary productivity and phytoplankton abundance that characterise the shelf waters of the region. Spatial and temporal variations in community composition were driven by changes in the abundance of classes of meso-zooplankton common to all regions in both years of this study. Meroplanktonic larvae and opportunistic colonizers dominated the community through the upwelling season, in response to increased primary productivity and phytoplankton blooms. Differences in community composition between upwelling influenced waters and the more HNLC regions appear to be reflected in the relative abundances of cladocera and appendicularia, with cladocera more abundant in productive upwelling influenced areas, and appendicularia thriving in the more HNLC regions of the EGAB. Highest potential grazing rates in the EGAB occurred in nearshore regions with highest meso-zooplankton biomass, most likely in response to the high phytoplankton biomass that occurs in the same regions. Peak meso-zooplankton grazing rates in the EGAB were ~80% less than those measured in south west Spencer Gulf in March 2007, and ~35% greater than grazing rates in the Huon Estuary in February 2005.

Productivity in the EGAB shows significant spatial and temporal variation, with changes reflecting regional and seasonal variation in meteorology and oceanography, and the water masses present in the region. The overall productivity of a summer/autumn upwelling season was highly dependent on within-season variations in wind strength and direction, which dictate the number, intensity, and duration of upwelling events. Rates of primary productivity measured in the EGAB at a given time depended on the meteorological and oceanographic conditions in the region in the lead up to, and during, the sampling event. We hypothesise that during upwelling events, high productivity in the EGAB is driven by the enrichment of waters above Z_{cr}, but below the surface mixed layer, with micro-nutrients. Low productivity within summer/autumn upwelling seasons follows the suppression of this enrichment during downwelling/mixing events, and the overall productivity of the upwelling season will depend on the number, duration and intensity of these downwelling/mixing events.

Low productivity during winter/spring is driven by the absence of upwelling, low irradiances and short daylengths.

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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