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Biophysical characteristics of a morphologically-complex macrotidal tropical coastal system during a dry season

N.L. Jones [a, b, *], N.L. Patten [a, b], D.L. Krikke [a, b], R.J. Lowe [b, c], A.M. Waite [a, b], G.N. Ivey [a, b]

[a] School of Civil, Environmental and Mining Engineering, The University of Western Australia, Australia
[b] UWA Oceans Institute, Australia
[c] School of Earth and Environment, The University of Western Australia, Australia

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A B S T R A C T

Four boat-based surveys and several moored measurements were conducted over the dry season in June, July, August and September 2008 in the central Kimberley region of northwestern Australia; a macrotidal tropical coastal region, characterised by numerous island archipelagos and shallow reefs. The objective was to determine the influence of this complex morphology on the biophysical properties of the local coastal water masses and the resultant impact on phytoplankton biomass. Despite negligible rainfall during the dry-season, decreased salinity towards the coast suggested a persistent fresh water source. The water column was weakly vertically-stratified throughout much of the study region, only becoming well-mixed in topographically constricted regions. The vertical stratification resulted in a cross-shore subsurface *in situ* chl-*a* fluorescence maxima (at ~30 m depth) in June, July and August. The presence of a chain of islands and shallow reefs led to the partial isolation of the semi-enclosed embayment, Collier Bay, creating distinct water masses across this relatively small area. The confluence of the two most distinct water masses formed a front at latitude ~15.65–15.7 °S, in both June and August, indicating it was a persistent feature during the dry season. *In situ* chl-*a* fluorescence was highest at the front location. In Collier Bay, NO_x concentrations were up to five times higher, with a 20% higher proportion of larger extracted chl-*a* biomass (cells > 5 μm), a proxy for phytoplankton. In the more open waters of Camden Sound, relatively high concentrations of picophytoplankton, bacteria and viruses were observed. Such spatial shifts in nutrient concentrations, phytoplankton biomass and phytoplankton and microbial community composition across the persistent density front are likely to have important consequences on the region's planktonic food web function.

1. Introduction

The complex morphology associated with island archipelagos, reefs, capes and headlands can play an important role in determining the ecological function of coastal waters. Regions inshore of reef and island matrices are isolated by varying degrees from adjoining offshore oceanic waters, potentially leading to localised physical and biogeochemical processes that can have a large influence on the local biological response (e.g., Furnas et al., 2005; Wyatt et al., 2012). Furthermore, the interaction of currents with island archipelagos and coastal headlands can create distinct frontal zones with converging and diverging flows, thereby influencing the distribution of sediment, phytoplankton and weak-swimming nekton (e.g., Johnston and Read, 2007). The combined effect of these processes can lead to large variations in the function of planktonic ecosystems over small spatial areas.

Islands and reefs can reduce the exchange of shallow coastal waters with the offshore deeper ocean. For example, the extensive offshore reef and island matrix of the Great Barrier Reef (GBR), Australia hinders the cross-shelf exchange of water, in turn, leading to a relatively high residence time of coastal water within the GBR lagoon (e.g., Wolanski and Spagnol, 2000; Brinkman et al., 2002; Andutta et al., 2013). Intense recycling of nutrients is then required to sustain coastal water column productivity (Alongi and McKinnon, 2005; McKinnon et al., 2013). Another example is Kaneohe Bay, Hawaii, where the limited exchange with offshore water due the barrier reef leads to the stimulation of phytoplankton growth within the Bay, driven by episodic inputs of terrestrially-derived nutrients from storm water runoff (Drupp et al., 2011).

* Corresponding author. School of Civil, Environmental and Mining Engineering, The University of Western Australia, M015 35 Stirling Highway, Crawley, WA 6009, Australia.
E-mail address: nicole.jones@uwa.edu.au (N.L. Jones).

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In coastal areas with complex morphology, partial isolation of water masses through restricted exchange can lead to the creation of physically distinct water masses separated by a frontal zone (i.e., characterised by strong horizontal temperature and/or salinity differences) (Franks, 1992a; O'Donnell, 1993). Alternatively, features such as headlands or islands can also create fronts, characterised by locally well-mixed regions that contrast with the adjacent vertically stratified water column (O'Donnell, 2010). These frontal zones often contain high phytoplankton biomass due to either 1) passive convergent transport toward the front or 2) *in situ* production within the front itself driven by the establishment of optimal light and locally-enhanced nutrient supply conditions (Franks, 1992a,b; Li et al., 2007). Furthermore, the trophic structure of marine food webs can shift from one side of a front to the other: tending towards a herbivorous food chain (large phytoplankton to zooplankton to fish) (Ryther, 1969) on the nutrient-rich, well-mixed side of the front, and a nutrient recycling microbial loop food web (comprising bacteria, picoplankton, nanoplankton and viruses) (Azam et al., 1983; Fuhrman, 1992), occurring in the oligotrophic waters in the adjacent vertically-stratified ocean (e.g., Rodríguez et al., 2000; Fu et al., 2009).

The tropical central coast of the Kimberley in northwestern Australia contains an extensive system of islands and reefs that interact with its extreme tides (Fig. 1). This region has a broad continental shelf (~200 km in width) with a morphologically complex coastal region, where drowned river valleys have formed deep and narrow inlets, and isolated ridges have evolved into extensive island archipelagos (Masini et al., 2009). The tides are semidiurnal, with tidal ranges among the highest in the world; spring tides reach up to 11 m and result in current speeds in excess of 2 m s^{-1} (Anon, 1972). Combined with this region's tropical monsoonal climate, these unique conditions have produced a very ecologically diverse marine ecosystem, with marine communities including coral reefs, seagrass meadows, mangrove forests and sponge gardens. These communities provide habitat, shelter and food resources for culturally and commercially important species, including marine turtles, cetaceans, dugongs, fish, prawns and birds (Masini et al., 2009). Despite the importance of the region, remarkably little is known about its oceanography.

Below we describe results from a 4-month field study of the oceanography of the central Kimberley coast which, for the first time, quantifies the physical, chemical and biological properties of this unstudied coastal region during a dry season. Specifically, we utilise a combination of moored and ship-based measurements to determine: (1) the intra-seasonal variation in physical water properties, (2) the spatial variation in physico-chemical and biological parameters and (3) the influence of the complex morphology on the water mass properties, as well as the resultant impact on the planktonic ecosystem.

2. Methods

2.1. Study site

The study was conducted in two large bays, Camden Sound and Collier Bay, in the central Kimberley region (Fig. 1) within the southeast Indian Ocean. Camden Sound has an average depth of 30 m and is reasonably open to the offshore shelf ocean. In contrast, Collier Bay is encircled by a series of islands and reefs, including the extensive Montgomery Reef, and has an average depth of just 10 m. The total catchment area that discharges into Collier Bay, predominantly through Walcott Inlet, is ~20,000 km^2 compared with just ~500 km^2 into Camden Sound (http://www.ozcoasts.gov.au).

The region experiences a tropical monsoonal climate, with distinct dry (May to October) and wet (November to April) seasons. In the dry season, the average rainfall is only ~5% of the total annual rainfall (averaging 1449 mm $year^{-1}$) and air temperatures are also at their coolest (1962–2010 climate statistics from Kuri Bay meteorological station, http://www.bom.gov.au). The regional wind patterns in the eastern Indian Ocean are determined by the monsoon cycle. In April, the southeasterly trade winds become well-established, bringing dry continental air over the ocean, eventually dominating the region from May to September (Tomczak and Godfrey, 2003).

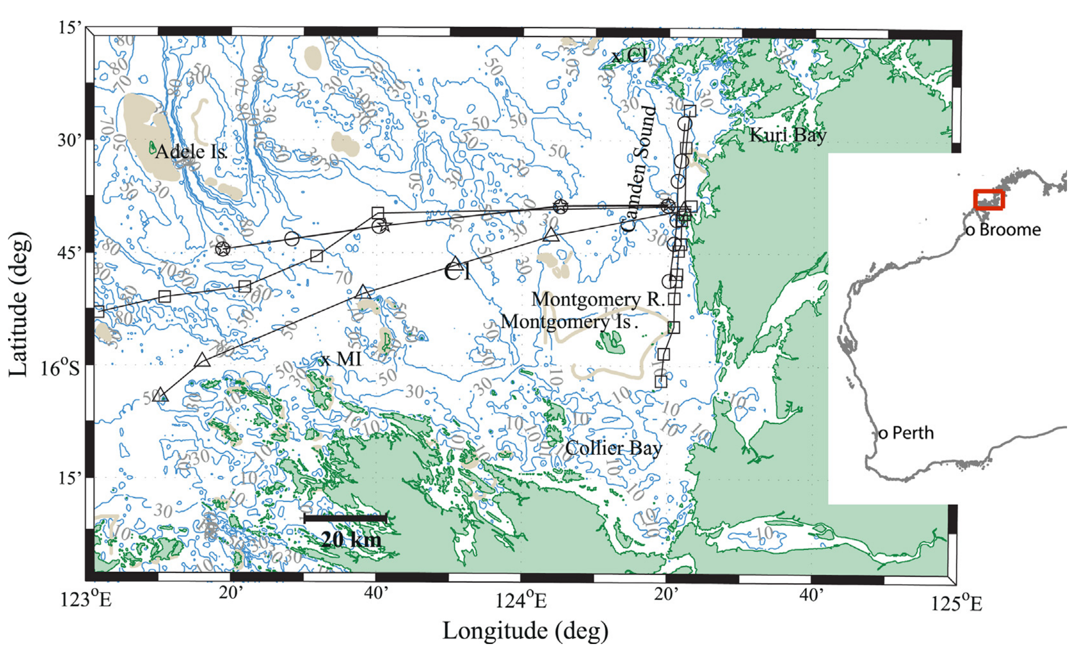

Fig. 1. Locations of temperature-pressure loggers at CI and MI and the locations of the CTD sampling stations shown in Figs. 4–6 (June: circles, July: crosses, August: squares and September: triangles). Note that due to repeated sampling over the surveys some station markers overlap. The beige regions identify the locations of the reefs. The inset map shows the location of study region (red box) in the context of Western Australia and the location of the Broome meteorological station. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)