OCEANOGRAPHIC PROCESSES OF CORAL REEFS

Physical and Biological Links in the Great Barrier Reef

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INTRODUCTION

The Great Barrier Reef (GBR) (Figure 1) is characterised by a juxtaposition of regions of low reef density (where the reefs block only 10% of the length along the shelf) and high reef density (where the reefs block about 90% of the length; Pickard et al., 1977). Each of these regions is a few hundred kilometres in length. A large spring-neap tide cycle exists on the GBR. Wolanski (1994) coined the term "sticky water" to explain why regions of high reef density may be less permeable to low-frequency currents at spring tides than at neap tides due to purely physical reasons. Wolanski and Spagnol (2000) further investigated this effect numerically. They used the two-dimensional model of King and Wolanski (1996) for a model barrier reef. In this idealised bathymetry the reefs were assumed to be rectangular. Also, the prevailing tidal and mean currents were parallel to each other. The prevailing currents were oriented perpendicular to the longest sides of the rectangles. To illustrate the blocking effect, passive tracers were seeded upstream of the matrix of reefs. Only half as much tracers filter through an ideal model reef matrix at spring tides than at neap tides; the rest was deflected sideways. This deflection was due to energy dissipation by bottom friction and island wakes. Further investigation into this effect for a realistic bathymetry and realistic currents could not be carried out due to lack of high resolution bathymetry data for the study region.

In this study, the work of Wolanski and Spagnol (2000) is extended to investigate the currents flowing through and around a high reef density area in the central GBR. In this area the spring and neap tide variability is pronounced, with the prevailing tidal currents oriented perpendicular to the mean current (the East Australian Current).

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METHODS

The field data were described by Wolanski and Spagnol (2000). In summary, the field study was carried out along a cross-shelf transect on the outer shelf of the central GBR (see Figure 1). The transect passes between Bowden Reef and Darnley Reef. North of Bowden Reef, the reef density is low, i.e., the reefs block about 10% of the distance along the shelf. South of Bowden Reef the reef density is high, i.e., the reefs block about 90% of the length along the shelf. Offshore, in the adjoining Coral Sea, the net flow is southward with the East Australian current (Wolanski, 1994). In this area the tidal currents at the shelf break are mainly oriented cross-shelf.

Vector-averaging Aanderaa and InterOcean S4 current meters were deployed along a cross-shelf transect at sites A to D (Figure 1) from January to March 1994. Table 1 summarises the water depth and immersion depths of the meters. All current meters and the tide gage recorded 30-min averaged currents. The water depth on the shelf varies between 40 and 100 m. In this region only the crest of the reefs come out of water at low spring tides.

CTD data were obtained at each mooring site at moorings' deployment and recovery.

Tidally predicted currents were calculated from field data using tidal harmonic analysis. The tidally predicted currents include the mean current over the whole period of observations. The residual currents were calculated as the difference between the observed and tidally predicted currents. The wind-driven currents were calculated as the linear fit between wind and residual currents.

The results from the field and the model were visualised using OpenDX, formerly known as Data Explorer (Galloway et al., 1995).

The depth-averaged two-dimensional model of King and Wolanski (1996) was used to calculate the currents in this region including the tidal currents. The model domain is shown in Figure 2; it was 169 km long and 119 km wide. The grid size was 500 m, the resolution at which bathymetric data were available. The forcing includes the tides, the wind, and the East Australian Current, the latter being forced by prescribing mean long-shelf and cross-shelf mean water slopes. These slopes were calculated from a large-scale model of the circulation in the GBR (R. Brinkman, unpublished data). The trajectories of water-borne tracers were predicted from these

TABLE 1
Current Meter Mooring Sites, January–March 1994

Site	Water Depth (m)	Elevation (m) of Current Meters
A	37	10 and 18
B	55	10 and 30
C	65	20
D	114	38
E	7	5

data using the Lagrangian advection-diffusion model described by Oliver et al. (1992) for which the eddy-diffusion coefficient was set to 3 $m^2 s^{-1}$.

RESULTS

The CTD data show vertically well-mixed conditions in salinity and temperature.

Two days of current data are shown in Animations 1 and 2 for, respectively, neap and spring tides. As noted also by Wolanski and Spagnol (2000), there was a net southward current of about 0.15 to 0.2 m s^{-1} at both inshore and offshore ends of the region of high reef density (sites A and D). During that time calm weather prevailed and the wind-driven currents were negligible. These two animations illustrate what happens when in calm weather a net current meets a region of high reef density. At neap tides (Animation 1) the currents at site B pointed for several hours toward the passage between Old and Darnley Reef. Hence, the current was able to filter through the reef matrix. However, at spring tides (Animation 2) the currents were deflected offshore or inshore and largely flowed around, instead of through, the reef matrix.

The model was run for two tidal regimes, a neap tide of 2 m and a spring tide of 4 m (Animations 3 and 4, respectively). Clearly the model reproduced well the spring-neap tide variability.

What is striking in these animations is the evidence of topographic steering of both the tidal and mean currents. At neap tides, tidal and mean currents are of similar magnitude and the currents are able to filter through the reef passages. However, at spring tides, the tidal currents are stronger than the mean currents and a boundary layer effect develops. By this process the water entering the reef passage originates from a tidal boundary layer along the upstream side of the reef. This layer is about 2 km wide. Outside of this layer the water is deflected around the reef. The reef matrix thus becomes impermeable to the bulk of the water upstream; this water moving toward the reef assemblage with the East Australian Current is deflected sideways at spring tides.

This blocking effect is made obvious by the evolution of a plume of passive tracers released upstream from the area of high reef density. As shown in Animation 5 the plume spreads and diffuses through the reef at neap tides. However, it is deflected sideways around the reef matrix at spring tides (Animation 6). Thus the connectivity of reefs for water-borne larvae (crown-of-thorns starfish, coral, and fish) is quite different at spring tide and at neap tides.

CONCLUSION

The variability of reef density and marked spring neap tidal cycle serves to introduce spatial and temporal variability in the water circulation through the GBR that previous studies have neglected. This has profound implications for understanding the connectivity between reefs and the degree of self-seeding of reefs. Studies of reef recruitment of larvae have focused on individual reefs (see a literature review in Carleton et al., Chapter 13, this book) and assumed either that larvae are available from upstream or that the currents around a reef can be studied independently from other reefs. Previous reef connectivity studies (see a review in Wolanski & Spagnol, 2000) have not considered the blocking effect detailed in this chapter. All these respective assumptions thus may be invalid in an area of high reef density at spring tides; therefore the conclusions from these studies may also be invalid for high reef density areas.

It is suggested that studies of reef recruitment and connectivity be initiated for high reef density areas. This is important because these high reef density areas occupy about half of the GBR.

ACKNOWLEDGMENTS

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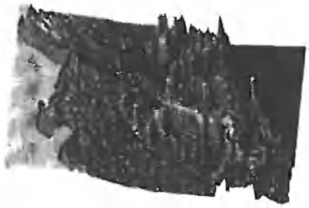


FIGURE 1 Three-dimensional view of the area around Old Reef in the central region of the GBR. This view also shows the mooring sites. The view is from the north looking south. Australia is to the right and the Coral Sea to the left. The view is vertically distorted, mean depth around the reefs is 40 to 60 m, and the width of the outer shelf where reefs are scattered is about 50 km.

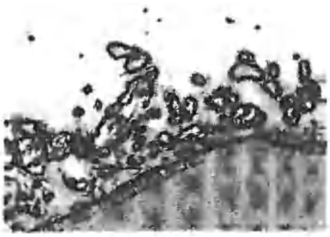
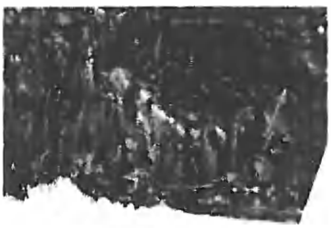


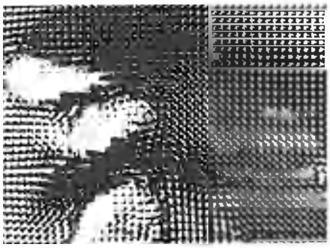
FIGURE 2 Bathymetry of the model domain of the central region of the GBR. The area shown in Figure 1 is a subset of this figure.



ANIMATION 1 Three-dimensional visualisation of the measured currents at the mooring sites during neap tides and calm weather. The red arrows indicate the tidally predicted currents and the blue arrows the wind-driven currents (the latter are negligible). Local time is indicated at the bottom. Australia is to the right and the Coral Sea to the left. The view is vertically distorted; mean depth around the reefs is 40 to 60 m, and the width of the outer shelf where reefs are scattered is about 50 km.

ANIMATION 2 Visualization of the measured currents during spring tides and calm weather. The red arrows indicate the tidally predicted currents and the blue arrows the wind-driven currents (the latter are negligible). Local time is indicated on the bottom. Australia is to the right and the Coral Sea to the left. The view is vertically distorted, mean depth around the reefs is 40 to 60 m, and the width of the outer shelf where reefs are scattered is about 50 km.

ANIMATION 3 Visualization of the predicted currents near Old Reef at neap tides in calm weather, *during one tidal cycle.*



ANIMATION 4 Visualisation of the plume of water-borne tracers released upstream of Old Reef at neap tides, no wind.

ANIMATION 5 Visualisation of the plume of water-borne tracers released upstream of Old Reef at neap tides, no wind.

ANIMATION 6 Visualisation of the plume of water-borne tracers released upstream of Old Reef at spring tides, no wind.