Circulation and Water Mass Characteristics of the Southern Great Barrier Reef

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Abstract

Data acquired during a winter (May) cruise of the RV Franklin to the southern Great Barrier Reef indicate that the dynamics of the shelf/slope region are governed by the tides, the poleward-flowing East Australian Current (EAC), and the complex topography. Over the Marion Plateau in water deeper than \(-100\) m, the EAC appears to drive a slow clockwise circulation. Tides appear to be primarily responsible for shelf/slope currents in the upper layers, with evidence of nutrient uplift from the upper slope to the outer shelf proper in the Capricorn Channel. Elsewhere, the bottom Ekman flux of the strongly poleward-flowing EAC enhances the sloping isotherms associated with the longshore geostrophic balance, pumping nutrient-rich waters from depth to the upper continental slope. Generally, shelf waters are cooler than oceanic waters as a consequence of surface heat loss by radiation. A combination of heat loss and evaporation from waters flowing in the shallows of the Great Sandy Strait appears to result in denser ‘winter mangrove waters’ exporting low-oxygen, high-nutrient waters onto the shelf both north and south of Fraser Island; these subsequently mix with shelf waters and finally flow offshore at \(-100\) m depth, just above the salinity-maximum layer, causing anomalous nutrient values in the region of Fraser Island.

1. Introduction

The southern Great Barrier Reef (SGBR) is one of the most topographically complex continental-shelf regions in Australia. Part of the complexity is due to the extensive offshore reefs, which significantly impede the flow over the outer shelf. In addition, the most southern part of the SGBR is dominated by the presence of Fraser Island (and its associated reef, called Breaksea Spit, at the tip of Sandy Cape) at \(25^\circ\)S, which extends from the coast to the shelf break. Between Fraser Island and the coast lie extensive mangrove forests through which several narrow and deep channels occur. The main channel connecting coastal waters north and south of Fraser Island is called the Great Sandy Strait. To the north, the continental shelf widens at about \(23^\circ\)S from about \(80\) km to more than \(200\) km, leaving a substantial gap in the reefs named the Capricorn Channel. A bathymetric map of the region is shown in Fig. 1, in which the Marion Plateau is seen to provide additional complexity at depths of several hundred metres between the continental shelf and the Coral Sea just south of the Capricorn Channel.

Previous studies have concentrated on the continental-shelf tidal circulation (e.g. Middleton et al. 1984) or have attempted to elucidate the dynamics of the long-period (7-14 day) coastal trapped waves that dominate the current variability on the continental shelf and slope (Middleton 1983; Middleton and Cunningham 1984; Griffin and Middleton 1986; Wilkin and Chapman 1990). An overall description of the tidal and longer-period
current variability on the continental shelf and slope south of the Capricorn Channel appears in Griffin et al. (1987). There has also been a set of cruises designed to map the flow of the East Australian Current (EAC), which flows strongly poleward in the deeper waters adjacent to the reef (Church 1987).

Despite the accumulating knowledge, there remain many unanswered questions associated with the dynamics of the region. In particular, there is a clear need for an understanding of the interaction between the EAC and the shelf waters, particularly with regard to water-mass exchange at the shelf break. Previous studies have not attempted to address this question in the SGBR, although this region was identified by Griffin et al. (1987) as being important for nutrient upwelling.

The present work describes the hydrographic structure of the SGBR on the basis of data acquired during cruises that were undertaken in May and November 1990 aboard RV Franklin. During the cruises, profiles of water properties were taken with a Neil Brown Instrument Systems CTD (Conductivity, Temperature, Depth) system, a Sippican XBT (eXpendable BathyThermograph) system, and an RD Instruments ship-mounted ADCP (Acoustic Doppler Current Profiler). A profiling fluorometer was mounted on the CTD system for the November cruise. CTD profiles were accompanied by water samples taken for calibration of temperature, conductivity and dissolved oxygen and for nutrient analyses. Fig. 1 shows locations where CTD profiles were acquired. A number of current-meter moorings were deployed (Table 1) to investigate the scattering of coastal-trapped waves by Fraser Island and the Capricorn Channel, this being the main objective of the cruises, although the major analyses of the current-meter data acquired will appear elsewhere.
The primary objective of the November cruise was to recover the moorings, and as a result of the shorter time available and some technical difficulties, only a few CTD profiles were accomplished.

This paper is organized as follows. A description of the overall circulation pattern is undertaken in Section 2, and the major differences between shelf and ocean water masses are delineated in Section 3. Section 4 describes the overall features of the Fraser Island region, followed by the Capricorn Channel region in Section 5 and the Saumarez Reef region in Section 6. Section 7 concludes the paper with a discussion.

2. Overall Circulation Pattern

Plots of surface isotherms and salinities, based on data acquired with a thermostalino-graph in May, are shown in Fig. 2. These show evidence of a poleward-flowing current at the edge of the reef proper, characterized by a small region of low-salinity (34.8 psu)
surface water apparently flowing south-east from the outer Swain Reefs. The 25.5°C surface temperature contour appears to align itself with the topographic contours between 500 and 1000 m depth, consistent with the EAC following depth contours around the Marion Plateau and finally rejoining the shelf break near Fraser Island. Waters near the coast are coldest, being some 1.5-2.5°C colder than surface waters in the EAC.

For the period May to November, average velocity vectors were calculated for each of the current meters in the mooring array. Fig. 3 shows the locations of the moorings (the squares), and the sticks represent the average velocity vectors. The EAC is seen to flow strongly poleward in the upper layers at both the northern and southern offshore moorings, with average current values of 0.4-0.5 m s⁻¹. Elsewhere, average currents are much smaller but have a northward component at the tip of Fraser Island and off Lady Musgrave Island and an easterly component in the Capricorn Channel. The overall picture is consistent with a strongly flowing EAC driving a weak clockwise circulation over the Marion Plateau.

During the May cruise, current velocities were measured at selected levels by the shipborne ADCP. Over the shelf proper and in water shallower than 100 m depth, the ADCP data tell us little of the average circulation features in this region because of the contamination by tidal currents. Velocity vectors are depicted in Fig. 4 for four levels: 25, 75, 115 and 160 m. At the deeper levels (115 and 160 m), there is again an overall clockwise circulation over the Marion Plateau, although near the 200 m contour there is evidence of additional variability that appears to be tidal in nature. East of Fraser Island, there is evidence of a very strong poleward current at all depths just offshore from the 200 m

![Fig. 3. Locations of current-meter moorings (squares) and amplitudes and directions of average currents for the period May-November 1990.](image-url)
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contour where the EAC reattaches itself to the shelf break. The general circulation pattern is therefore in overall agreement with the contention by Griffin et al. (1987) that a clockwise eddy is a feature of the Marion Plateau, although the ADCP data show substantially more complexity than would be expected from a single cold-core eddy.

Fig. 4. Current vectors at 25, 75, 115 and 160 m depth acquired by the shipborne Acoustic Doppler Current Profiler (ADCP) during the May cruise. Where bottom tracking was not possible (depths > -300 m), ship's velocity estimates derived from the Global Positioning System (GPS) were used to earth-reference the ADCP data. Gaps occur when the GPS was unavailable or when data quality was poor.
Temperature sections completed in May at Saumarez Reef (22°S), Lady Musgrave Island (24°S), Sandy Cape (24–30°S) and Double Island Point (26°S) are depicted in Fig. 5. These confirm the overall circulation pattern as described above, as do the XBT sections (not shown here) across the Marion Plateau. The EAC is clearly reflected in the deepening of all isotherms above 200 m depth toward the outer edge of each section at CTD Stations 7, 8 and 14–17 and above 300 m depth at Station 55, although not at Station 30, which is on the Marion Plateau. At depth offshore from Saumarez Reef, the equatorward-flowing countercurrent (observed first by Church 1987) is evident in the isotherms that tilt downward to the west at depths greater than about 350 m.

Other overall similarities are the well mixed surface layers at all sections, whereas the waters over the shelf proper at Double Island Point and Lady Musgrave Island are significantly cooler. A small mass (hereinafter ‘blob’) of anomalously cold water appears on the shelf proper at about 40–50 m at Station 3. These features are discussed further in later text.

Fig. 5. Temperature sections (°C) for the four major hydrographic sections occupied during May on RV Franklin Cruise 4/90: Double Island Point, Sandy Cape, Lady Musgrave Island and Saumarez Reef. The locations of these sections are depicted in Fig. 1. The contour interval is shown in the bottom left-hand corner of each section.
3. Water Mass Differences between Shelf and Ocean

Representation of the property profiles on a temperature–salinity (T–S) diagram enables easy comparison of different stations. Fig. 6 shows the T–S diagrams for all the outer sections that extend to the EAC. These diagrams have a common shape for offshore stations, even for the surface waters, a feature which is strongly suggestive of the fact that the EAC properties change little over the few degrees of latitude of interest here. Over the shelf proper at Stations 1–4 and 21–23, the temperatures are significantly lower than in the upper waters of the EAC. Currents on the inner shelf tend to flow southward under the influence of the alongshore pressure gradient that drive the EAC (Middleton and Cunningham 1984), although this feature is not evident in Hervey Bay, where Fraser Island effectively stops all southward transport over the continental shelf. The observations depicted in Fig. 6 were made in winter (May), when the net heat budget is negative at these latitudes. As a consequence, the shelf waters cool at the surface and a convective mixed layer forms.

Fig. 6. Temperature–salinity diagrams comparing overplots of all stations from each of the four major hydrographic sections.
Once the mixed layer reaches depths equal to the shelf depth, further cooling can take place more effectively over the shelf, in contrast to deeper waters where mixed-layer deepening is associated with the transport of heat upward from the (now warmer) waters below. In May, surface waters are thus cooler (and denser) over the shelf than offshore.

A temperature section along the shelf comprising CTD Stations 20, 21, 31–34 and 65–69 extends from Hervey Bay north to the inner entrance of Hydrographers Passage, a distance of some 500 km. This is shown in Fig. 7a. Temperatures are generally uniform with depth, as might be expected from active convective cooling, and the temperatures in the water column on the shelf are substantially lower than those at the same depth in the EAC (Fig. 7b). The coldest shelf waters are seen near Station 20 in Hervey Bay, these being 2°C colder than those at the inner entrance of Hydrographers Passage (Station 69) and 2.5°C colder than the adjacent offshore surface waters (Station 79). In contrast, differences

![Temperature section](image)

**Fig. 7.** (a) Temperature section (°C) for the shelf stations from Hervey Bay to Hydrographers Passage, and (b) the equivalent offshore section in the East Australian Current. The contour interval is shown in the bottom left-hand corner of each section.
in the EAC are minor in the upper 400 m, with the northern station (Station 79) being perhaps 1°C warmer at the surface than the southernmost station (Station 8). Thus, changes in shelf waters do not occur simply as a consequence of changes in the EAC waters directly offshore; rather, the modification of shelf waters occurs through changes in the net heat budget and admixture with the EAC waters near the shelf break as a consequence of the dynamical processes that occur there.

4. Fraser Island Region

At Double Island Point, the EAC joins the shelf break and the mean currents are strongly poleward. The strength of the current on the slope is reflected in the steeply sloping isotherms (e.g. the 18°C isotherm), which indicate not only a strong poleward current but also a strong bottom Ekman flux that drives colder waters from depths of more than 200 m up onto the shelf break at about 80 m depth. The temperature section at Double Island Point (Fig. 8) also shows a cold blob of 18°C water residing on the inner shelf and centred on Station 3. The corresponding salinity, oxygen, phosphate, nitrate/nitrite and silicate sections mirror the temperature section, with strongly sloping property contours near the continental slope and a blob of anomalous water on the shelf proper. The temperature and salinity properties of the blob are consistent with properties at a depth of about 200-300 m offshore, thus suggesting that the blob may have been upwelled by the strong Ekman pumping. The weak, fluctuating currents on the shelf proper make it difficult to deduce how long the blob has existed on the shelf.

A salinity maximum occurs broadly between 120 and 170 m depth at Station 8, with the actual maximum at 140 m. This depth also corresponds to relatively low nutrient values. Above, at about 100 m depth, lies a region of apparently anomalously high nutrient values. This appears (especially in the phosphate section) to be associated with an extension of the nutrient-rich blob that lies on the shelf proper, thus suggesting that the blob subsequently intrudes offshore at its own density level (to about 100 m) in the deep ocean. Thus, we might be tempted to hypothesize the following. Strong EAC currents cause upwelling of low-oxygen, nutrient-rich water from below the salinity maximum to the shelf proper through the bottom Ekman flux. A blob of this water remains for some days, slowly mixing with the adjacent warmer and less saline shelf waters but remaining relatively nutrient-rich and with low dissolved oxygen. Perhaps aided by tidal currents or wind-induced Ekman flux, the 'modified' upwelled waters flow offshore into the deeper ocean, descending to a new equilibrium level of ~100 m.

Sections drawn from data acquired near Sandy Cape near the tip of Fraser Island are somewhat different from those near Double Island Point, with evidence of a weaker poleward current and no strong upwelling. Fig. 9 depicts the structure of the water column, with the notable feature being the depressed isotherms and isohalines near the surface just near Sandy Cape itself. This suggests that there is a strong current in the upper 80 m or so, running around the tip of Sandy Cape. Reference to the tide tables shows that Station 10 was profiled 50 min before high tide at Bundaberg (Burnett Heads), and the strong current and depressed isotherms near the surface are therefore just a manifestation of the later part of the flood tide flowing around the tip of Sandy Cape. Here, the property contours intersect the bottom topography at right angles, as might be expected to occur as a consequence of the existence of boundary turbulence generated by the strong tidal currents.

Sections of oxygen and nitrate/nitrite also show peculiar structures at depths of 50-200 m at Sandy Cape, with high nutrient and low oxygen values appearing at about 100 m depth at Stations 12, 13 and 14. These anomalies do not appear to be directly associated with the temperature or salinity structure. In an effort to deduce additional information, oxygen–nitrogen plots from stations in both the Sandy Cape and the Double Island Point sections were constructed (Fig. 10). The peculiar feature of unusually low dissolved oxygen values at depths of about 100 m occurs in both sections, although not all the stations show
Fig. 8. Hydrographic sections for the Double Island Point section. Depth profiles of temperature (°C), salinity (psu), dissolved oxygen (μmol L⁻¹), inorganic phosphate (μmol L⁻¹ × 100), inorganic nitrogen (μmol L⁻¹) and silicate (μmol L⁻¹) are included. The contour interval is shown in the bottom left-hand corner of each section. H and L show local High and Low values of contours, respectively.

this anomalously low oxygen data. Comparison of CTD and Winkler titration values is nevertheless consistent, indicating the anomaly to be real. At 136 μmol L⁻¹, the dissolved oxygen content at the bottom of Station 2 on the shelf near Double Island Point is the lowest observed on this cruise, and indeed is lower than any value we have been able to find in historical data from either the Coral or the Tasman Seas for areas shallower than ~200 m!
The combination of anomalous low oxygen and high nitrogen does not appear to be fully explained by the upwelling mechanism discussed earlier, and a more plausible explanation of the low oxygen and high nutrient values may be considered by noting that they appear in both the Sandy Cape and the Double Island Point sections. At the coastal end of Fraser Island, an extensive mangrove forest separating the island from the mainland through which runs a channel known as the Great Sandy Strait. There is quite a large difference in tidal phase at the coast between Hervey Bay to the north of Fraser Island and Double Island Point to the south, with tides flooding (ebbing) to the north (south). This difference manifests itself at Sandy Cape through strong tidal currents running across Breaksea Spit. This difference in tidal phase will also act to flush the coastal mangrove forest at Great

Fig. 9. Hydrographic sections for the Sandy Cape section. Units, contour intervals and abbreviations are as for Fig. 8.
Sandy Strait on a regular basis, with the flushed waters being carried by tidal currents both into Hervey Bay and onto the continental shelf near Double Island Point as the tides flood and ebb, respectively. This flushing would be enhanced by wind set-up of sea level on weather-band timescales.

Boto and Bunt (1981) and Boto and Wellington (1988) have examined dissolved oxygen and dissolved inorganic nutrients in tidal mangrove forests separating Hinchinbrook Island from the coast at 18°30'S. They find that, on each tidal cycle, the forest exports low-oxygen and high-nutrient waters (in comparison with adjacent coastal surface waters). The same is likely to be true of the Great Sandy Strait region, and in winter when the shallow waters of the mangrove forest are liable to be cooled more effectively and made more saline by evaporation than are shelf waters, the tidally exported mangrove waters would be sufficiently dense to sink to the bottom of the continental shelf.

Mangrove sediments are largely anaerobic and anoxic, and nutrients contained therein, being trapped in the sediments as partly decomposed organic matter, cannot be directly dissolved in the overlying waters. Through a combination of tidal and wind-driven currents, sediments would be exported from the Great Sandy Strait in suspension in oxygenated waters. This would allow the organic matter to decompose further, releasing nutrients and reducing the dissolved oxygen concentrations through the high biological oxygen demand. The exported 'winter mangrove waters' would thus have (relative to shelf waters) lower temperatures, lower dissolved oxygen concentrations, and higher dissolved nutrients.

Thus, a second hypothesis is that the high-nutrient, low-oxygen waters that constitute the anomalous water masses observed at both the Sandy Cape and Double Island Point sections consist partly of cooler, saltier 'winter mangrove waters' exported both north and south of the Great Sandy Strait on each flood and ebb tide. The exported waters would subsequently sink off the continental shelf to their own density level, progressively mixing with ambient waters.

Unfortunately, there are no data for the study period from the coastal channel to test this hypothesis, and a literature search has not yielded any additional information on the mangrove forests of the Great Sandy Strait.

5. Capricorn Channel Region

The region of Broad Sound is well known to have the largest tides on the eastern Australian coast (Flinders 1814; Middleton et al. 1984), and the flood tide consists of a
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tidal current flowing north-westward in the Capricorn Channel as described by Griffin et al. (1987). Tidal upwelling was shown by Thompson and Golding (1981) to be a significant feature of shelf/ocean interaction in Cook’s Passage on the northern Great Barrier Reef at 15°S. To investigate the effects of tides on upwelling in the region of interest here, short CTD sections were made in the Capricorn Channel at both high and low tide.

Figs 11a and 11b show sections taken in the mouth of the Capricorn Channel at times corresponding to high and low tide at the neighbouring port of Gladstone. Griffin et al. (1987, fig. 4) indicate that the phase of the tide at Gladstone is within about 3° of that at the region of the CTD stations in the Capricorn Channel. Of major interest in Fig. 11 are the differences between the high- and low-tide sections, these being exemplified by the depth of the 18°C isotherm in the temperature sections. At high tide, this isotherm is drawn into the channel and up the slope to a depth of about 140 m, whereas at low tide it appears to be depressed near the slope proper to a depth of about 190 m. A close inspection of the sections does not reveal any zone of bottom mixing that would be typified by well mixed layers near the bottom, but it should be noted that the channel slopes very gradually in this region and has a very smooth bottom.

We have compared our observations with predictions of a model by Thompson and Golding (1981), who argue that upwelling will occur whenever the tidal inflow velocity of a surface well mixed layer exceeds the internal wave velocity of waves in the stratified fluid below. The Thompson and Golding model has a homogeneous surface layer of constant depth overlying the stratified water. Calculation of the internal wave speed proceeds via a numerical solution of the dispersion relation that is obtained by matching vertical velocities at the interface. Tidal flow speed outside the channel is calculated through the use of a simple mass-flux conservation argument. The width of the channel is assumed to be constant, and so tidal flow speed outside the channel is inversely proportional to the depth. Parameters used in this application of the model include a surface-layer depth of 50 m and a Brunt-Vaisala frequency of 0.016 s⁻¹ for the lower layer. These values were calculated from CTD profiles taken in the channel. The bottom depth is modelled as piece-wise linear.

For the Capricorn Channel, the model predicts that upwelling should raise slope waters from depths of 146, 168 and 188 m into the channel proper at a depth of 135 m for tidal inflow speeds of 1.5, 2.0 and 2.5 kn, respectively (Fig. 12). The sections from the Capricorn Channel (Figs 11a and 11b) are consistent with the model predictions. For example, the 35.5 isohaline of the flood-tide salinity section is upwelled from a depth of 170 m in 250 m of water over the slope to a depth of 130 m in the channel. Similar features can be seen in the nitrate/nitrite and phosphate nutrient sections. The 9.0 μmol L⁻¹ nitrogen contour finds its way from a depth of 180 m on the slope to 150 m at the channel mouth during the flood tide. Similarly, the 0.72 μmol L⁻¹ phosphate contour extends from 170 m over the slope in 250 m of water up to a depth of 140 m at the mouth of the channel.

Thus, the hydrographic sections provide convincing evidence for the presence of upwelling of slope waters into the Capricorn Channel on the flooding tide. Furthermore, there is a quantitative consistency between the model predictions and observations.

6. Saumarez Reef Region

Hydrographic sections taken from Archer Shoals (Station 46) to beyond Saumarez Reef are shown in Fig. 13. Temperature contours show isotherms generally rising to the west, consistent with the poleward-flowing EAC, in the upper 200–300 m. The equatorward-flowing countercurrent (Church 1987) appears as isotherms that slope downward to the west at depths exceeding 350 m in the waters east of Saumarez Reef. The salinity structure clearly shows the salinity-maximum layer intruding from the deeper Coral Sea toward the shelf, but this layer almost disappears near the slope proper (toward the left of the section), presumably because of the enhanced mixing occurring in the vicinity of the upper slope and shelf break, where strong tidal and EAC currents overflow submerged coral reefs and
Fig. 11. (a) High-tide and (b) low-tide sections from the Capricorn Channel, showing the relative raising and lowering of isotherms in the range 17–19°C during the flood and ebb tide, and the corresponding nutrient sections. Units, contour intervals and abbreviations are as for Fig. 8 except that phosphate is displayed as μmol L⁻¹×1000 in (a).

significant turbulent mixing occurs. The dissolved oxygen and nutrients also show contours sloping upward toward the west, consistent with the flow features inferred from the temperature structure and observed from the averaged current-meter data. Strong poleward-flowing currents are characterized by temperature and nutrient contours that tilt upward to the west as a consequence of the geostrophic balance. Toward the (sloping) seabed, the Ekman pumping in the bottom Ekman layer enhances this effect, presumably also enhancing the longshore vertical current shear through the thermal-wind balance. Thus, the effects of
the Ekman pumping are to be seen in the offshore current structure, through an enhanced longshore current shear in the vertical (intensifying the surface currents) as well as an onshore nutrient pump. Unlike the anomalous sections from Double Island Point and Sandy Cape, the nutrient data from the Saumarez Reef region show a monotonic increase with depth, as is observed elsewhere in the deep Coral Sea.

7. Discussion

There appear to be three main mechanisms for potentially increasing the flux of nutrients from depth up the slope toward the shelf proper in the SGBR: tidal inflow, bottom Ekman layer upwelling due to the strongly flowing EAC, and quasi-periodic upwelling due to
Fig. 12. Relationship between the tidal inflow speed (solid lines) and the interval wave speed (dashed line) for tidal upwelling in the Capricorn Channel. When the tidal inflow speed exceeds the internal wave speed, nutrients can be drawn up into the shallowest depths. The depth and distance along-channel from which nutrients may be drawn is indicated on the upper and lower abscissae.

coastal trapped waves. The third of these will be dealt with elsewhere in conjunction with the analyses of current-meter data.

The EAC flows strongly poleward in the surface layers between Saumarez Reef and the Great Barrier Reef at about 22°S. On the shelf, there is evidence of both upwelling of deeper waters and mixing of these waters with true shelf waters. The upwelling mechanisms here appear to be due to a combination of both tidal and EAC effects, wherein the tidal flood and ebb periodically exchange outer slope and shelf waters as the EAC flows poleward. The effects are thus three-dimensional in that much of the mixing implied by the water properties has probably occurred upstream (equatorward) of the observation point. The EAC appears to flow along the 500–1000 m depth contours around the shallower Marion Plateau, rejoining the continental slope at Fraser Island.

At the southern tip of Fraser Island, the EAC is again observed to be flowing very strongly poleward along contours, with the strong currents immediately adjacent to the steep continental slope producing significant bottom Ekman layer upwelling onto the upper slope and (perhaps) to the shelf proper. The EAC does not appear to directly affect the inner shelf of the Marion Plateau, except perhaps to generate the slowly flowing clockwise eddy observed in the present, and earlier, studies over the plateau.

Tidal upwelling appears to be active on the inner Marion Plateau, where the tide flooding toward Broad Sound produces significant upwelling on the upper slope. ADCP data confirm this as a principle mechanisms for upwelling here, where other (mean) currents are small.

Anomalous low-oxygen and high-nutrient waters observed on the shelf and over the slope to the immediate north and south of Fraser Island are thought to be a consequence of the export of denser waters from the mangrove forests of the Great Sandy Strait through a combination of wind-induced and tidal flushing. Since mangroves draw their nutrients from land-based sources, this nutrient export can be perpetual.

One key feature of the argument supporting this concept of an export of denser waters is the mismatch of relative values of oxygen, nutrients and physical properties of the blob, compared with those of the deeper continental-slope waters. No uniform mixture of the deeper waters with shelf water will provide typical blob values, suggesting that the blob on the shelf (and the tongue leading offshore) cannot be due to upwelling alone. A second feature is the location in the water column of the anomalous low oxygen and high nutrient values, since this occurs above the salinity maximum in this area. Some confusion may arise, however, when the low-oxygen waters of Stations 50–52 on the Saumarez Reef section are considered. Here, the low-oxygen layer straddles the salinity-maximum layer and the low-oxygen, high-nutrient properties are not as extreme as they are near Fraser Island. This would appear to be due to upwelling processes. A potential criticism of these conclusions
is that they are not fully definitive, being drawn from circumstantial evidence. Despite this, the unusual nature of the data suggests that the observations are important in their own right.

Overall, there appears to be significant interaction between the shelf and the slope water masses over the entire SGBR through one mechanism or another. These mechanisms act to move nutrients from deeper waters onto the shelf proper and presumably are an important source of nutrients for ecosystems of the Great Barrier Reef.
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