2. THE STUDY AREA

The approach taken in this study is to quantify or estimate nutrient pools within and fluxes into or out of two arbitrarily defined boxes encompassing a contiguous section of the central GBR shelf: a northern box (hereafter the **Cairns box**; 16° 5' - 16° 52.5'S) between Cape Tribulation and Cape Grafton, and a southern box (hereafter the **Tully box**; 16° 52.5' - 17° 55'S) between Cape Grafton and Dunk Island (Figure 1). The Cairns box covers a north-south distance of approximately 88 km while the Tully box is 116 km in north-south length. Each box is taken to extend from the coastline to the shelfbreak (100 m isobath). For specific calculations, estimations of nutrient stocks and fluxes will also be made for thin (ca. 1 m wide) sections normal to the coast or smaller areas (e.g. per m^2) appropriate to the scale of sampling and measurement. Wherever possible, calculations will be extrapolated to the full areas of the two boxes. Time periods of interest for rates are either per day or per year.

There are several reasons for dealing with nutrient processes within sections of the shelf (boxes). First, terrestrial inputs are derived from both point and diffuse sources along an extended length of the coast. These inputs can be most reasonably averaged over a larger area. Nutrient processes associated with reefs are also most conveniently area-averaged over larger areas, rather than a m^{-2} or a narrow latitudinal basis. While adjacent to each other, the two boxes front coastlines with different levels of riverine freshwater input, agricultural land use and development. There is a well agriculturalized coastal plain adjoining the Tully box, while the coastal plain adjacent to much of the Cairns box is relatively narrow or absent. The Cairns box is the site of extensive urban, suburban and semi-rural development. The Cairns coastal region now supports a permanent population on the order of 98,000 people and continues to grow. In contrast, agricultural development still overwhelmingly predominates in the watersheds adjacent to and feeding into the Tully box.

Computed area and volume statistics for the two boxes are given in Table 1. Areas between defined isobaths were estimated from navigational charts by trapezoidal integration of polygons within narrow latitude bands (5'). Shelf water volumes were estimated by ruling a series of parallel lines normal to the shelfbreak between Cape Tribulation and Farquharson Reef, NE of Dunk Island. The distances of defined isobaths (5, 10, 20, 30, 40, 50, 60 m) from the coast along each cross-shelf line were then measured. Areas of the individual cross shelf sections were determined by trapezoidal integration. Volumes between adjacent sections were calculated from the mean areas of the two adjacent sections and the mean horizontal distance between the sections. An estimation of the volume displaced by reefs was made by subtracting the area of reefs as given in the Great Barrier Reef Marine Park Authority (GBRMPA) Reef Gazetteer within each box, multiplied by the approximate mean depth of the outer shelf (ca. 40 m).

The width of the continental shelf varies considerably within the two sections. The shelf is narrowest (42 km) off Cape Tribulation, increasing to 57 km in width off Cairns and then to 81 km seaward of Dunk Island at the southern end of the Tully box. South of Dunk Island the shelf widens quickly. The increasing width of the shelf south of Dunk Island and poor depth charting on the wide outer shelf made volume and area estimates for the Dunk Island-Farquharson Reef line difficult to quantify or connect with terrestrial processes. To avoid the added complexity of shelf bathymetry near Hinchinbrook Island, the southern boundary of the Tully box was defined at Farquharson Reef to give the Tully box a tractable size and shape.

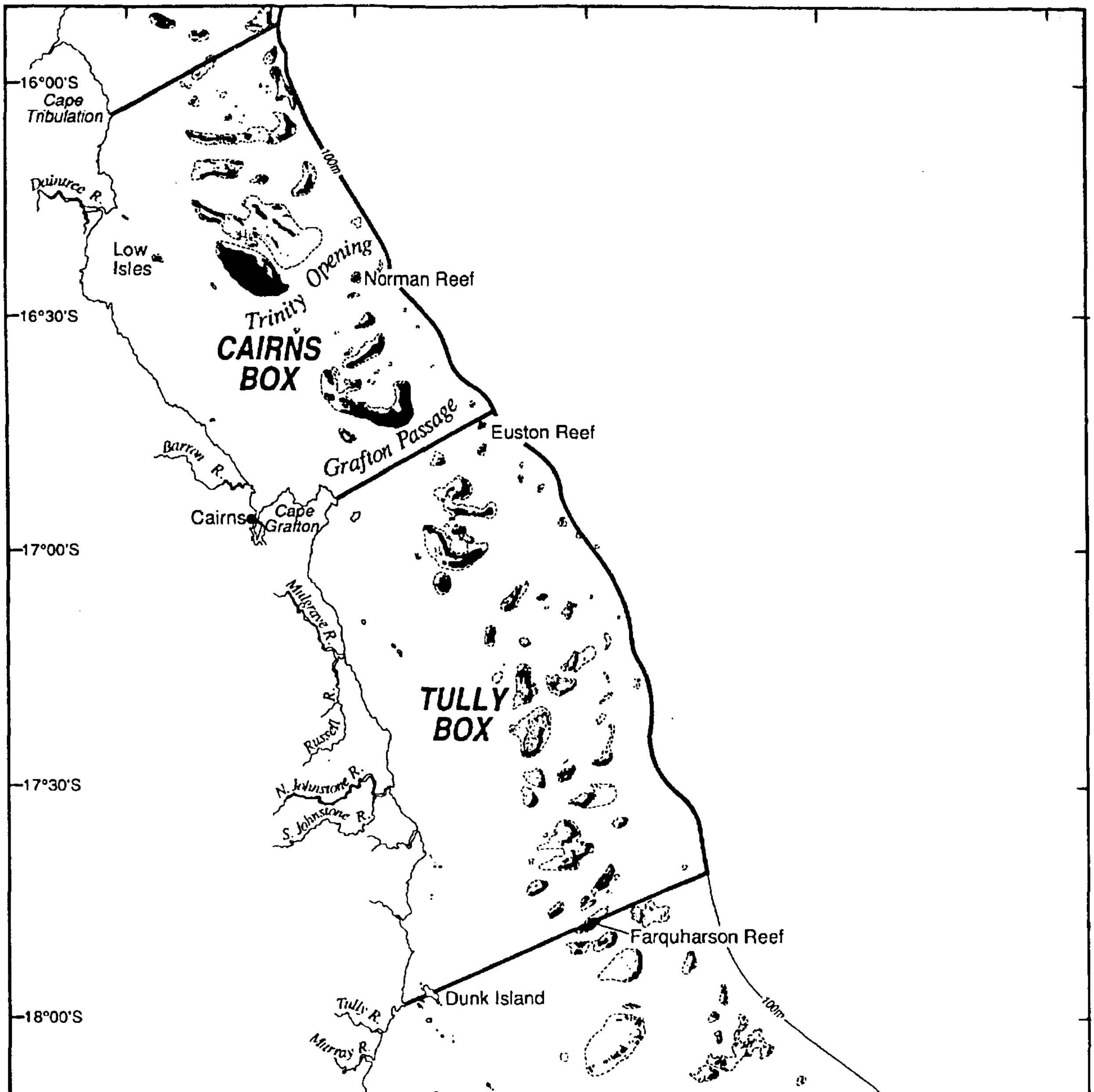

Figure 1. The central Great Barrier Reef and the shelf boxes covered for budgeting purposes. Near-bottom temperature recorders were deployed near Euston Reef and Norman Reef to collect long-term records of shelfbreak water temperatures.

Table 1. Shelf areas and volumes of water between isobaths on the central GBR shelf. Volumes estimates include a correction for the displaced volumes of reefs. Volumes in italics are percentages of the total areas or volumes given for the sections.

	0-10 m	10-20 m	20-30 m	30-100 m	Total
Area (km^2)					
Cape Tribulation to Cape Grafton	377	636	856	4068	5937
	6.4	*10.7*	*14.4*	*68.5*	
Cape Grafton to Farquharson Reef	310	535	1306	5675	7826
	4.0	*6.8*	*16.7*	*72.5*	
Volume (km^3)					
Cape Tribulation to Cape Grafton	1.9	10.9	20	164	197
	1.0	*5.5*	*10.3*	*83.2*	
Cape Grafton to Farquharson Reef	1.5	8.5	31	271	312
	0.5	*2.7*	*10.0*	*86.8*	

Most of the coral reefs in both boxes are free-standing platform reefs on the outer half of the continental shelf in water depths exceeding 30 m. A small number of coastal fringing reefs occur in both boxes. The areas of the outer-shelf platform reefs in the Cairns and Tully boxes are estimated to be 724 and 731 km^2, respectively (GBRMPA Reef Gazetteer; Table 2). No explicit estimate was made of the area of coastal fringing reefs in either box, though on a shelf-scale, their contribution to total reef areas is relatively small. Analysis of LANDSAT MSS imagery of a subsample of reefs situated throughout the entire GBR (209 reefs - imagery processing provided by AUSLIG) indicates that reef area < 2 m in depth makes up approximately 18 percent of the total classified area of the sample reefs (Figure 2 Top). Areas classified as hard substrate in the imagery, presumably corals, coral rubble and calcareous algae, comprised 12 percent of total classified reef area (Figure 2 Middle), though the percentage of total area is quite variable for reefs of similar size (Figure 3 Top). The area covered by sand at depths < 5 m averaged 33 percent of total classified reef area (Figure 2 Bottom), again with highly variable percentages for individual reefs (Figure 3 Bottom). Classification of sand cover at depths > 5 m was uncertain, but it is highly likely that the total sand area and percentage of total area are higher. These classifications have not as yet been rigorously ground-truthed using a subsample of the classified reefs. Visual comparisons with aerial photographs and maps indicate the broad categories of depth and shallow cover classification are reasonable as a first approximation.

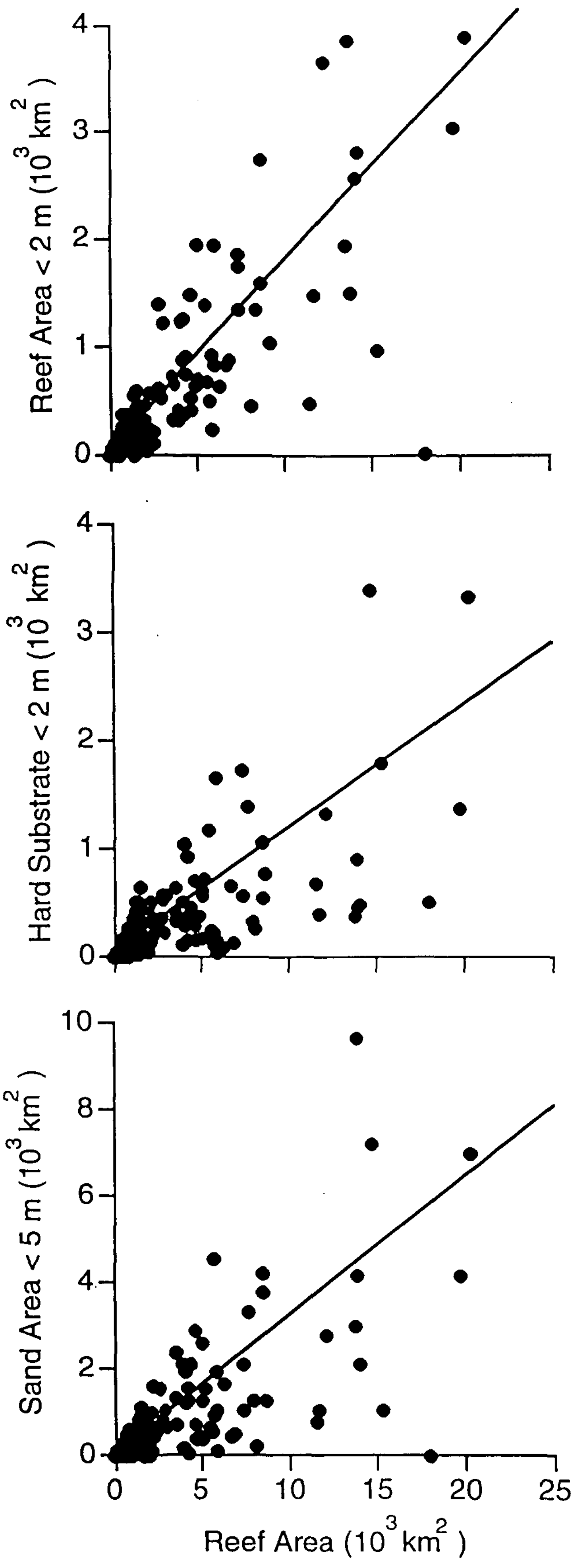

Figure 2. Top: Reef area < 2 m deep estimated from satellite imagery in relation to total reef area for 209 reefs throughout the GBR. Middle: Area of reefs classified as hard substrate < 2 m deep in relation to total classified reef area. Bottom: Area of reefs classified as sand < 5 m deep in relation to total classified reef area. The lines shown are the GM functional regressions (Ricker, 1973).

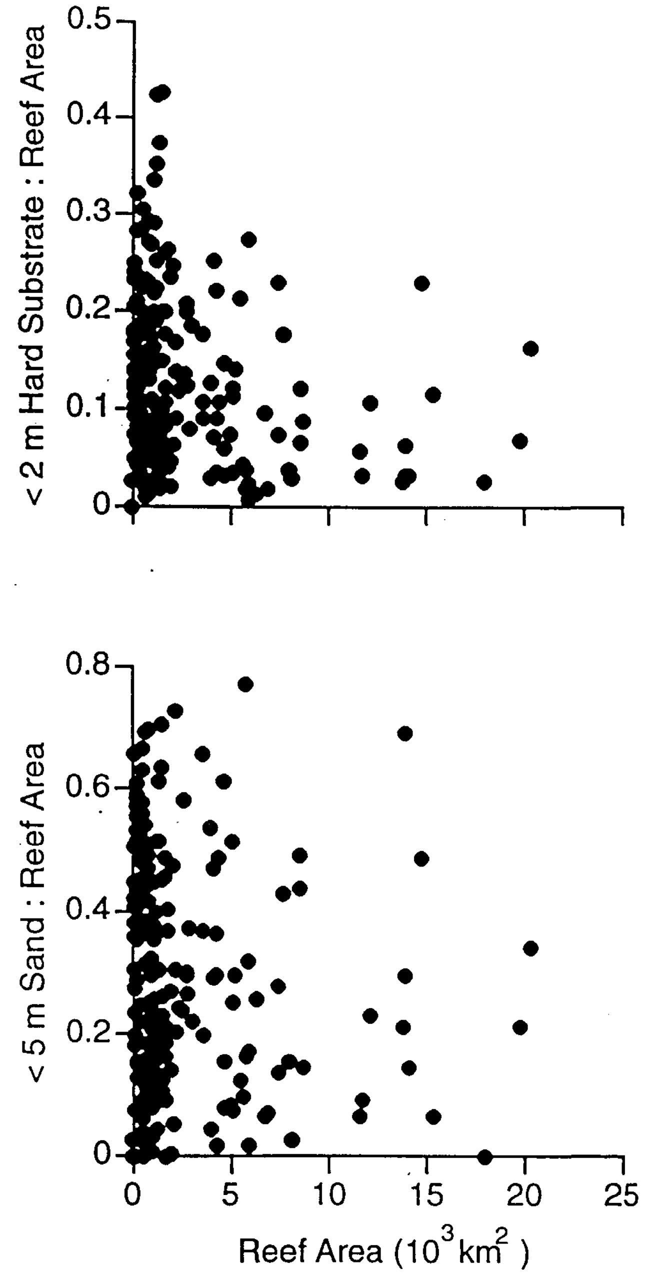

Figure 3. Top: The proportion of reef area classified as hard substrate < 2 m deep in relation to total classified reef area. Bottom: The proportion of reef area classified as sand < 5 m deep in relation to total classified reef area.

Table 2. Areas of reefs in the study area (km^2) and the estimated area of reef flat. Area values are summed from the GBRMPA Reef Gazetteer. Reef flat and shallow (< 5 m) sand areas are taken as 18 and 33 percent of total reef area based upon analysis of LANDSAT MSS imagery.

	Total Area	Reef Flat	Shallow Sand
Cape Tribulation to Cape Grafton	724	130	239
Cape Grafton to Farquharson Reef	731	132	241

Approximately 70 percent of shelf area within the two boxes and > 80 percent of estimated water volume (reef corrected) occurs seaward of the 30 m isobath. The obvious implication is that sampling to estimate total shelf stocks of nutrients and the impact of area-specific processes needs to be weighted toward this depth band to resolve both spatial variability and define any subtle spatial gradients present. In contrast, the 10 m isobath encompasses only 4-6 percent of total shelf area, depending on the box considered and no more than 1 percent of total shelf water volume within a particular box. Even though small in area and volume, the shallow coastal depth band directly receives the inputs of nutrient materials from river runoff and urban sewage, and because of its shallow depth, is prone to a greater degree of sediment resuspension from wave action. The residence time of water within the < 10 m depth band is therefore a key consideration in future nutrient budgeting activities.

Figure 4 identifies the location of all hydrographic stations occupied in support of nutrient budgeting for the Cairns and Tully boxes. At several sites, stations were occupied on more than one occasion. In particular, a transect of eleven stations lying along the coast between Cape Tribulation and Cairns, then extending seaward to Green Island, was occupied 11 times during the study period (Figure 5). Over the course of this study (1988-1992), 300+ hydrographic stations were occupied within the Cairns box. For consistency, all hydrographic stations within the Cairns box are designated with the prefix CNS. The situation for the Tully box is somewhat different. Fewer hydrographic stations were occupied within the defined area of the box; however, a considerable number (108) were occupied immediately to the south of the box. Oceanographic conditions on the shelf to the south of the box, particularly along its southern boundary are analogous to those inside the box. The results should therefore be readily transferable to conditions within the Tully box, avoiding complications associated with the wider continental shelf south of Dunk Island and complicated circulation and mangroves around Hinchinbrook Island.

Eighty (80) hydrographic stations were occupied at five sites on a cross-shelf line parallel to, but just south of, the southern boundary of the Tully box (prefix FAM) during 1988 and 1989. The FAM stations are complemented by an earlier series of stations occupied in the same region during 1987-88 (prefixed - COT, n = 28 stations). Wherever appropriate, the FAM and COT stations are considered collectively.

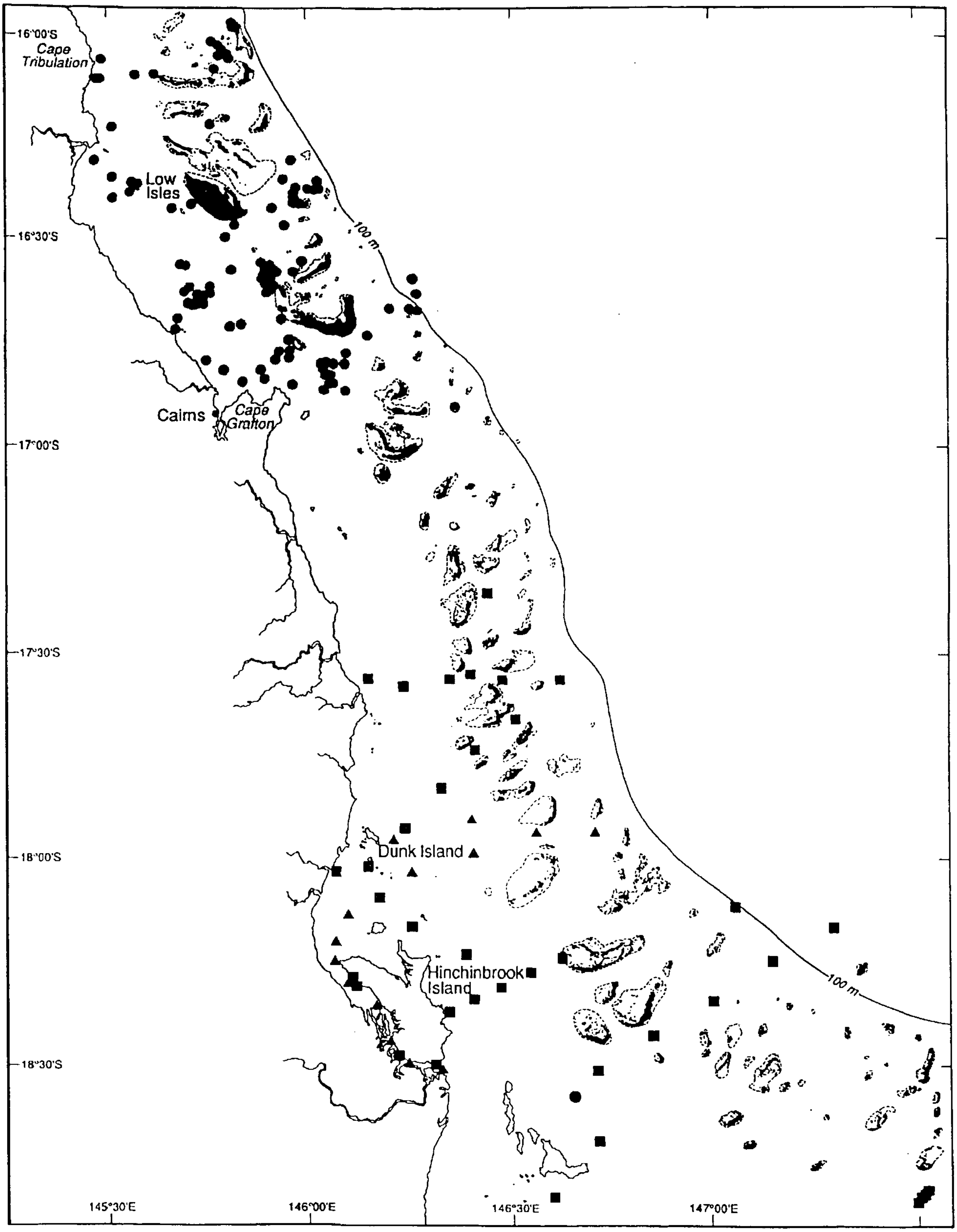

Figure 4. Locations of hydrographic stations used to develop the nutrient budget (● - CNS, ▲ - FAM, ■ - COT).

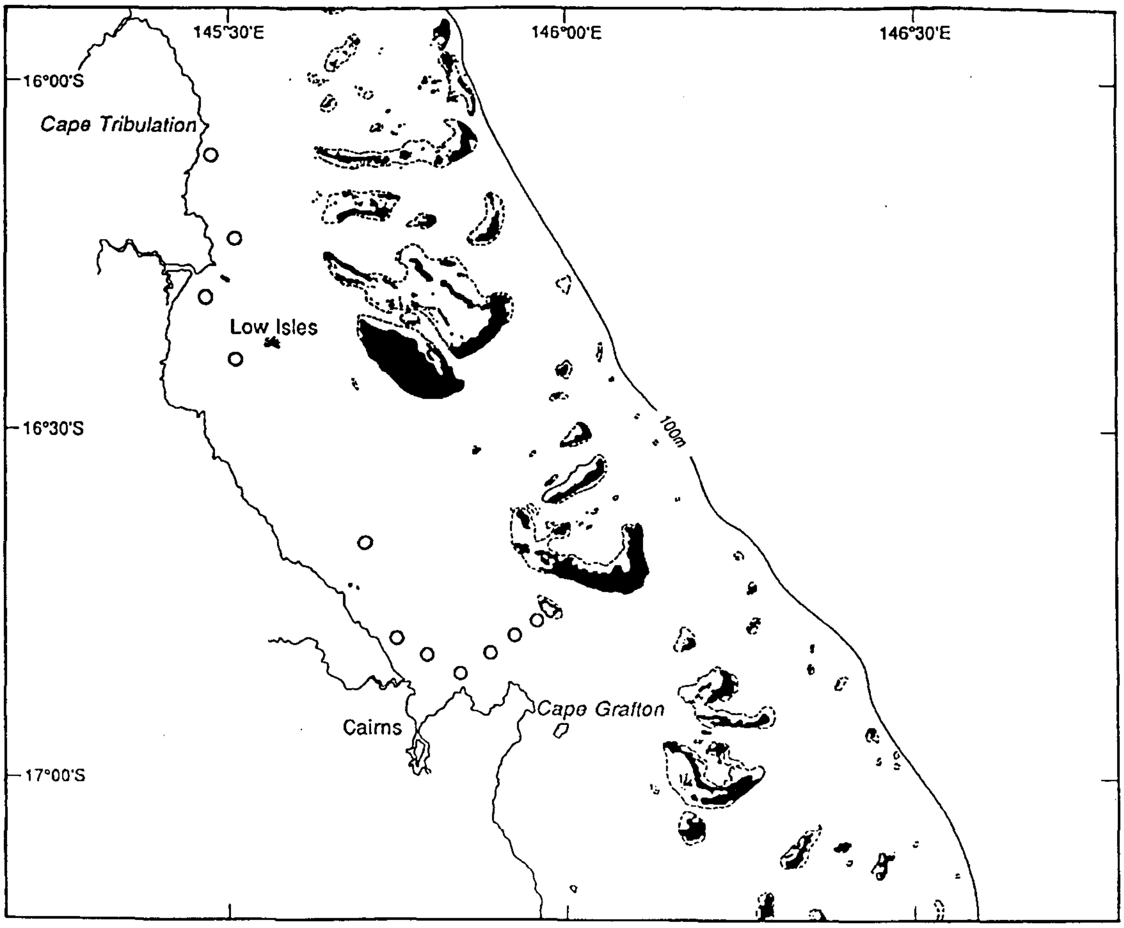

Figure 5. Locations of transect stations in the Cairns box (O) resampled ten times between February 1989 and July 1991.

Four gauged rivers (South Johnstone, North Johnstone, Russell, Mulgrave) discharge directly into the Tully box (Figure 6). Three other regionally significant rivers (Herbert, Murray, Tully) discharge onto the shelf immediately south of the southern boundary of the box. Because of geostrophic forces associated with the buoyancy in the freshwater plumes from these rivers, their waters tend to run northward along the coast and into the Tully box as well. The combined mean discharge of these seven rivers is 11.4 km^3 of water per year. In contrast, only two significant gauged rivers (Barron, Daintree) with an average combined discharge of 4.4 km^3 per year discharge directly into the Cairns box. Discharge statistics for the rivers in question are summarized in Table 3. The length of gauged periods for individual rivers varies. On a year-to-year basis, total discharge from individual rivers or groups of rivers can vary significantly, particularly in response to variability in heavy rainfall during and after cyclones or incursions of monsoonal low pressure systems (Lough, 1993). During periods of heavy flooding, identifiable plumes of low salinity water from the Burdekin River have also been tracked northward into the Tully box (Wolanski and van Senden, 1983).

Table 3. Mean annual discharges (x $10^6 m^3$) and ranges for rivers flowing into the Cairns and Tully boxes. Streamflows are obtained from Queensland Water Resources Commission.

River	Watershed km^2	No. Years	Mean	Maximum	Minimum
Cairns box					
Daintree	2125		3560		
Barron	2175	70	839	2611	203
Tully box					
Mulgrave	555	15	766	1537	324
Russell	1475	39	1036	2121	455
No. Johnstone	1940	22	1880	3852	1059
So. Johnstone	555	72	811	1574	200
Tully	1685	14	3119	4973	1632
Murray	1140	17	170	420	52
Herbert	10131	72	3582	11559	468

Sedimentation fluxes of particulate materials and particulate phase nutrients were measured with moored sediment traps over an annual cycle at four sites on a cross-shelf transect parallel to the southern end of the Tully box between September, 1988 and August, 1989 (Figure 7 Bottom). Particulate nutrient sedimentation fluxes in the Cairns box were measured between May, 1990 and July, 1991 with both moored and free-drifting sediment traps. Because of the actions of currents, the drifting sediment traps moved within general areas (Figure 7 Top).

Water column primary production rates used to indirectly estimate phytoplankton nitrogen and phosphorus demand were measured at three sites in Palm Passage during 1983-85 (n= 41 expts.) and at seven (7) sites within the Cairns box during November-December, 1990 (Figure 8).

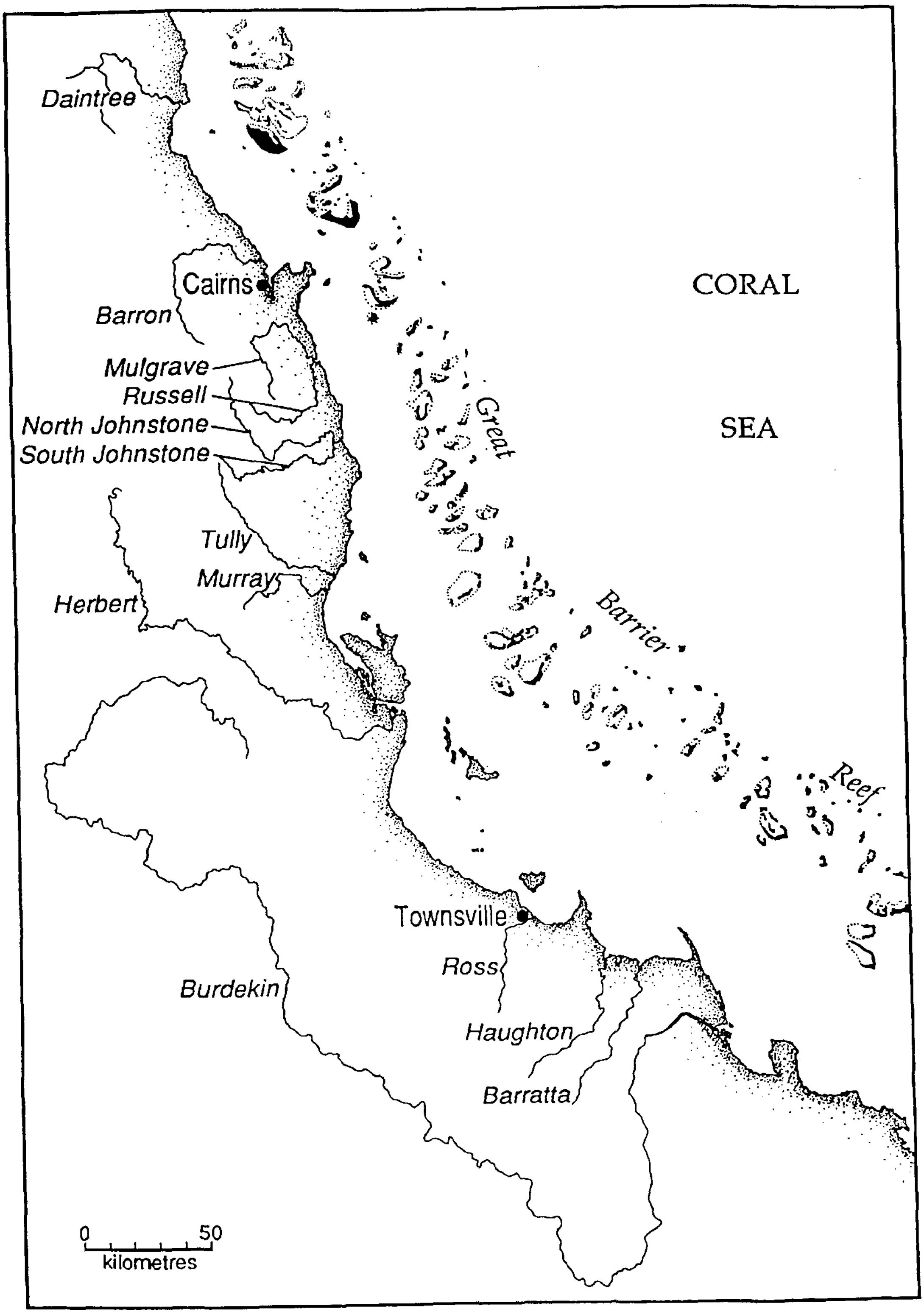

Figure 6. Major rivers discharging into or adjacent to the Cairns and Tully boxes.

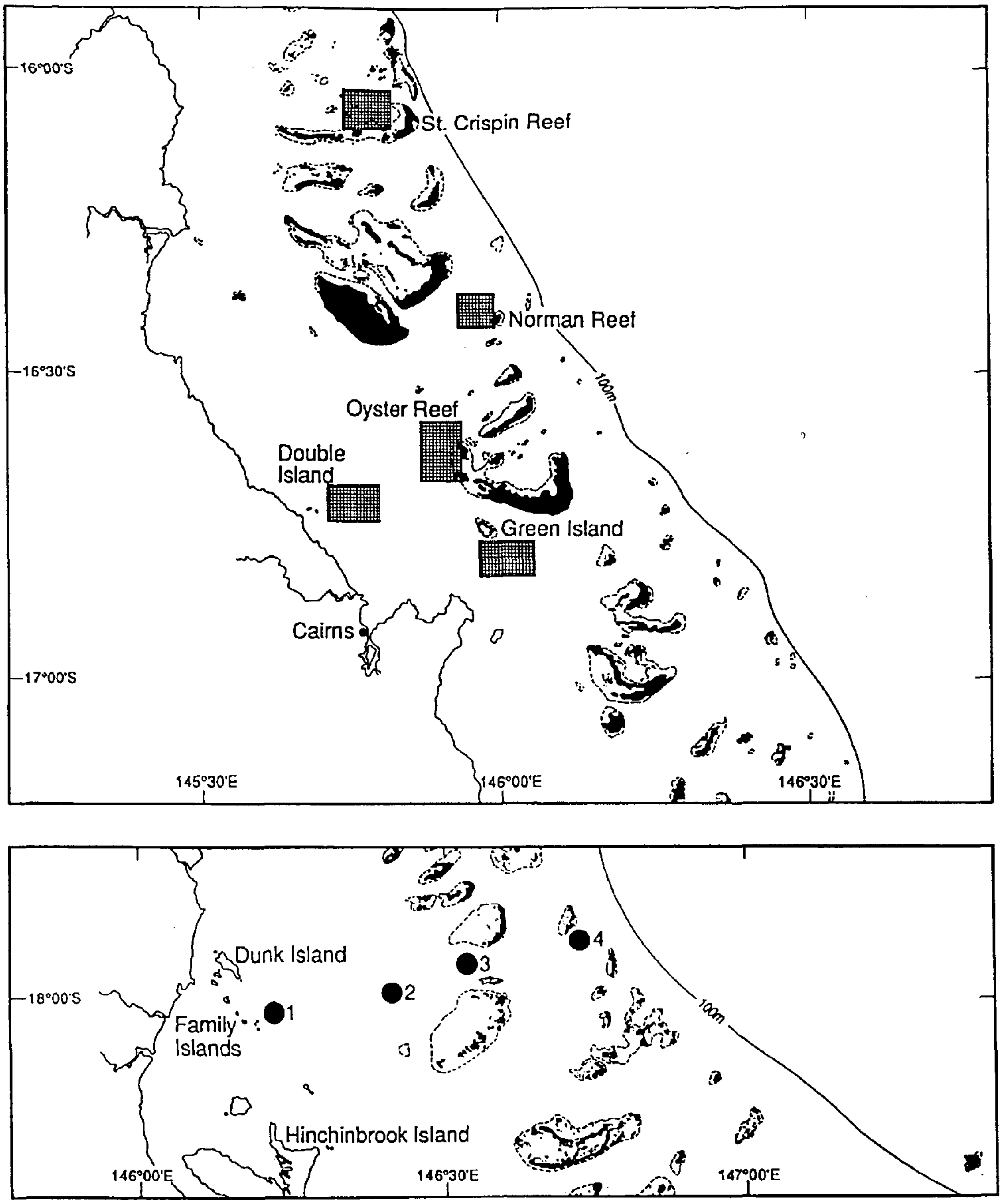

Figure 7. Top: Zones (shaded boxes) where free-drifting sediment traps were deployed in the Cairns box between May 1990 and July 1991. Moored sediment traps were deployed several times in the zones near Green Island and St. Crispin Reef. Bottom: Transect sites off the Family Islands where moored sediment traps were deployed between September 1988 and August 1989.

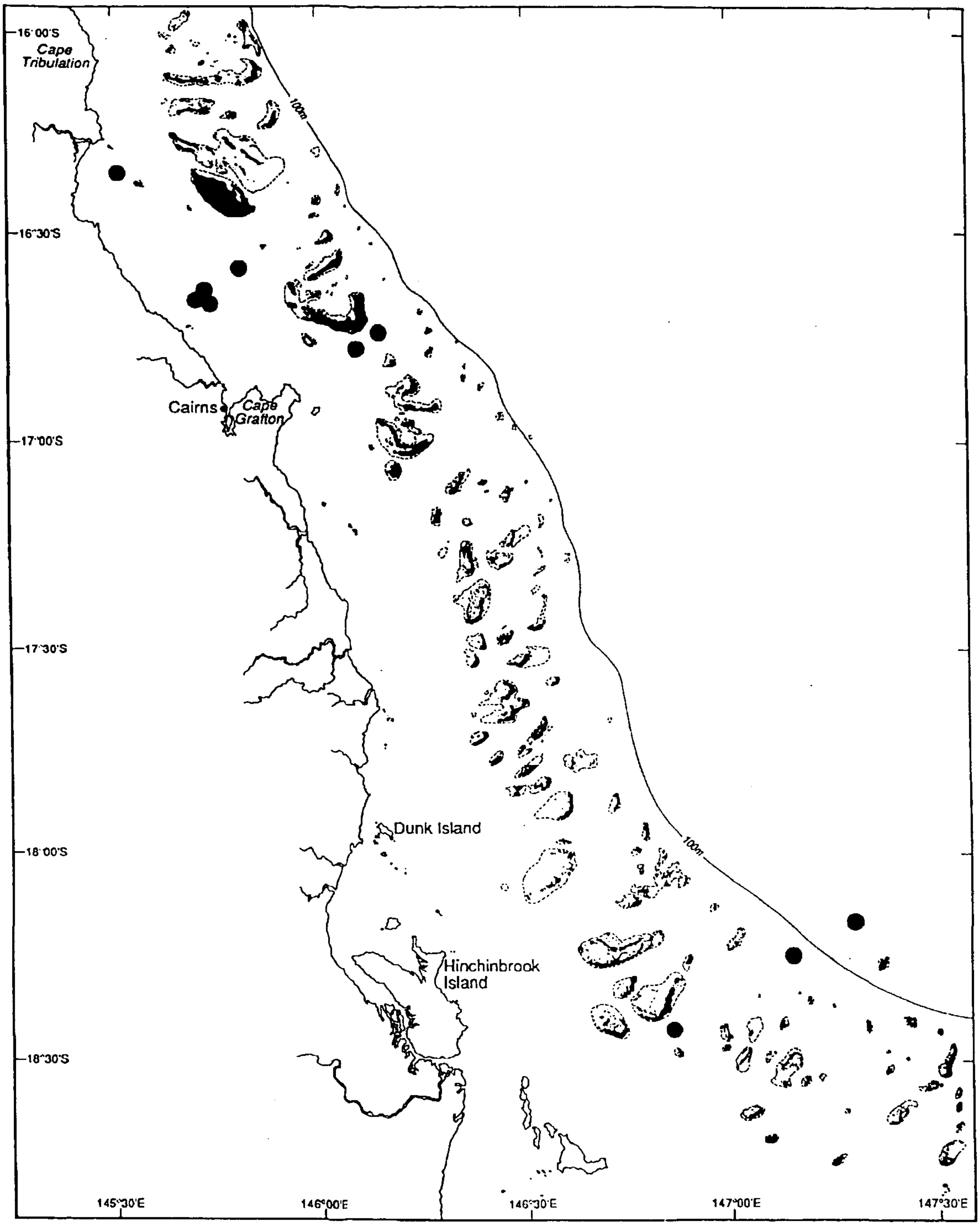

Figure 8. Locations of stations (●) where water column primary production measurements were made between January, 1983 and December, 1990.