PART 1.

THE DUGONGS' ENVIRONMENT

CHAPTER 2.

PHYSIOGRAPHY

2.1. Description of the study areas

Moreton Bay (153.3° E, 27.5° S) is located at the south-east corner of Queensland, on the East Australian coast. It is a 1,400 km^2, wedge-shaped embayment, protected by high sand islands (Moreton and North Stradbroke) on the east and the coastal plain of the mainland to the west (Newell, 1971; Figure 2.1). Moreton Bay is approximately 100 km long and ranges in width from 1 km in the south to 31 km in the north. The southern Bay contains a complex of islands, which form the delta of the Logan River. The eastern Bay, north of these islands, is largely ocean-influenced (Maxwell, 1970; Young, 1978). The sediments of this area are predominately quartz sand, while in the west and the south, they are mud. Relict and existing coral communities contribute to a restricted area of carbonate sediment (Maxwell, 1970). The Bay is generally shallow in the western and southern areas, shelving to maximum depth of 60 m in a deep basin in the eastern central area (Milford and Church, 1977; Newell, 1971; Figure 2.1).

Further information on the physical and biotic environment of Moreton Bay can be found in the following reports: hydrology (Milford and Church, 1977; Newell, 1971; Patterson and Witt, 1992), sediments (Maxwell, 1970; Stephens, 1992), water quality (Moss et al., 1992), seagrasses (see Chapters 3 and 4), macro-benthos (Stephenson et al., 1970), fisheries (Williams, 1992) and cetaceans (Corkeron, 1989). In addition, an overview of the natural resources of Moreton Bay, as well as a description of human activities that affect the Bay is provided by a report of the Department of Environment and Conservation (1989).

Two study areas were established in Moreton Bay. The East study area encompassed the fan-shaped sand delta between Moreton and North Stradbroke Islands, while the West study area was located in the adjacent, inshore waters on the western side of the Bay (Figure 2.1). These two study areas contained 45% of the estimated 229 km^2 of seagrass in Moreton Bay (Hyland et al., 1989).

The East study area supports the majority of dugongs living in Moreton Bay (section 5.2.2). The West study area supported dugongs in the past (Alfredson, 1984; Petrie, 1932; Welsby, 1905), but is now the waterfront of Brisbane's eastern suburbs and is the centre of many anthropogenic influences (recreational boating, industrial, rural and urban run-off).

Place names for areas in the East study area are illustrated in Figure 2.2. Some of these names are well known and are clearly located on most charts and maps of Moreton Bay. Other names are only vaguely or inconsistently attributed to areas on charts. I have given boundaries, which may not be universally accepted, to these names. Still other names are my own, used to identify areas or features that are not labelled on charts and maps.

2.2. Climate

2.2.1. Introduction

The restriction of dugongs to tropical and sub-tropical regions (Nishiwaki and Marsh, 1985) suggests a relationship between climate and dugong distribution. The boundaries of this distribution (27° N and S), like those of the West Indian manatee (Lefebvre et al., 1989), are probably determined by the dugong's limited capacity to tolerate cold water. Although the thermal physiology of the dugong has not been studied, evidence suggests that it is similar to that of manatees (see below). Manatees have high thermal conductivities, low metabolic rates and consequently, limited thermoregulatory abilities (Gallivan and Best, 1980; Gallivan et al. 1983; Irvine, 1983). The lower critical water temperature for the

Amazonian manatee is between 22 and 23.6° C (Gallivan et al., 1983). Florida manatees cannot maintain themselves indefinitely in water below 20° C (Irvine, 1983) and they seek warm water refugia when water temperatures drop below 21° C (Bengtson, 1981; Hartman, 1979).

Evidence of intolerance of cold water by dugongs is less empirical. During a winter survey of Shark Bay (similar latitude to Moreton Bay), less than 4% of sighted dugongs (n = 437) were in water that was colder than about 18° C (Marsh et al., 1991). These dugongs are reported to abandon favoured feeding areas when water temperature drops below about 19° C (Anderson, 1986). In the Arabian Gulf the distribution of dugongs is determined, apparently, by water temperature: dugongs are not found in areas that experience mean water temperatures below 19° C for more than three months each year (Preen, 1989a).

Moreton Bay is the southern limit of the dugong's distribution in eastern Australia (Heinsohn et al., 1978). Consequently, the water temperature regime, at least during winter, is likely to be an important determinant of dugong movement and habitat selection.

Climatic variables which may influence seagrass growth, and therefore, have the potential to influence the dugongs of Moreton Bay include day length, cloud cover and rainfall. Light/temperature interactions are the main factors that govern the seasonal changes in the growth and productivity of seagrasses at any site (Hillman, et al., 1989). Separation of the roles of these factors is difficult, as water temperature is largely determined by solar radiation. The parameters of irradiance to which the seagrasses respond are likely to be the daily periods of saturating irradiance and compensation irradiance (Dennison, 1987; Dennison and Alberte, 1982). By affecting these periods, cloud cover also has the potential to influence seagrass growth.

The growth and abundance of seagrasses is linked, at least at inshore tropical Townsville (Queensland), with the wet season rains (Lanyon, 1991). Whether this is due to the higher temperatures during this period, or to the flush of nutrients resulting from rainfall run-off is not clear (Lanyon, 1991). The availability of nutrients, however, has been shown to have a significant impact on the growth of seagrasses (Short, 1987) and the artificial elevation of nutrient levels (through the addition of fertilisers) can increase growth and biomass of seagrasses (Harlin and Thorne-Miller, 1981; Orth, 1977) and nutrient levels in the seagrass tissue (Bulthuis and Woelkerling, 1981). Moreton Bay is a semi-enclosed water way that receives the discharges of five rivers (Newell, 1971). The pattern of rainfall, therefore, has the potential to influence the growth of seagrasses, and hence the seagrass-feeding dugongs in Moreton Bay.

2.2.2. Methods

2.2.2.1. Water temperature

Thermometer measurements

I recorded surface water temperature (to 0.1° C) on 318 occasions between May 1988 and January 1990 using a mercury thermometer . By measuring surface temperature, the data were comparable with satellite derived data. Temperatures were recorded from four main areas: the nearshore waters in the west of the Bay; the mid-bay, between the West and East study areas; the main banks in the East study area; and the deep water immediately outside Moreton Bay to the east of South Passage (see Figure 2.1).

Satellite imagery

The spatial pattern of surface water temperatures was examined using 12 NOAA AVHRR satellite images captured between May 1988 and October 1989. Brightness temperature channels 4 and 5 were used in a window correction algorithm to account for atmospheric water vapour, and Barton's algorithm was used to calculate water temperatures. The temperatures are accurate to approximately 1° C during winter and 1-2° C during summer. I used these images, which have a resolution of 1 km^2, to estimate the water temperature on the eastern banks and in the area outside South Passage.

2.2.2.2. Air temperature

Average daily air temperatures, at Brisbane, were provided for each month of this study and for the 42 years up to 1990 by the Bureau of Meteorology (Queensland Regional Office).

2.2.2.3 Day length

The predicted day lengths for the study period were obtained from the Queensland Department of Lands, Division of Information.

2.2.2.4 Cloud cover

Average daily cloud cover, at 0900 h and 1500 h, was provided for each month of the study period by the Bureau of Meteorology. The mean morning and afternoon measures of cloud cover (measured in octas) were averaged to obtain a single daily measure, and converted to percent cloud cover.

2.2.2.5. Rainfall

Monthly rainfall records for the period of this study and for the 42 years up to 1990 were provided by the Bureau of Meteorology.

2.2.3. Results

2.2.3.1 Water temperature

Water temperature on the seagrass banks in the East study area paralleled air temperature with no detected lag period (Figures 2.3a and 2.4a).

Both the satellite and thermometer derived data described the same seasonal change in the temperature of water on the eastern banks (Figures 2.3a and b). There was particularly close accord between the two data sets during the cold months of 1989.

Definition of seasons

On the basis of the suggested importance of water temperature to the distribution and movements of dugongs (above), water temperature on the eastern banks was used to define the seasons in Moreton Bay.

Winter was defined by months with mean water temperatures below 19° C on the main seagrass banks in the East study area (Figure 2.3a). This threshold was chosen because of the apparent sensitivity of dugongs to this temperature (Anderson, 1986; Preen, 1989a). Summer was arbitrarily defined by months with water temperatures above 25° C. Spring and autumn were the intervening seasons of rapid temperature change (Figure 2.3a).

Winter comprised three months (June, July and August) in both 1988 and 1989 (Figure 2.3). Water temperatures on the eastern banks were recorded below 16° C on 14 occasions, and were recorded below 15° C twice (14.7° C on 7 August 1989 and 14.8° C on 15 July 1989).

Spatial patterns

During winter, the western and southern sections were the coldest areas in the Bay (Figure 2.5). Temperatures on the eastern banks were tempered to some extent by the proximity of the warm East Australia current, which passes near the coast in this area. Tidal currents partially flush the eastern banks with relatively warm oceanic water during rising tides (Figure 2.5; Patterson and Witt, 1992).

The patterns described by the satellite images were supported by the thermometer readings. During the winter months of 1989, the water temperatures in the inshore area, in the west of the Bay, were significantly colder than on the main banks (one-way ANOVA: df = 1, 105, F = 16.8, p = 0.0001). During the three winter months, the water temperatures in the inshore area averaged 16.0° C (SE = 0.25), compared with 17.3° C (SE = 0.16) on the banks in the East study area.

The water immediately seaward of the South Passage was significantly warmer than the water on the seagrass banks just inside the Bay (one-way ANOVA: df = 1, 38, F = 18.29, p = 0.0001). Although this comparison is just for July 1989 (the only month in which I measured several (n = 13) temperatures from outside the Bay), the pattern was consistent during all the winter months. The satellite images indicate that the waters immediately seaward of South Passage were consistently 2-5° C warmer than the water on the nearby banks in winter (Figure 2.3b).

Inter-year variation

The winter of 1989 was colder than the winter of 1988. The mean daily air temperature maxima during July and August 1989 were respectively the coldest and second coldest in 42 years, while the mean daily minima during August and September were both the coldest in 42 years (Bureau of Meteorology data). Consequently, the water temperatures on the eastern banks were significantly colder during the winter of 1989 (17.3° C, SE = 0.16) than during the winter of 1988 (18.6° C, SE = 0.11; Figure 2.3a; one-way ANOVA: df = 1, 125, F = 31.48, p = 0.0001). Based on the 19° C and 25° C thresholds, the spring of 1989 spanned three months compared with two in 1988 (Figure 2.3a).

2.2.3.2. Day length

The median day lengths for each month of the study are plotted in Figure 2.4b. Day length, the period between sunrise and sunset, ranged from 10 h 25 min in June to 13 h 52 min in December.

2.2.3.3. Cloud cover

Cloud cover was highly variable throughout the study (Figure 2.4b), but tended to be highest (50-70% cover) during summer and autumn (December - May) and lowest (25-50%) during winter and spring (June-November).

2.2.3.4. Rainfall

Brisbane experiences a summer rainfall peak, although rain normally falls in every month of the year (Figure 2.4c). Unusually high rainfall was received on two occasions during the study. In April 1989, Brisbane received 502 mm of rain, the highest April total in 42 years (mean = 96 mm). The following February 359 mm was received: the seventh highest in 42 years.

2.2.4. Discussion

Although lone dugongs are occasionally reported from higher latitudes (Marlow, 1962; Marsh, 1989a; D. Osborne, pers. comm., 1988), Moreton Bay is the southern limit of the dugongs' normal distribution in eastern Australia. Moreton Bay is a shallow embayment, mostly less than 10 m deep and with a maximum depth of 60 m (Milford and Church, 1977). Consequently, surface water temperature parallels air temperature without a time lag (Figures 2.3a and 2.4a).

The western and southern areas of the Bay became relatively cold during winter (Figure 2.5), averaging 16.0° C (SE = 0.25) during the winter months of this study. If the thermal tolerance of the Moreton Bay dugongs is similar to that of manatees, these areas would be uninhabitable during winter.

The tidal flushing of relatively warm oceanic water through South Passage ameliorated the temperatures on the eastern banks (winter temperatures: 1988: 18.6° C, SE = 0.11; 1989: 17.3° C, SE = 0.25), and this is where the majority of dugongs live in Moreton Bay (see section 5.2.2). However, even here water temperatures were measured as low as 14.7° C, and averaged less than 19° C for one quarter of each year. The dugongs may have been physiologically stressed during these periods.

Day length, cloud cover and rainfall will be discussed in relation to the seasonality of the seagrass resource in sections 4.3.8 and 4.4.3.

2.3. Sediments

2.3.1. Introduction

The substrate in which seagrasses grow could be important to the bottom feeding dugongs for two reasons. Firstly, the type of sediment can determine microbial activity, oxygen content and levels of nutrient availability in the interstitial water (Hillman et al., 1989). Interstitial nutrients are related to the levels of nutrients in the seagrasses (Short, 1987). The dugongs may benefit by feeding selectively on seagrasses with relatively high levels of otherwise limiting nutrients (see section 6.6.3).

Secondly, the physical characteristics of the sediments may determine the ease with which dugongs can grub the seagrasses. Dugongs usually feed by pushing a furrow through the sediment and collecting the seagrasses as they swim slowly forward (pers. obs.). Characteristics of the sediment that may affect the efficiency of the dugongs' feeding include its compaction, the predominant grain size, and the amount of shell and other hard objects. Hence, differences between sediments may be relevant to the dugongs' selection of preferred habitats.

Maxwell (1970) mapped the sediments of Moreton Bay and Young (1978) classified the sediments around the Bay's littoral fringe. These surveys looked only at particle size and carbonate content, and paid little attention to the main seagrass banks of the East study area. To fill this gap, and to examine other sediment characteristics, I examined the sediments at a selection of sites in the East and West study areas. These data were also to provide a base for comparison with the sediments at feeding sites selected by dugongs (section 6.2).

2.3.2. Methods

Sediments were examined from the 10 sites that were used to monitor temporal patterns in seagrass abundance (section 4.2). Eight sites were located on the banks in the East study area (sites E1-E8), and two sites (W1-W2) were in the West. Although the locations of these sites were randomly determined, the sites generally were positioned to sample a selection of the seagrass communities present (section 4.2).

2.3.2.1. Grain size

The distribution of particle sizes provides some insight into the type and origin of the sediment. For example fluvial deposits tend to have a higher silt and mud content than well-sorted sand banks (Blatt, 1982).

Single sediment samples were collected at each site using an 8 cm diameter corer in October 1988. Only sediment from the top 10 cm was examined. Most seagrass roots and all dugong grazing occurs within this depth (pers. obs.). Samples were analysed using standard methods of granulometric analysis (Buchanan, 1971; Folk, 1961). The nest of sieves consisted of the following meshes: -4 ϕ (4 mm), -1 ϕ (2 mm), 0 ϕ (1 mm), 1 ϕ (0.5 mm), 2 ϕ (0.25 mm), 3 ϕ (0.125 mm), 4 ϕ (0.063 mm) and greater than 4 ϕ (<0.063 mm). The corresponding Wentworth size classes are cobble, pebble, very coarse sand, coarse sand, medium sand, fine sand, very fine sand and silt (Folk 1961). 'Cobble' and 'pebble', in this instance, refer to different sizes of shell fragments. The mean grain size (M_Z) was calculated by the method of moments (Folk, 1961).

2.3.2.2. Shell content

Due to the relatively large size of shells and shell fragments, the single sediment core used for grain size analysis did not provide a representative sample the shell content of the sediments. Therefore, the abundance of shells and shell fragments were sampled in 25 quadrats, each 0.05 m^2 at each site in October 1988. Quadrats were positioned at 2 m intervals along a 50 m north-south oriented transect. The quadrats were excavated to a depth of 6-8 cm and sieved through the 5 mm mesh of a dive bag. The retained shells were oven-dried at 65° C for 48 h, weighed and expressed as grams of shell and shell fragments per square metre.

The depth to which the quadrats were excavated could not be controlled precisely. At one site with a very high shell content (W1), the quadrats were shallower (4-6 cm), while at sites with a very thick rhizome mat (E3, E4), the quadrats tended to be deeper (6-10 cm). The site specific characteristics which determined the depth of sampling would also operate on a foraging dugong, so the depth of sampling approximated the depth to which dugongs could grub for seagrass rhizomes.

2.3.2.3. Sediment compaction

An index of sediment compaction was obtained by measuring the resistance of the surface sediment to vertical penetration. The 'penetrometer' consisted of a 1.2 m by 1 cm, round-tipped, stainless steel rod. The rod was fired vertically into the sediment by the release of a stretched surgical rubber band (in the manner of an Hawaiian sling spear 'gun'). The stretch of the rubber, and the height above the sediment from which the rod was fired were rigidly standardised and the 'penetrometer' was always completely submerged. Sediment compaction was measured by the distance of penetration.

Penetration was determined at nine or 10 haphazardly located positions at each site on one or two occasions (October 1988 and January 1989). Measurements were made at the 10 standard sites plus two supplementary sites (EA and EB).

2.3.3. Results

Data on seagrass communities and biomass are taken from Chapter 3.

2.3.3.1. Grain size

The frequency distributions of grain sizes from sites in the East and West study areas are shown in Figure 2.6. This graph includes the shell fragments to show their approximate abundance relative to the main components.

Excluding the shell fragments retained by the 4 and 2 mm sieves, the mean particle size of sediments in the East study area (1.8 ϕ: 0.31 mm), was significantly larger than the mean particle size in the West study area (2.5 ϕ: 0.16 mm; one-way ANOVA: df = 1,8, F = 15, p = 0.0047). Inclusion of the shell fragments did not change the significance of the results at $\alpha = 0.001$. Sediments in the East were made up almost exclusively of medium and fine sands (94.9%), while sediments in the West were composed largely of fine and very fine sand (70.3%) as well as some silt (2%; Figure 2.6).

2.3.3.2. Shell content

Sediments from the two sites in the West study area contained significantly more shell than sediments from sites on the eastern banks (ANOVA: df = 1, 243, F = 98.76, p = 0.0001), largely due to the very high shell content of site W1 (Figure 2.7). Irrespective of study area, there was a significant difference between the 10 sites (ANOVA: df = 9, 235, F = 99.74, p = 0.0001), which separated into six groups based on LSD tests (Figure 2.7). Site W1 was a relatively deep (1.9 m) inshore site and its sediments contained a large proportion of old, flat oyster shell. Sites E3 and E4 also contained high levels of shell. These sites were characterised by very high seagrass biomass (community ZB1; see Chapter 3). A small (1-2 cm long) thick-shelled gastropod (Rhinoclavis articulatus, Cerithiidae) dominated the shell fauna. The other sites fell into three broadly overlapping groups characterised by relatively low abundances of shell in their surface sediments.

2.3.3.3. Sediment compaction

The compaction of the sediments did not differ significantly between study areas (one-way ANOVA: df = 1, 169, F = 0.08, p = 0.7755), although it did differ significantly between sites (one-way ANOVA: df = 11, 159, F = 40.61, p = 0.0001). The 12 sites separated into four non-overlapping groups on the basis of LSD tests (Figure 2.8). Two sites, E3 and E4, which were significantly different from each other and from all the other sites, had the loosest sediments, with mean penetrometer readings of 24.7 cm and 17 cm respectively. These sites occurred in areas of high seagrass biomass (community ZB1). The second group of sites (sites E1, W2 and E2), with an average penetration of 14.2 cm contained relatively dense stands of Zostera capricorni with thick rhizome mats, or occurred at a muddy inshore location. The remaining sites, with the exception of site W1, represent the seagrass communities occupying the majority of the banks in the East study area. These sites had a mean penetration of 7.2 cm and were characterised by relatively low seagrass biomass (Figure 4.2).

Penetration was positively correlated with seagrass biomass ($r = 0.8433$, $n = 9$, $p = 0.0043$): thus sediment compaction was inversely correlated with biomass. Where the rhizome mat is thick, the surface sediments were loose, whereas areas with little seagrass cover tended to have well packed, dense sediments. Due to the high penetration values and high shell content of sites E3 and E4, seagrass biomass was also correlated with shell content ($r = 0.7849$, $n = 9$, $p = 0.0123$) and hence penetration was also positively correlated with the amount of shell ($r = 0.7750$, $n = 9$, $p = 0.0142$). Penetration was not correlated with the mean grain size of the sediments ($r = 0.1214$, $n = 9$, $p = 0.7557$).

2.3.4. Discussion

Maxwell (1970) showed that carbonate sediments are very restricted in Moreton Bay, occurring around the islands in the West study area, and to the south of both study areas. The remaining sediments are terrigenous, and divide into three main facies: clean sand, muddy sand and mud. My sampling confirms Maxwell's (1970) finding that the entire East study area is composed of clean terrigenous sand while the West is predominantly muddy sand.

Young (1978) classified the littoral and infralittoral sediments of Moreton Bay into two major groups: ocean influenced areas and river influenced areas. Based on their particle size distributions the East and West study areas are respectively ocean and river influenced.

Different sites were characterised by different quantities of shells in their surface sediments, and different types of shell dominated different sites. For example, site W1 was characterised by an abundance of oyster shell, sites E3 and E4 by large quantities of a gastropod (Rhinoclavis articulatus) and sites E7 and E8 by thin shelled mussels. From the dugongs' perspective, the differences in the shell fauna at different sites may be significant. The gastropods at E3 and E4 were very solid, and it is doubtful that they would be crushed by a chewing dugong. As these gastropods were both very abundant, and difficult to separate from the seagrass (seagrass roots often grew into the cavity of dead shells) they may limit the efficiency of the dugongs' grazing.

Sediment compaction was inversely correlated with seagrass biomass. However, it is unlikely that it would be easier for dugongs to grub the rhizomes of dense seagrasses than sparse seagrasses as the resistance of the rhizome mat itself is probably a significant impediment.

2.4. Bathymetry

2.4.1. Introduction

Dugongs are restricted to feeding in areas with suitable water depths. With an abdominal diameter of up to nearly 1 m, adults cannot feed in water much shallower than this depth. At the other extreme, dugongs have been considered to be poor divers, compared with most marine mammals (Marsh et al., 1978). Although previously thought to be restricted to relatively shallow inshore waters (Heinsohn, 1972; Heinsohn and Birch, 1972; Jarman, 1966; Nishiwaki and Marsh, 1985), recent observations of dugongs up to 58 km from shore, in 37 m of water (Marsh and Saalfeld, 1989), and of feeding trails made by dugongs at depths of 24 m (Lee Long et al., 1989) have extended the depth range within which dugongs are known to forage.

Dugongs occur most commonly at different depths in different areas. In north-eastern Queensland most dugongs have been seen in water <5 m deep (Marsh and Saalfeld, 1989), compared with 12-16 m in Shark Bay (Western Australia; Marsh et al., 1991) and 11-18 m in Hervey Bay (southern Queensland; Marsh et al. 1990). The distribution of seagrass probably determines where dugongs most commonly occur, and this depends on water depth and turbidity (Dennison, 1987; Duarte, 1991; Kenworthy et al., 1991). An understanding of the bathymetry of an area is, therefore, an integral part of understanding habitat use and selection by dugongs.

2.4.2. Methods

There are no published water depths for the banks of the East study area, and those for the West are largely restricted to sub-tidal areas. In order to plot the bathymetry of the study areas, water depth was measured with a sounding line (to nearest 0.1 m) at each of 512 sampling stations throughout the study areas (see Appendix 1 for the location of sites and section 3.2.2 for details of site selection). The depth of each site, relative to Port Datum was determined by subtracting the predicted tide height, at the time of sampling, from the measured depth. Predicted tide heights were corrected for differences in time and magnitude of tides, relative to Port Datum, on the basis of published tidal planes for appropriate Secondary Places (Queensland Department of Harbours and Marine, 1989).

The plotted depths of each site in the East study area were used in conjunction with aerial photos of the banks (see section 3.2) to draw the isolines of a topographic map. Bathymetry from published charts was used for the West study area, supplemented in some shallow areas by my data. Depths were plotted at the following intervals: +1, +0.5, 0, -0.5, -1, -2, -5 m relative to Port Datum.

2.4.3. Results and Discussion

The bathymetric charts of the East and West study areas are presented in Figure 2.9 a and b, respectively. Based on published data (Queensland Department of Harbours and Marine, 1989), the relationships between plotted depths (which are relative to Port Datum) and various water levels are:

For water depth at this water level	Add this amount (m) to the plotted depth
Mean high water springs	2.16
Mean high water	1.96
Mean sea level	1.24
Mean low water springs	0.35

Most of the eastern Banks are subtidal, covered by 1-5 m of water at mean sea level (Figure 2.9b). Inter-tidal areas are restricted to small strips and patches along the edges of the Rous and Rainbow Channels, and the area surrounding Crab Island, which itself is inter-tidal and covered by mangroves.

Figure 2.1. Location of the West and East study areas in Moreton Bay.

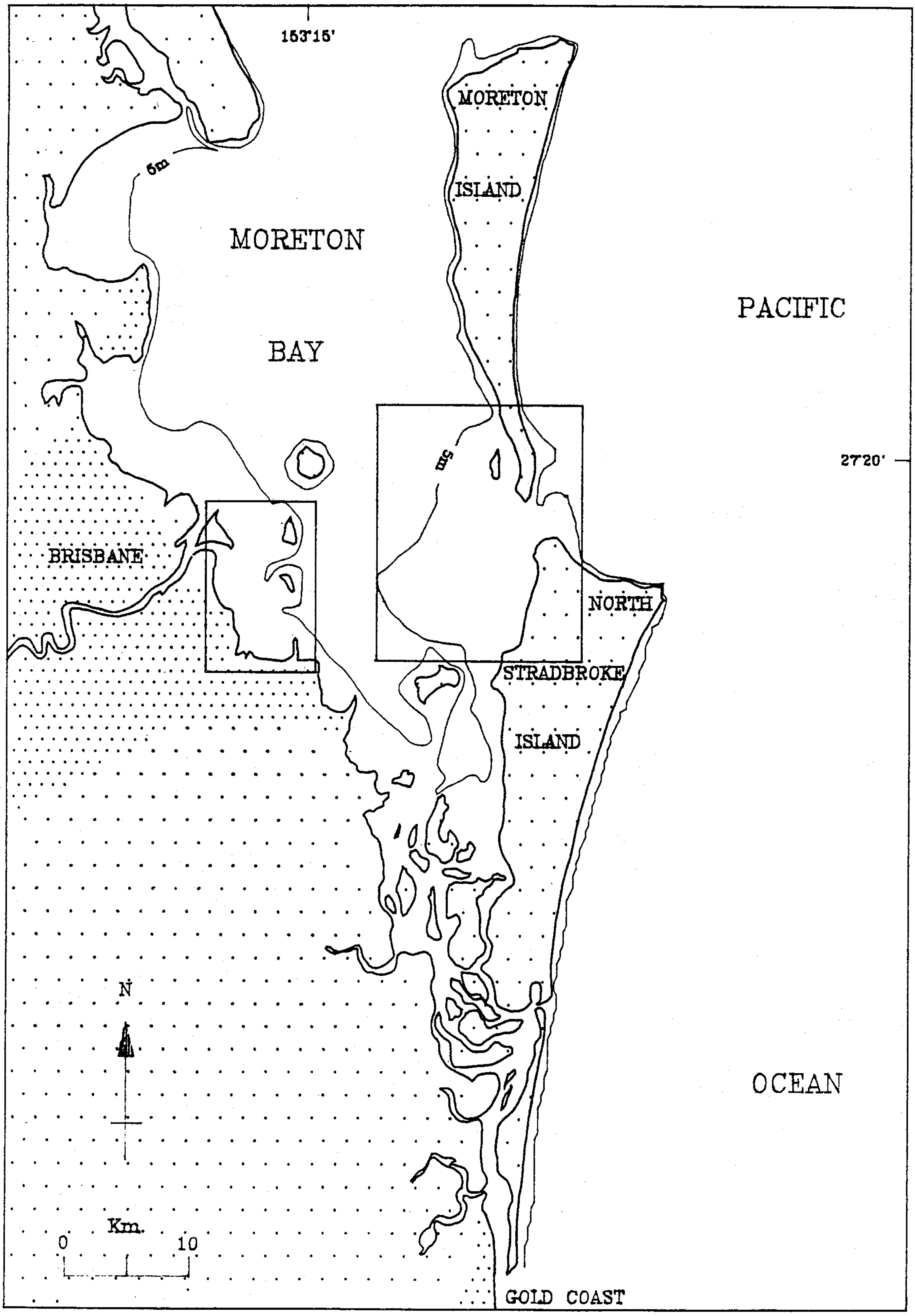


Figure 2.2. The East study area in Moreton Bay. Place names referred to in text.

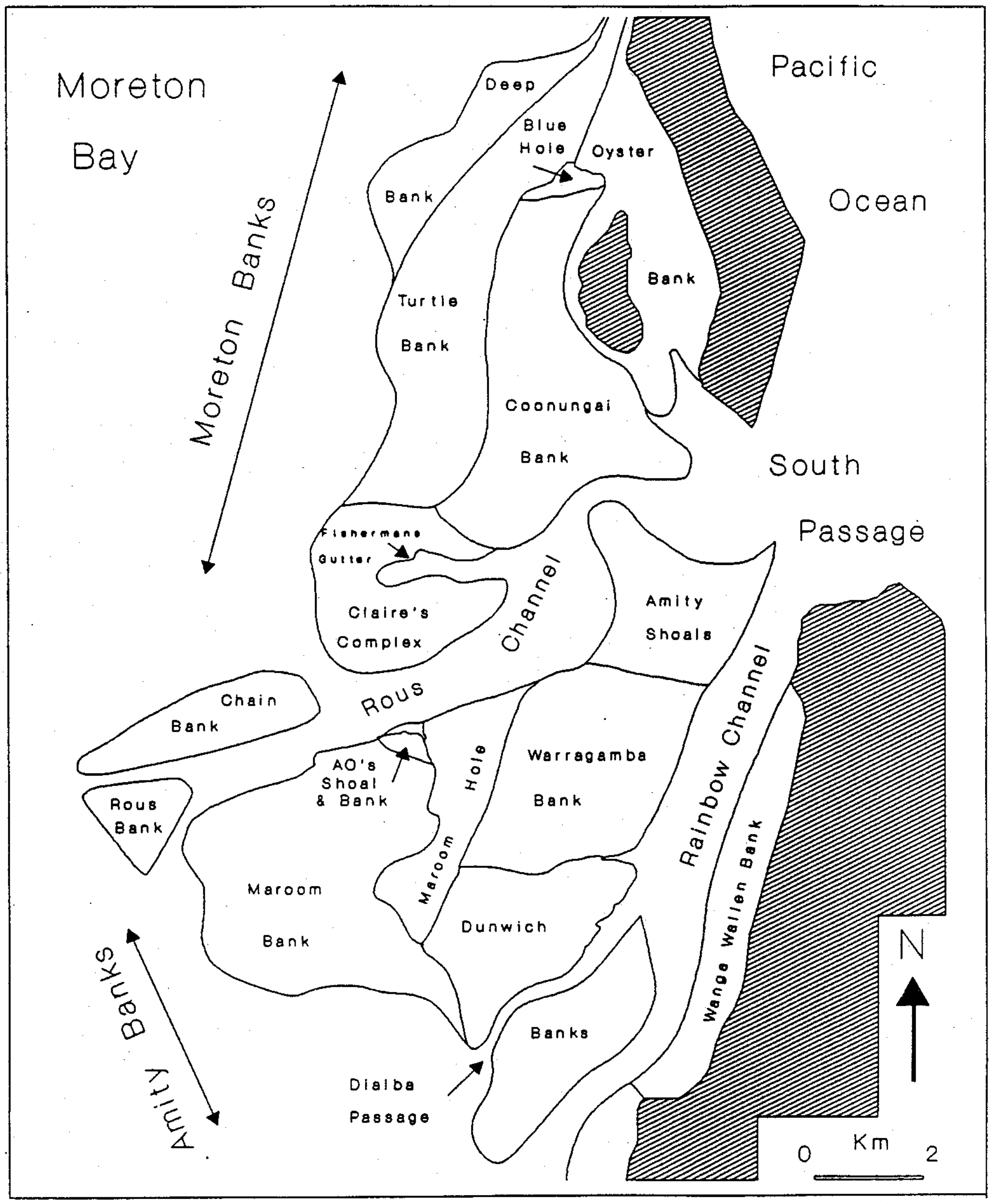


Figure 2.3. Temporal variation in surface water temperatures from (A) the seagrass banks of the East study area: based on 213 thermometer measurements (mean and SE plotted) and (B) the seagrass banks in the East study area and the deep water areas immediately outside (east) of South Passage: derived from NOAA AVHRR satellite imagery. Graph (A) also shows the distribution of seasons, based on water temperatures.

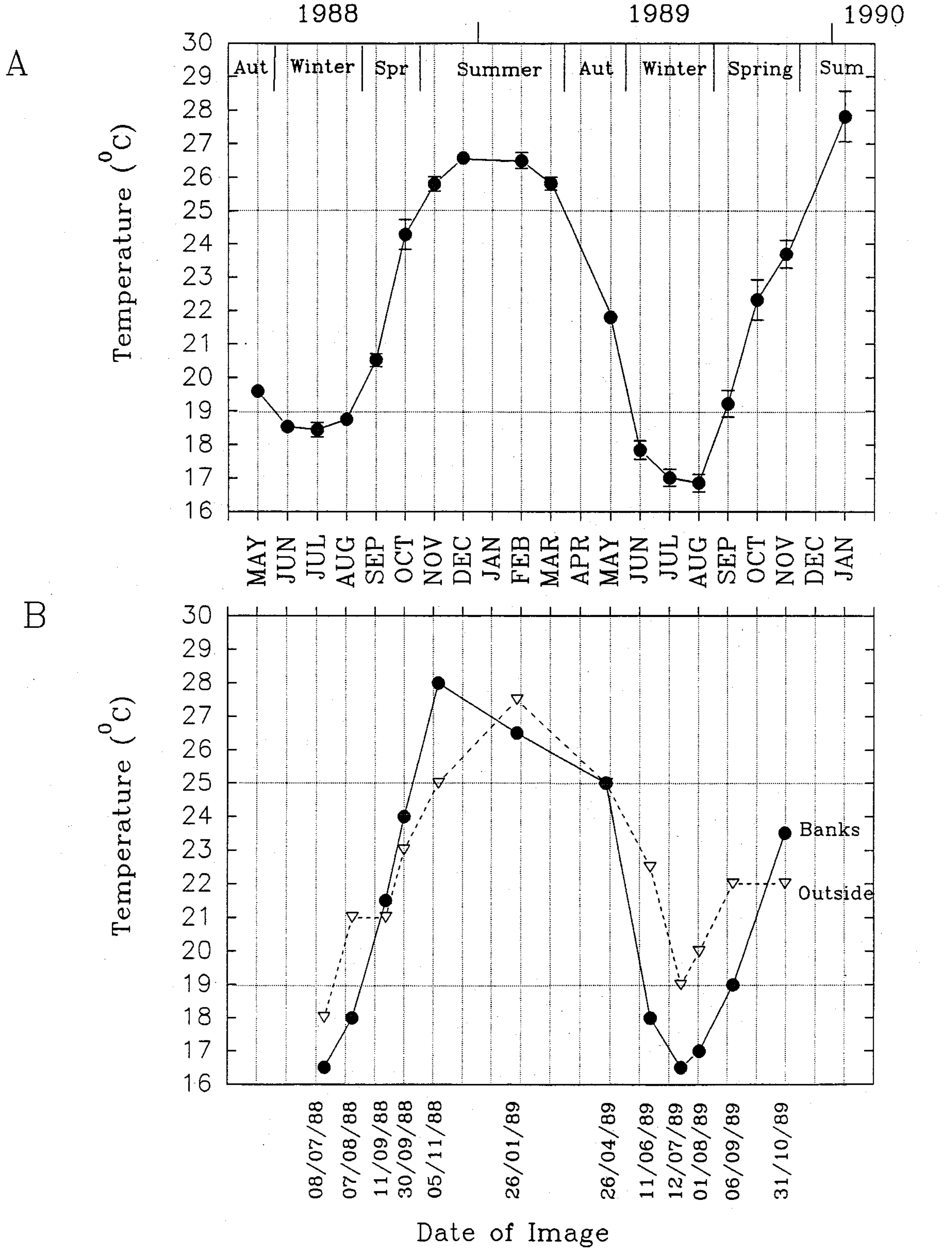
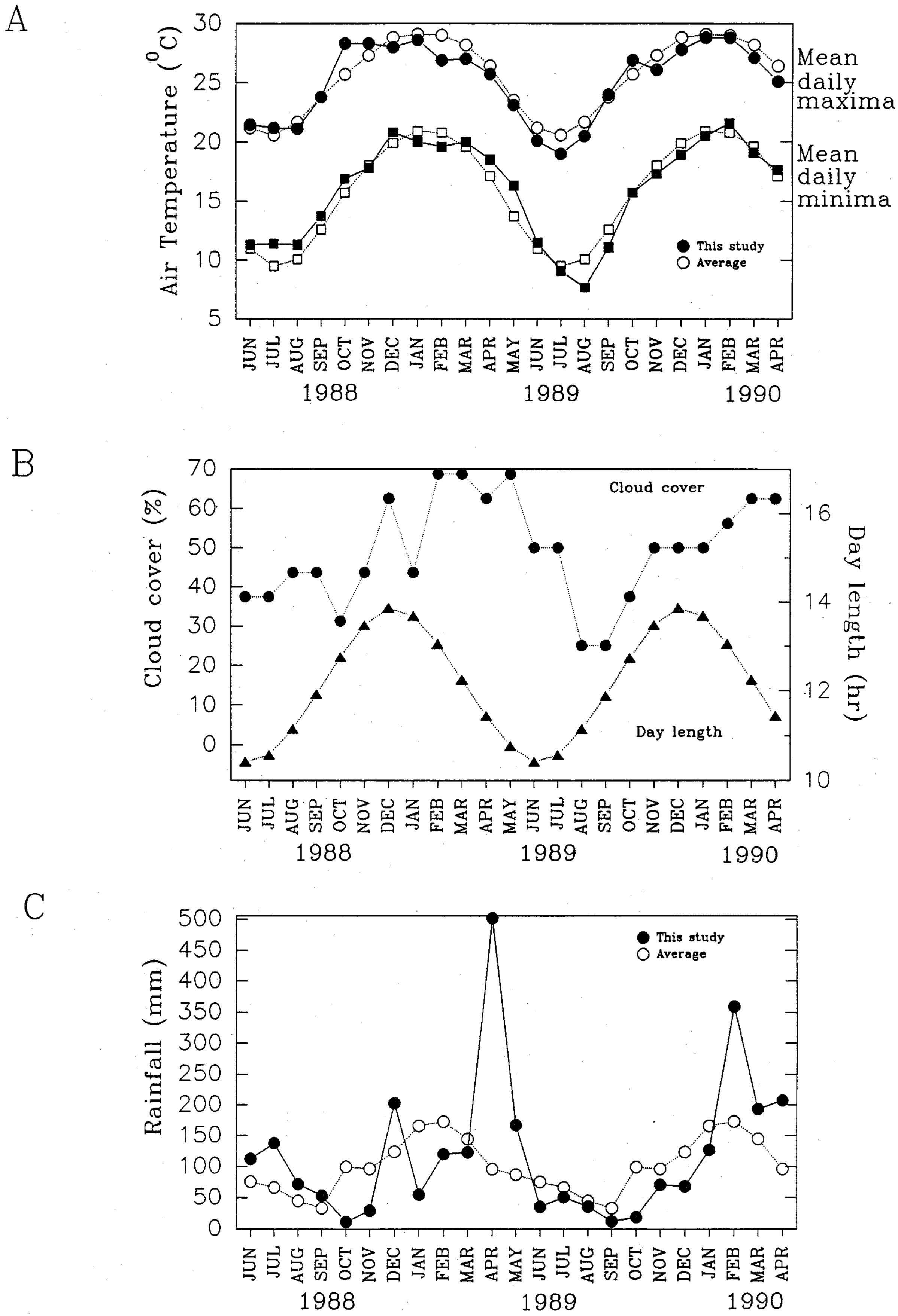


Figure 2.4. Air temperature (A), day length and cloud cover (B) and rainfall (C) recorded at Brisbane during the months of this study and the comparative 42 year averages (1949–1990).



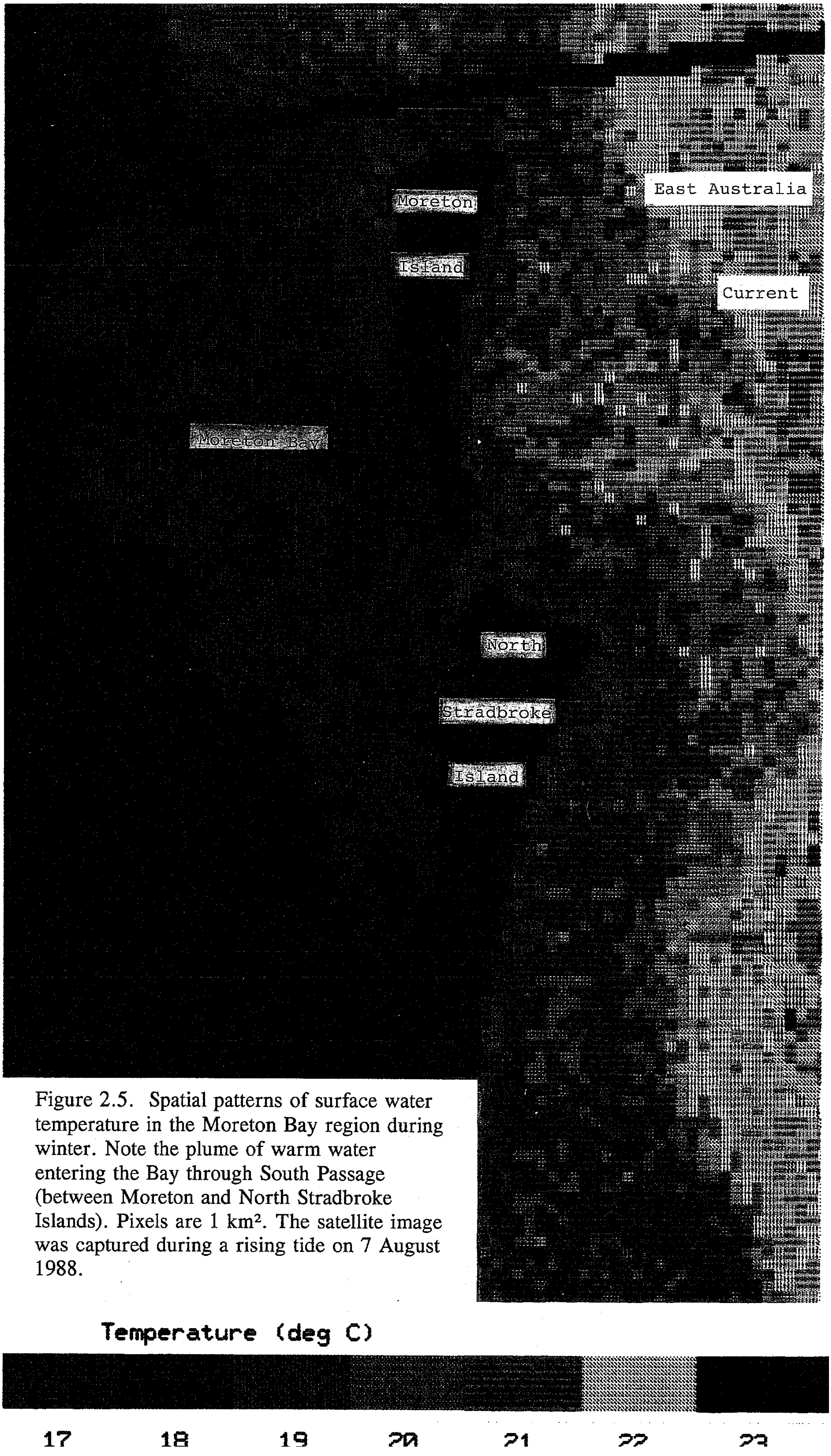


Figure 2.5. Spatial patterns of surface water temperature in the Moreton Bay region during winter. Note the plume of warm water entering the Bay through South Passage (between Moreton and North Stradbroke Islands). Pixels are 1 km². The satellite image was captured during a rising tide on 7 August 1988.

Figure 2.6. Frequency distribution of grain sizes (mean plus SE) in sediments from the East (n = 8) and West (n = 2) study areas in Moreton Bay.

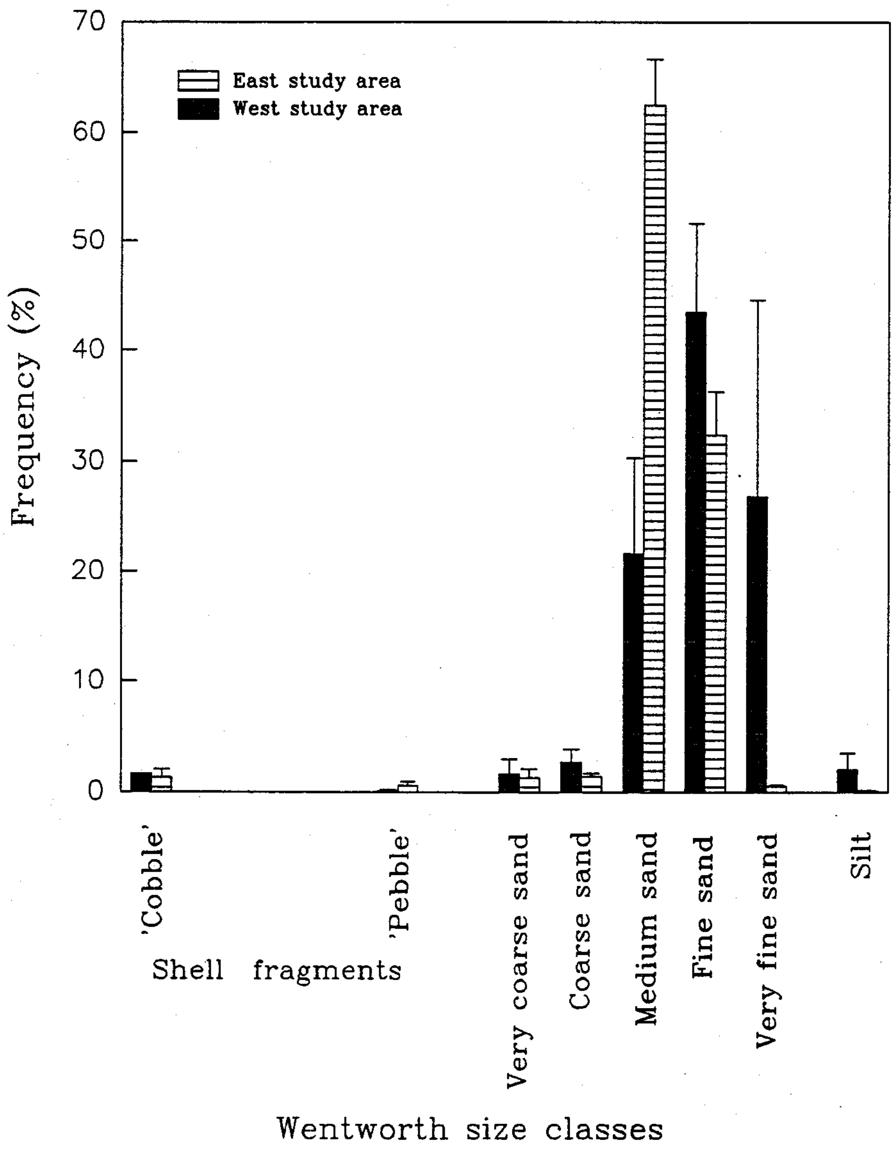


Figure 2.7. Amount of shell and shell fragments (mean plus SE) in surface sediments at 'random' sites in the East and West study areas. The amount of shell did not differ significantly among sites with the same capital letter. Multiple comparisons were based on the Least Significant Difference.

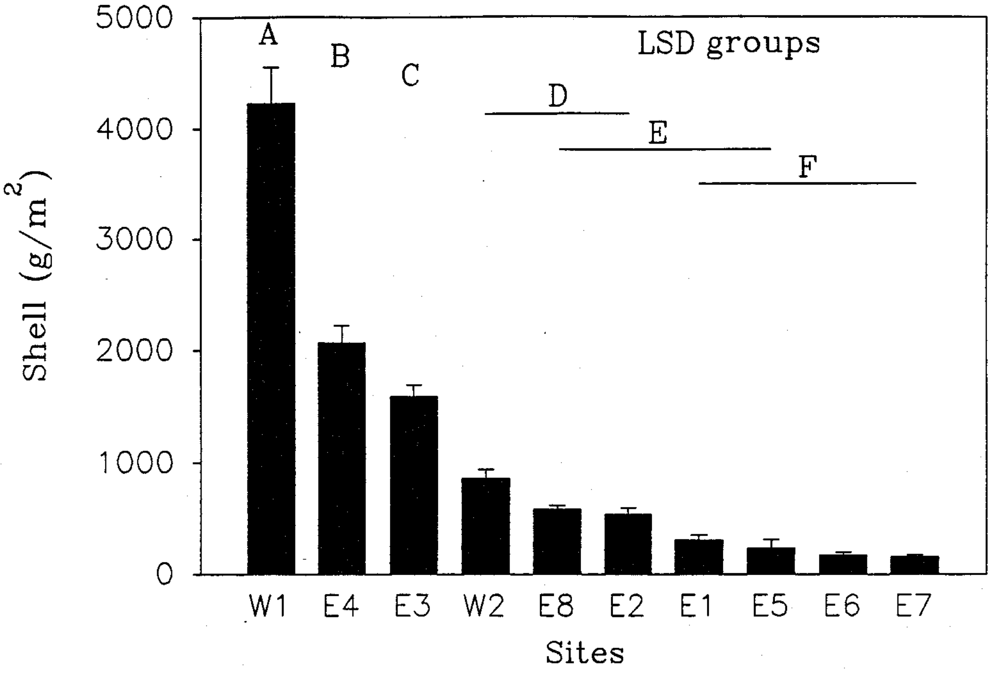


Figure 2.8. Penetrometer readings (mean plus SE) at 'random' sites in the East and West study areas. Depth of penetration did not differ significantly among sites with the same capital letter. Multiple comparisons were based on the Least Significant Difference.

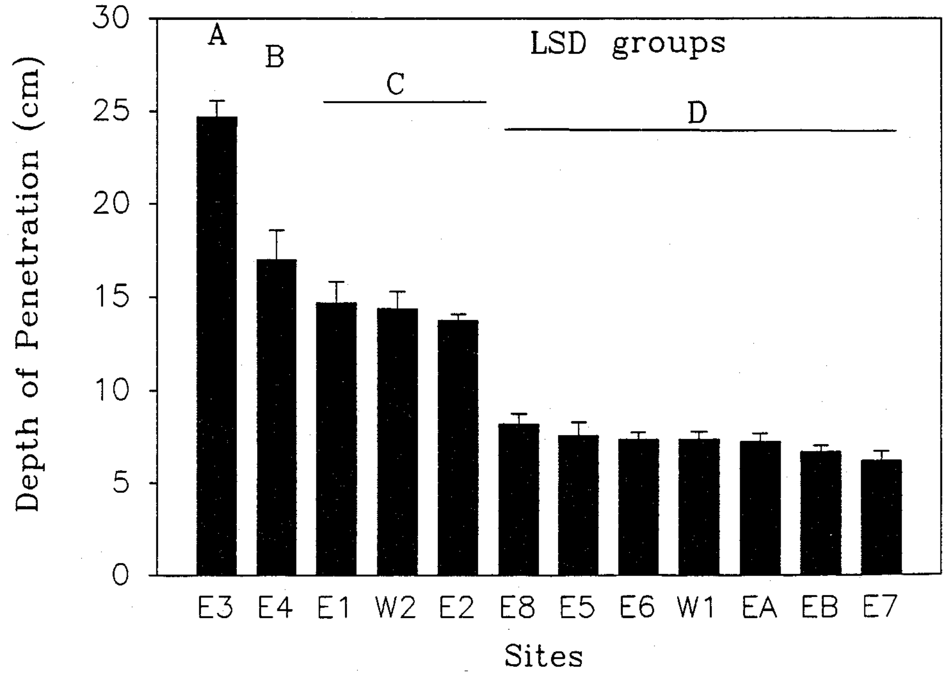
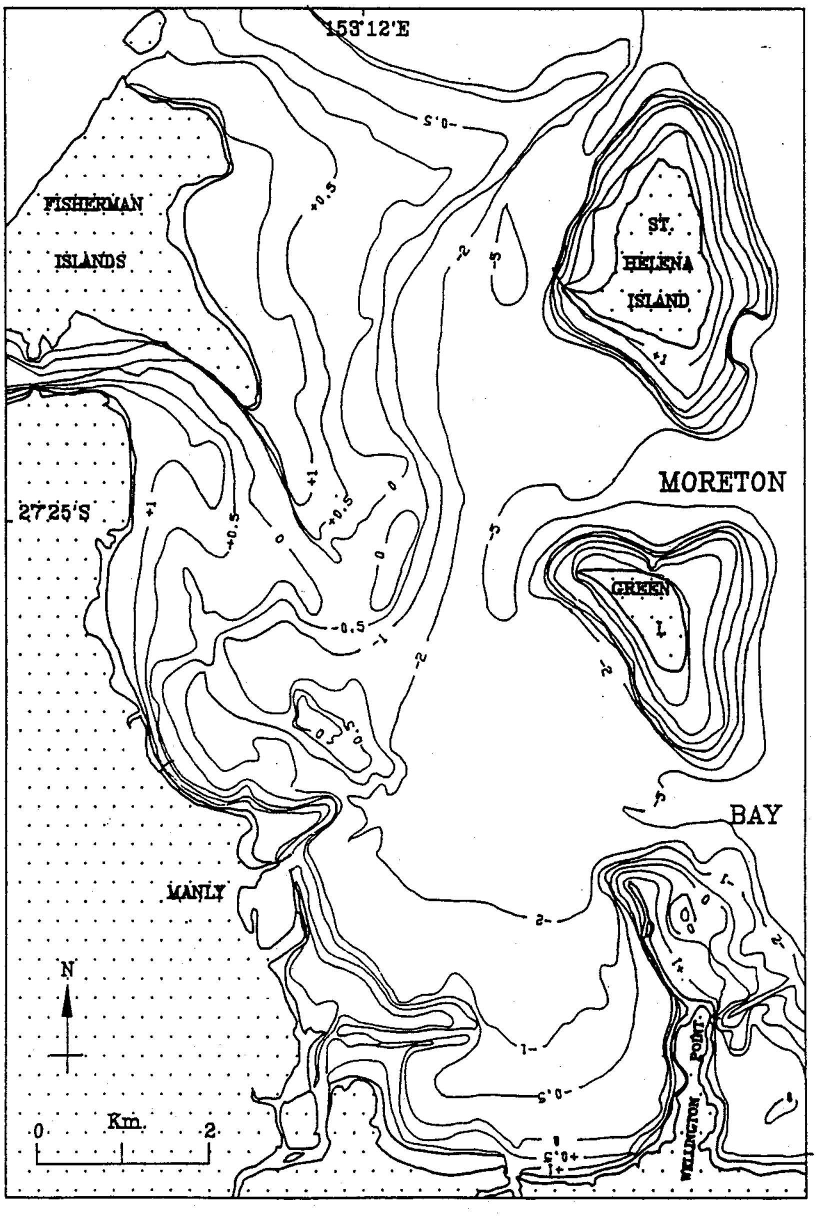
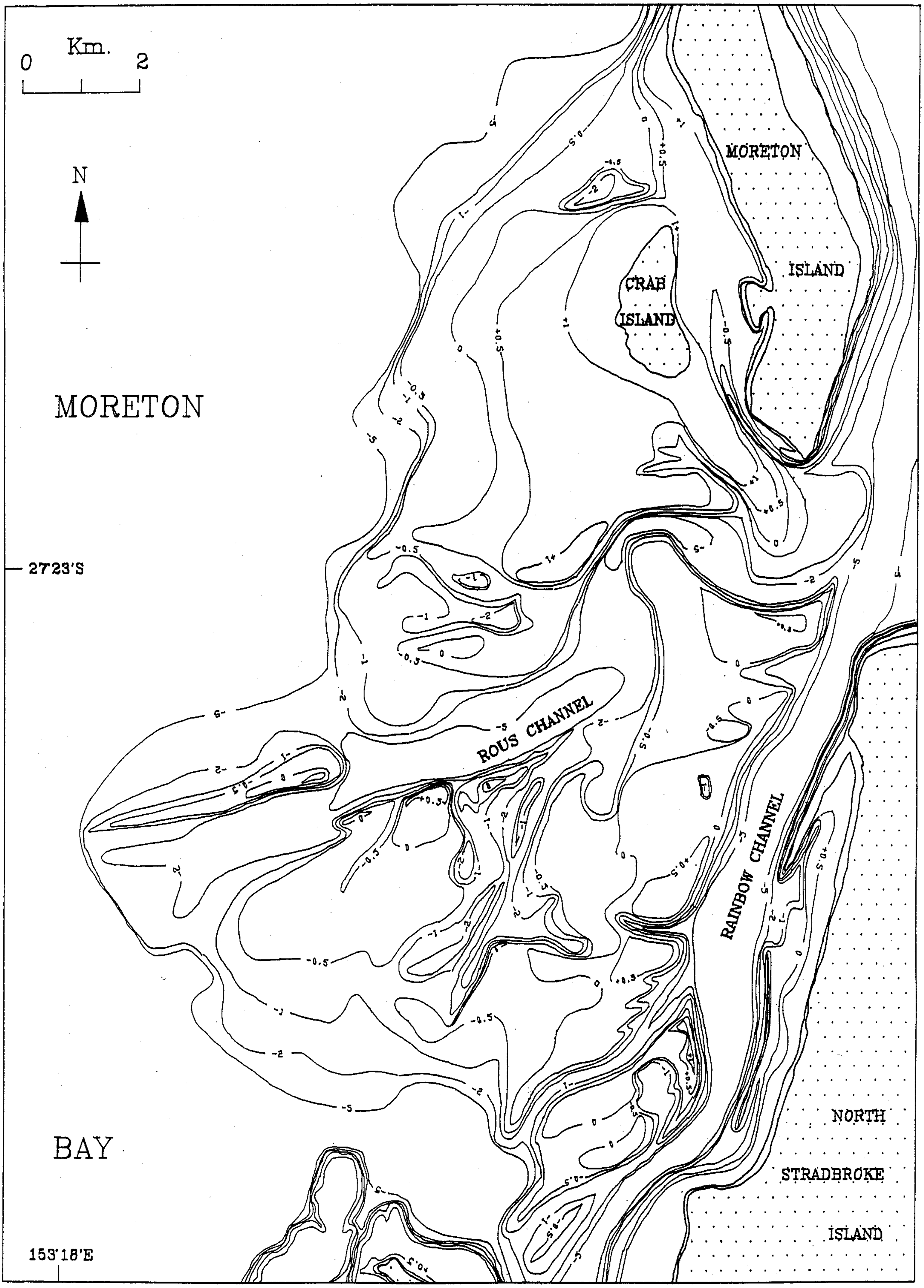


Figure 2.9. Bathymetry of the (A) West and (B) East study areas in Moreton Bay. Depths are in metres, relative to Port Datum.

A



B


0 Km. 2
N
MORETON
BAY
MORETON ISLAND
CRAB ISLAND
ROUS CHANNEL
RAINBOW CHANNEL
NORTH STRADBROKE ISLAND
27°23'S
153°18'E