DISTRIBUTION OF SEAGRASSES IN PRINCESS ROYAL HARBOUR AND OYSTER HARBOUR ON THE SOUTHERN COAST OF WESTERN AUSTRALIA

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DISTRIBUTION OF SEAGRASSES IN PRINCESS ROYAL HARBOUR AND OYSTER HARBOUR, ON THE SOUTHERN COAST OF WESTERN AUSTRALIA

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ABSTRACT

The distribution and area of seagrass meadows in Princess Royal Harbour (35° 3' S, 117° 53' E) and adjacent Oyster Harbour (34° 58' S, 117° 58' E) in Western Australia were recorded in 1981 and 1984. The possible extent before 1981 was estimated from historical aerial photographs, previous studies and coring for rhizome remains. Three species were found to be dominant: Posidonia australis Hook f., Posidonia sinuosa Cambridge et Kuo and Amphibolis griffithii (J.M. Black) den Hartog. It was estimated that between 1962 and 1984 the seagrass areas in Princess Royal Harbour and Oyster Harbour had been reduced by 66% and 46% respectively. A definite loss between 1981 and 1984 was recorded, most probably due to smothering by macroalgae in Oyster Harbour and both macroalgae and epiphytes in Princess Royal Harbour. In addition, a thinning of the meadows at the lower limit of the depth range was apparent.

INTRODUCTION

In response to local concern regarding the apparent decline of environmental quality of Princess Royal Harbour, Atkins et al. (1980) studied its water quality. Subsequently they recommended that a biological survey of the benthos should be undertaken. This report is concerned with the distribution of seagrass and macroalgae in Princess Royal Harbour (35° 3' S, 117° 53' E) and adjacent Oyster Harbour (34° 58' S, 117° 58' E).

Documenting the distribution of seagrasses within such harbours is important because of the ecological significance of these plants. Reduction in the area occupied by seagrass meadows may provide an important means of documenting decline in water quality (Cambridge, 1979; Cambridge and McComb, 1984).

The reduction of seagrass beds may be caused by changes in climate, sedimentation, succession, grazing, nutrients, turbidity, salinity, or result from disease or toxic chemicals. Cambridge et al. (1986) attributed the deterioration of seagrass meadows in Cockburn Sound, Western Australia, to a combination of increased phytoplankton blooms and high epiphyte loads. This was supported by Silberstein (1980), Silberstein (1985) and Silberstein et al. (1986), who also concluded that light attenuation in the water column was not the limiting factor, but that where epiphyte cover was high, light levels reaching the seagrass were reduced, with a consequent decline in seagrass leaf production.

This report presents data collected from two surveys (1981 and 1984), work done by McKenzie (1962) and aerial photographs taken in 1943, 1957, 1977 and 1982.

STUDY AREA

Princess Royal Harbour and Oyster Harbour are two large (28.7 km^2 and 15.6 km^2 respectively), essentially marine harbours located near Albany (Fig. 1). Both have narrow channels communicating with King George Sound, which has water of oceanic quality.

The geomorphology of the two harbours is generally similar. They are shallow with gently sloping sandy margins, which carry seagrass meadows subtidally (Table 1). The dominant seagrass species are Posidonia australis Hook f., Posidonia sinuosa Cambridge et Kuo and Amphibolis griffithii (J.M. Black) den Hartog.

Princess Royal Harbour has no river inflow. Freshwater comes from rainfall, seepage, and run-off from adjacent land, especially via the Elleker Road drain (Fig. 2). Sources of nutrients are outlined by Atkins et al. (1980). Princess Royal Harbour is a significant port for the town of Albany and its hinterland.

Oyster Harbour is fed by two large rivers and several minor streams (Fig. 3). Much of the catchment, especially that of the Kalgan River, has been cleared for agriculture. The Kalgan River also appears to be the most significant source of sediment (McKenzie, 1962). There are no industrial discharges into, or port facilities in, Oyster Harbour.

The average annual rainfall for Albany is 953 mm, and rain falls mainly from May to October. Princess Royal Harbour has a salinity of 31 $^o/oo$ to 37 $^o/oo$ and a temperature of 13 ^oC to 21 ^oC (Atkins et al. 1980). Oyster Harbour varies from 9 $^o/oo$ to 32 $^o/oo$, and may be separated into brackish and marine sectors (Figs 4 and 5 from McKenzie, 1962).

Tides are usually semi-diurnal, but may be diurnal. The maximum predicted tidal range at Princess Royal Harbour is + 0.20 m to 1.20 m, the mean variation being 0.40 m (Australian National Tide Tables 1981).

MATERIALS AND METHODS

Surveys of macrophytes were carried out in January 1981 and January 1984, involving extensive use of manta-board, SCUBA-diving and snorkel-diving. In shallow clear water, observations were made from a dinghy.

A tide datum was established for reference with the navigational charts, and leadline soundings (accurate to 50 mm) together with a hand-held compass were used for position fixing. All depths were corrected to chart datum. Colour aerial photographs were also used, and interpretations checked in the field where possible.

The distribution of seagrass and algal species was recorded as percentage cover by the following method: transects were run both along and at right angles to selected depth contours (Figs 2 and 3). Percentage cover was assessed visually, and recorded every five metres unless an abrupt change occurred. Both depth and position fixes were recorded whenever a significnt change was observed in cover or species. Seagrass percentage cover was divided into four categories, numbered 1 to 4, 100-75, 75-40, 40-15, < 15% (Orth and Moore, 1983). These intervals best typify the relative status of these marine meadows in the range from optimal to sub-optimal cover and biomass. In some instances, where distribution was not .pa continuous, the term "patchy" was used. Notes were made on the extent of macroalgal epiphyte cover, the apparent state of plant 'health' or 'vigour', plant height and algal occurrence. The presence of rhizome material in recently degraded areas was noted.

Biomass data were collected for P. australis and P. sinuosa (8 replicates of 0.25 m^2 quadrats, leaves only, Table 2).

Historical data relating to Posidonia distribution (but not density) for Oyster Harbour came from McKenzie (1962) (Fig. 6). A distribution map was compiled for Princess Royal Harbour by combining data from early aerial photographs (1943, 1957) with evidence of rhizome existence and with data extrapolated from McKenzie (1962) (Fig. 7, Table 2). Aerial photographs from 1977 were considered, although water clarity was poor when these were taken. Distribution of seagrass was mapped for 1981 and 1984 from the field data and the 1982 aerial photographs (Figs 8, 9, 11 and 12). Short transects are depicted on these Figures and correspond with the cross-sectional diagrams presented in Figures 14 and 15. These transects were selected to represent both differences and changes within each harbour for 1981 and 1984. It must be noted that transects depicted in Figures 2 and 3 are quite different and represent the actual survey transects undertaken.

Distribution of the dominant algae in 1984 was mapped for each harbour (Figs 10 and 13).

Areas were obtained with a digitizer (Summergraphics Maker LD-2-20, USA).

RESULTS

General

Distribution maps are presented in Figures 8 to 13, and transect drawings have been made to depict changes that have occurred in various areas over three years (Figs 14 and 15).

The marginal platforms of both harbours consist of hard, coarse sand, except in areas adjacent to river mouths. Two species of Phaeophyta, Cystophyllum muricatum (Turner) J. Argardh and Hormosira banksii (Turner) Decaisne, are common and are often attached to Katalesia (cockles) and several species of mussel. These macroalgae occur generally where the water is too shallow for Posidonia, but in Princess Royal Harbour C. muricatum may also form a blanket over the seagrasses.

The distribution of these algae in Oyster Harbour was noted by McKenzie in 1962. Apart from the recent appearance of Cladophora prolifera (Roth) Kuetzing, no additional macroalgal species were observed in Oyster Harbour in the present work. In contrast, by 1981 Princess Royal Harbour supported abundant plants of the genus Caulerpa, red algae mainly of the genera Gracilaria, and by 1984 Cladophora prolifera was dominant. There were few seagrass epiphytes in Oyster Harbour, but in Princess Royal Harbour they were abundant.

The bathymetry is shown in Figures 2 and 3, and Table 1 shows the extent of seagrass meadows in 1981 and 1984 as well as the total areas of the harbours and of two ranges of depth. Table 2 compares seagrass biomass of both harbours with data from Cockburn Sound. Table 3 lists actual areas of .pa seagrass, estimated areas and the seagrass loss over time. The distribution of seagrasses and macroalgae in each harbour is discussed below.

Oyster Harbour

For convenience of interpretation, Oyster Harbour has been divided into seven sectors, as defined below by location of convenient landmarks (Figs 8, 9 and 10).

Table 1: Extent of seagrass meadows in January 1981 and January 1984, in Oyster Harbour and Princess Royal Harbour.

	OYSTER HARBOUR		PRINCESS ROYAL	
	Area (km^2)	% of Total	Area (km^2)	% of Total
Total Area	15.6	100	28.7	100
Depth <0.1m	6.6	42.3	8.2	28.6
Depth >0.1m and <5.0m	6.7	42.9	17.2	59.9
1981*				
Total Seagrass	4.8	30.8	6.7	23.3
Seagrass <15%	1.3	8.3	0.5**	1.7
Dead Rhizomes	Trace	Trace	0.06	0.2
1984*				
Total Seagrass	3.6	23.1	5.9	20.6
Seagrass <15%	1.04	6.7	0.67	2.3
Dead Rhizomes	0.62	4.0	0.46	1.6

* Cover was divided into total seagrass cover, the amount of the total which consisted of seagrass <15%, and areas of dead rhizomes.

** An additional 5.2 km of very sparse (2%) seagrass existed in 1981 but was absent by 1984.

Table 2: Above-ground biomass of two seagrasses occurring in monospecific stands from Princess Royal Harbour, Oyster Harbour and Cockburn Sound.

	OYSTER HARBOUR biomass* g dry wt m^{-2}	PRINCESS ROYAL HARBOUR biomass* g dry wt m^{-2}	COCKBURN SOUND** biomass g dry wt m^{-2}
Posidonia australis	South Kalgan bank (0.9 m)	Shoal Bay (1.0 m)	Garden Island(1.5 m)
	541 ± 61	442 ± 64	433 ± 45
	North Kalgan bank (0.9 m)		
	223 ± 44		
Posidonia sinuosa	Southern Sector (Post 4, 1.5 m)	Bramble Point(1.7 m)	Garden Island(2.5 m)
	528 ± 120	709 ± 200	536 ± 31

* Biomass is the mean of 8 replicates of 0.25 m^2 quadrats.

** Data from Cambridge (1979).

Table 3: Estimated areas of seagrass meadows in Oyster Harbour and Princess Royal Harbour.

	OYSTER HARBOUR		PRINCESS ROYAL HARBOUR	
	Area(km^2)	% Cover	Area(km^2)	% Cover
Maximum theoretical seagrass area* (Total area - area <0.1 m)	9.0	100	20.5	100
Likely original seagrass area ** (area between 0.1 and 5.5 m)	6.7	74.4	17.2	83.9
1962 Seagrass area (from McKenzie 1962)	6.1	67.8	16.6	81.0
1981 Seagrass area	4.8	53.3	6.7	32.7
1984 Seagrass area	3.6	40.0	5.9	28.8
Seagrass loss between 1962 and 1984	2.5	46.2	10.7	66.2
Recorded loss between 1981 and 1984	1.2	25.0	0.8	11.9

* The area below 0.1 m, available for seagrass colonization.

** The area between 0.1 and 5.5 m depth. Below 5.5 m, seagrasses have been observed rarely. Also, this depth was cited by McKenzie (1962) as being the lower limit for seagrass growth.

(i) North sector

This region, north of the marina and to the Kalgan channel, contained no macroalgae other than H. banksii and C. muricatum. There was a high density of fan-tubeworms (often 20-30 m^{-2}), suggesting a detrital-based food web.

Since 1981 the Posidonia immediately north of the Kalgan channel entrance has become less dense. This has been particularly obvious for P. sinuosa (Fig. 14.1: 1981 and 1984). Although P. australis density is represented for 1984 as 100 - 75% cover, the plants, although apparently healthy, had about half the height and 40% of the biomass of the stands immediately south of the channel (Table 2, Figs 16 and 17).

Salinity and sedimentation data provided by McKenzie (1962) show that this northern sector is strongly influenced by the King and Kalgan Rivers (Fig. 5). Low salinities (about $9\,^{o}/oo$) and increased turbidity occur during the period of winter flow, and may affect seagrass metabolism.

Aerial photographs from 1943 and 1957 show that, for this northern sector, there was a decrease to 1984 of up to 80% in the cover of seagrass around the periphery of Oyster Harbour, in water depths of 0.3 to 0.8 m. Most of this decrease occurred after the 1977 photographs were taken. The 1943 and 1957 photographs also showed dense seagrass meadows in the Kalgan channel which is now barren.

Sea urchins (Temnopleurus michaelsenii) were observed grazing in 1981 and 1984, in densities of 30 to 50 m^{-2}.

(ii) Western sector

This sector, between Bayonet Head and the marina, had undergone little change over the three years, 1981 to 1984. Amphibolis occupied the depth range 1.8 to 4.5 m, a horizontal distance of about 5 m to 8 m, on this steep bank. This appeared to be the only Amphibolis meadow in Oyster Harbour by 1984.

Towards the north the meadow thinned and the depth at which seagrass grew was reduced. The Posidonia meadow had thinned in the vicinity of the marina, where it may have been affected by dredging. Otherwise the bulk of the shallow (0.3 to 1.0 m) seagrass appeared to have changed little since the 1957 aerial photographs were taken. The deep channel to King George Sound probably allows reasonable tidal flushing.

(iii) South Kalgan bank

Figure 14.2 depicts this bank, and Figure 17 the seagrass. This P. australis bed between Posts 3 and 5 was the most vigorous in appearance of any meadow in the harbour, and probably in both harbours (Table 2). McKenzie (1962) found that this bank was rapidly extending westwards owing to sedimentation which may promote vigorous seagrass growth. The biomass of 541 g dry wt m^{-2} was above the 400 g dry wt m^{-2} reported for healthy seagrass by Cambridge (1979) in Cockburn Sound. In 1984 remains of the seagrass at the eastern tip of the bank had been covered by drifts of decomposing Cladophora (Fig. 18) while P. sinuosa meadows had become thinner at depth.

(iv) Central banks

These shallow (<2 m) banks south and east of Post 4, had hardly changed since 1981. P. sinuosa meadows in water depths of 2 to 2.5 m had reduced very little in area (the loss may have occurred through the presence of Cladophora) but percentage cover remained the same. This area of seagrass had low cover (< 15% cover) because of the substrate, which consisted mostly of oyster shells. A sparse (< 15% cover) Amphibolis bed seen on the western steep edge in 1981 (2.5 to 4.5 m depth) was not seen in 1984.

(v) Eastern sector

This sector, lying between Post 5 and Post 6 had undergone the most marked change of any recorded. This sector in 1962 (Fig. 6) supported dense seagrass meadows from the 0.3 m contour to at least 6 m. By 1984 only very sparse clumps existed. This degradation had occurred relatively recently.

Figure 14.3, 1981 and 1984, and Figure 19 depict the impact that Cladophora made upon the former beds. It must be noted that a considerable area of seagrass had died before 1981 at depths between 2.5 and 6 m.

Considerable portions of the former meadows showed symptoms of smothering in 1981, but the algal material had decomposed and could not be recognised. Anecdotal evidence from local fishermen indicated that filamentous algae (possibly Rhizoclonium or Enteromorpha) had bloomed heavily in the late winter of 1980, in the northern brackish waters derived mainly from the rivers.

The Cladophora banks by 1984 extended in a continuous thick carpet from Hormosira flats in shallow water to the east, down to 4.5 m. The water of the south-east bay (near Post 6) was very turbid with organic detritus near a large Cladophora bank (500 m x 150 m x 0.60 m deep). Inshore the shell flat was overlain with a "black ooze" and the aquatic angiosperm Ruppia was present.

(vi) Southern sector: (Post 6 west to Emu Point).

This sector supported one of the most extensive remaining areas of dense seagrass meadow. P. sinuosa had a biomass of 528 g dry wt m^{-2}, which was some 25% less than the densest stands in Princess Royal Harbour, but may be compared with the highest biomass in Cockburn Sound, 536 g dry wt m^{-2} (Cambridge 1979, Table 2). In 1981 macroalgal drifts occurred along the sharp boundary of this meadow, at 0.8 to 1.5 m.

Figure 14.4, 1981 and 1984, depict the eastern side of this sector, just west of Post 6. A deeper (2 m) basin is surrounded by shallow beds, and contained accumulated algae and detritus. This 'sink' may be contributing excessive nutrients to the surrounding area as, by 1984, adjacent seagrasses were showing obvious epiphyte development.

To the west, the area between Post 7 and Post 8 (Fig. 14.5) showed little change between 1981 and 1984, but P. sinuosa in the deeper zone (> 2 m) did appear to have thinned. At depths of more than 2.4 m there was even greater thinning. Loss at these depths appears typical for most of this harbour, whereas little change had occurred since 1943 in depths shallower than 2 m.

(vii) Emu Point banks and Yakamia Bay

No detectable change had occurred to the Emu Point and Green Island banks, other than the loss of small areas reclaimed for the boat harbour. The waters in this sector were essentially marine, because of regular tidal flushing. P. australis occurred to at least 3 m depth, although the leaves of plants at the deepest part of the range were relatively short. Scouring by strong currents was a regular feature of the habitat.

Changes in Yakamia Bay were difficult to define. The water in this bay was very turbid during the 1984 period, possibly because of material from Yakamia Creek, which may also contribute a significant annual nutrient input (F. Salleo, personal communication). The available information was not sufficient to draw conclusions about changes for this region, particularly over the years prior to 1981 at depths greater than 1 m.

Princess Royal Harbour

This harbour was divided into eight sectors as defined below by location of convenient landmarks (Figs 11, 12, and 13).

(i) Town Jetty to wreck

This north-western edge bore a patchy seagrass meadow, intermingled with areas of the alga, C. muricatum. Plants growing between 0.8 and 1.2 m were heavily covered in epiphytes (Fig. 20). Other substrates such as shells and pylons were colonized by algae.

Scattered populations of Amphibolis at depths > 1 m were more widespread in 1981 than in 1984. Since 1977 in shallow water (< 1 m), seagrasses had been reduced in both area and density by 40 to 50%. Considerable changes had occurred both in the shallows and at depth (> 1 m) since 1957 (Figs 11 and 12).

(ii) Wreck to Navigation Beacon

This western fringe supported three species of intermixed seagrasses. A shallow fringe of P. australis and Amphibolis appeared to have undergone little change since 1981. On the other hand the meadow fringing the deeper basin, at 2.2 to 2.8 m, was markedly reduced in area, and Amphibolis plants were no longer present; they appeared very unhealthy in 1981. Figure 15.1

shows *Cladophora* was abundant below 2 m, and any remaining seagrasses bearing prolific epiphyte growths in 1984.

At intermediate depths (0.8 to 1.6 m) *P. sinuosa* appeared to support the heaviest epiphytes, particularly in the area north of the beacon (Fig. 20). On the dense seagrass meadows (> 75% cover), the epiphytes covered 50% to 80% of the seagrass.

This area may have been receiving high nutrient loads, particularly from the Elleker Road drain. Orthophosphate samples taken during January 1984 (a time of little drain flow) indicated an input of 0.61 kg PO_4^{-2} day^{-1}. Atkins *et al*. (1980) quoted a winter input of 62 kg PO_4^{-2} day^{-1}.

Aerial photographs suggest that little change took place between 1943 and 1957. However, a marked change occurred between 1957 and 1982. Meadows in the north-west shallows had decreased by 60% since 1977, while seagrasses had been eliminated from depths greater than 2.5 m.

(iii) Beacon to Yacht Club

This area had extensive blanketing of seagrasses by drifts of *Cladophora*. Approximately 5 ha of *P. sinuosa* (75 - 40% cover) had been smothered inshore and around the navigation beacon since 1981 (Fig. 15.2). Elsewhere, a thinning of the seagrass meadows had occurred, and epiphytes were prolific. In 1984 another area of 8 ha, north and inshore of the Yacht Club, supported a heavy matting of *Caulerpa* and *Gracilaria* species covering remnants of *Cladophora* and coralline red algae. *Posidonia* and *Amphibolis* rhizomes were present.

Aerial photographs from 1977 revealed seagrass meadows in this area (and perhaps some macroalgae), whilst earlier photographs show dense seagrass extending into the depths of the basin. Historical accounts and some personal observations indicate that effluent slicks from industries occurred in the area. If effluents rich in nutrients have frequently affected this area, prolific growth of epiphytes would be expected.

(iv) Yacht Club to South Spit

The southern portion of Princess Royal Harbour was divided into two by South Spit. The west (Yacht Club) side was mainly < 1 m in depth. The shoreline at depths < 1 m was colonized largely by P. australis (75 - 40%) and Cystophyllum; the substrate bore very little other algae, and there were few epiphytes. Aerial photographs indicate that the area had undergone little change since 1977.

The deeper fringe (about 0.9 - 1.6 m) carried patchy Amphibolis and P. sinuosa (75 - 40%) with some P. australis. Cladophora was present between the seagrass plants.

(v) Shoal Bay to Geak Point

This large but narrow tract of seagrass had suffered from heavy deposits of Cladophora, resulting from the prevailing winter westerly winds. The 1981 survey revealed a large strip of P. australis (0.3 - 1.5 m depth). This seagrass had a mean biomass of 442 g dry wt m^{-2} which, while less than for Oyster Harbour, was higher than for Cockburn Sound (Cambridge 1979; Table 2).

In 1981 a P. sinuosa meadow grew down to 1.8 m where a drift of Gracilaria, rather than Cladophora, smothered the lower edge of the meadow. By 1984 the

P. sinuosa meadow and much of the P. australis (to 1.3 m deep) had been smothered by deposits of Cladophora (Fig. 15.3: 1981 and 1984). This bank shelves fairly steeply, and a thick Cladophora bed had accumulated at the base (Fig. 19).

North to Geak Point the dead seagrass rhizomes were overlain by prostrate fronds of Caulerpa sp. From 1943 until just before 1981 the seagrass above the 2 m contour in this area appeared to be in good health.

(vi) Geak Point to Bramble Point

This north-east shoreline consisted of inshore P. australis (0.3 - 0.9 m depth) and an outer P. sinuosa meadows to 2.7 m depth. Little detectable change occurred between 1981 and 1984. Cladophora and heavy epiphyte growth occurred in the deeper water. The seagrass was more dense towards the ocean channel.

P. sinuosa collected from midway between these two points had a biomass of 709 g dry wt m^{-2}. This was 25% higher than the highest figures for Oyster Harbour, and some 20% higher than stands in Cockburn Sound (Table 2).

Degradation of the seagrass meadow at > 2.7 m depth had already taken place by 1981; then the seagrass had a density of only 5%.

(vii) Basin

This area, between about 2 and 5 m depth had undergone considerable changes since 1981. The initial survey revealed little or no macroalgae except in the south east (outer Shoal Bay). In 1984 the basin was covered with a thick mat of Cladophora. At 2.0 - 3.5 m the mean depth of the mat was 150 mm (100% cover), and for 3.5 - 5.0 m a mean depth of 50 mm (60% cover).

In 1981, traces of *Amphibolis*, with scattered *Posidonia*, were present throughout the basin to about 4.0 m. All plants were stunted, unhealthy and bore prolific epiphyte growth. Seagrass cover for the basin was less than about 5%. By 1984, only leafless stems of *Amphibolis* remained.

The 1943 and 1957 aerial photographs indicate that, prior to 1957, seagrass were dense at least to 6 or 7 m depths. This conclusion is supported by the subsequent discovery of rhizome material in the basin (Fig. 7). Aerial photographs from 1977 are not sufficiently clear to add further information. From observations made in 1981, the seagrass present prior to 1957 probably consisted of all three species, but with *Amphibolis* most abundant.

Theoretical seagrass distribution

Table 1 summarizes the observations of this study. Seagrasses by 1984 occupied 23.1% of Oyster Harbour and 20.6% of Princess Royal Harbour. The 0.1 m and above inter-tidal zone cannot support seagrass; hence seagrasses by 1984 occupied 40.0% and 28.8% respectively of the area of the basins which might be available for colonization by these plants (Table 3). Depths greater than 5.0 m now carry no seagrasses except at the mouth to King George Sound.

Using McKenzie's 1962 data for Oyster Harbour, where he mapped seagrass down to 5.5 m, and assuming seagrass could grow to the same depth in Princess Royal Harbour, we have a crude estimate of the area which may once have supported seagrass, as 74.4% of Oyster Harbour and 83.9% of Princess Royal Harbour, calculated as a percentage of the total area of each harbour greater than 0.1 m and less than 5.5 m (Table 3; Fig. 7). Thus, the degradation of seagrass from 1962 to 1984 may be calculated as follows:

Oyster Harbour, from 74.4 down to 40.0% of the area, representing a reduction in seagrass of 46.2% and Princess Royal Harbour from 83.9 down to 28.8%, representing a reduction of 66.2% (Table 3).

The figures calculated for the estimated extent of seagrass in Princess Royal Harbour using the 5.5 m contour as the limit (assumed from McKenzie 1962 and supported by 1943, 1957 aerial photographs) is considered an underestimate as, in the present work, rhizomes were located down to 6-7 m. Even though no continuous data are available for light, Atkins et al. (1980) gave average Secchi disc readings to show that light penetrated to 3 - 4 m in 1980. In Oyster Harbour light penetrates to only about half this depth; on all sampling days, the bottom at a depth of 4 - 5 m in Princess Royal Harbour was clearly visible from the surface using a face-mask, whereas in Oyster Harbour the corresponding depth was only 1.6 - 2 m.

One may conclude that at the time when the basin of Oyster Harbour was covered in seagrass to 5 m depth, the water must have been considerably less turbid.

DISCUSSION

The reduction in area of Posidonia meadows in the two harbours was minimal until 1962. The rate of loss apparently increased in the late 1970's and again after 1981. Most of the degradation in Oyster Harbour seems to have occurred since about 1981, whereas in Princess Royal Harbour, it had already occurred by 1981.

The 1984 seagrass distributions may be summarized as follows:

(1) P. australis was found in the range of 0.3 to 2.0 m depth (optimum 0.5 - 0.8 m) in Oyster Harbour. In Princess Royal Harbour the range was 0.3 - 1.8 m depth (optimum 0.5 - 1.3 m).

(2) P. sinuosa occurred at depths of 1.0 to 2.4 m in Oyster Harbour (optimum 1.2 - 1.9 m), and in Princess Royal Harbour the range was 1.2 - 2.7 m depth (optimum 1.2 - 2.1 m).

(3) Amphibolis occurred prior to 1981 in depths of 2.2 to about 7 m in both harbours, but in 1984 was found mainly in the shallow fringe (0.5 - 1.5 m depth) of Princess Royal Harbour. A narrow belt remained in Oyster Harbour from 1.8 to 4.5 m depth.

The depths at which seagrasses can grow are becoming less in both harbours (Figs 14 and 15). McKenzie (1962), in mapping the seagrass distribution in Oyster Harbour, noted that Posidonia was less dense in the brackish zones. Even though seagrass grew down to 5.5 m, he found Posidonia density differed either side of the 3.7 m contour, with the lower slope being less dense. Now the absolute lower limit is in much shallower water (at about 2.8 m).

There is no significant relationship between percentage cover and biomass for either system. Plant height, leaf width and number vary considerably. Variation is apparently influenced by proximity to channels and rivers, depth, sedimentation and salinity variation.

One of the most likely causes of seagrass degradation since 1981 has been the proliferation of Cladophora. Accumulations of this species are probably a major threat to the seagrass beds, as smothering has occurred on a large scale. More importantly, the accumulations appear to be destroying the fringing meadows which have the highest biomass, and are likely to persist when meadows at greater depth have died out. In addition, these macroalgal accumulations may prevent re-colonization by seagrasses.

Water quality may be expected to deteriorate as algal and seagrass beds decay, releasing nutrients, and allowing resuspension of detrital material and unprotected sediment through wind-driven water movement. These changes may well result in increased phytoplankton and epiphyte production. Strong indications that some of these processes are already occurring were noted in the form of "black ooze" accumulations over the large shell flats in both harbours. In addition, much of the fringing banks' sediment is easily stirred through wind driven water movement. Cladophora has also been seen to cover large areas of shell flats (Katalesia, Mytilus). By January 1984 Cladophora (Figs 10 and 13) occupied all substrate between 2 m and 5 m in Princess Royal Harbour, and between 1.5 m and 4.5 m in Oyster Harbour. Cladophora was found only south of the Kalgan River channel suggesting that it is a marine species. The onset of winter winds may result in increased accumulation of weed on the fringing banks.

Accumulations of other macroalgal species in both harbours were observed in the 1981 survey. The eastern edge of Princess Royal Harbour had an accumulation of Gracilaria and other red algae. The macroalgal blooms prior to 1981, described by local residents and fishermen, may have been responsible for much loss of seagrass along the eastern shore of Oyster Harbour during and before 1981. This area is a continuation of the Kalgan banks and the south-east banks, which support an exceptionally high biomass of seagrass. The degradation of this large tract of seagrass prior to 1981 was almost certainly not caused by a reduction in light penetration through the water column as the meadow was on a relatively shallow (0.3 to 2 m) bank and neighbouring meadows remained unaffected.

Another important factor which may result in seagrass degradation is the presence of epiphytes. These reduce light levels reaching the seagrass and hence reduce photosynthesis. The impact of epiphytes in Oyster Harbur was probably unimportant compared with their influence in Princess Royal Harbour. Epiphyte density in Princess Royal Harbour appeared to increase rapidly at depths between 1 and 2 m. The 1981 survey revealed a very sparse meadow of seagrass (1 - 4% cover) in the basin (2 - 5 m depth), which was not present three years later (Table 1). Before 1981, this area of between 5 km^2 and 8 km^2 appeared to consist of a reasonably dense seagrass meadow (75 - 40% cover), as seen, both from extensive rhizome mats and the 1945 and 1957 aerial photographs. Macroalgae were not found in 1981, and water transparency would appear to have been moderately clear (Atkins et al. 1980). The increased abundance of epiphytes in Princess Royal Harbour may be attributed both to industrial effluents and terrestrial run off (Atkins et al. 1980). Nutrient levels from these sources were found to be above background which may be significant because .pa there is limited exchange with the ocean. Agricultural run-off may well be the only significant source of nutrients to Oyster Harbour, though no data are available.

These results can be compared with data for Cockburn Sound and Peel Inlet. Cockburn Sound is a marine embayment without marked freshwater inflow, and consequently has a relatively constant salinity (34 - 36 $^{o}/oo$ annually). In Cockburn Sound, epiphyte growth has been a major factor in seagrass decline (Cambridge 1979, Silberstein 1980), 1981 observations suggest a parallel with Princess Royal Harbour. On the other hand, Peel Inlet, as with Oyster Harbour is estuarine, with river inflow and marked seasonal changes in salinity (9 - 32 $^{o}/oo$ in Oyster Harbour, 5 - 40 $^{o}/oo$ in Peel Inlet). In both, massive accumulations of macroalgae, including Cladophora, occur which cover seagrasses. The changes in algal growth in all systems may be attributed to increased nutrient loading.

So far, the discussion has been centred on the two most probable agents (epiphytes and macroalgae) that have lead to seagrass decline. There are other possible factors. To date, there is no evidence of disease, although sampling has been carried out intensively only over two periods in mid-summer in different years. There is, however, no known disease which might affect such a diverse assemblage of seagrasses.

Increased grazing is also a possible factor in the decline of seagrasses. The only obvious sign of grazing was in Oyster Harbour, by the urchin Temnapleurus michaelsenii (1984). Sea urchins were abundant and large numbers of tests were found on the shoreline south of the Kalgan Bridge. Sea urchins were noted only on relatively thinned Posidonia meadows by .pa Cambridge (1979), who concluded that urchin grazing may be a secondary cause of deterioration of already thinned seagrass. Such grazing may also prevent seagrass re-colonization.

Water clarity has been shown to be greater in Princess Royal Harbour than in Oyster Harbour. River water containing sediment contributes to the turbidity of the latter. Of significance in the 1943 photographs were the dense seagrass meadows extending some distance into the Kalgan River channel, an area which is now constantly turbid and devoid of seagrass. Aerial photographs since 1943 show reduced penetration through the water in both harbours and suggest reduced water clarity over time. Increased turbidity and hence insufficient light reaching the seagrass was unlikely to be the main cause of the decline. On the contrary the loss of seagrass has probably lead to an increase in turbidity through wind and wave action.

SUMMARY

Two major conclusions may be drawn from this study:

(1) Seagrasses within both harbours have been reduced in area, and to a lesser extent, in density.

- (a) In Princess Royal Harbour, a significant reduction occurred over the three years 1981 to 1984, but there was considerable evidence that a very large reduction had occurred before 1981.
- (b) In comparison, Oyster Harbour suffered a greater reduction in seagrass area over the three years 1981 to 1984.

A thinning in density of seagrass meadows was recorded, particularly in Oyster Harbour and towards the deeper limits of these meadows.

(2) There was considerably increased growth of algae in both harbours, which had a marked effect on the seagrass meadows.

- (a) Unattached macroalgae appeared to have increased markedly since 1981, and were seen to cover seagrass meadows particularly on the periphery of the shallow flats in both harbours. Before 1981, only Princess Royal Harbour contained unattached algae.
- (b) In Princess Royal Harbour, heavy epiphyte growth had reduced light available to seagrasses, whereas Oyster Harbour seemed relatively free of epiphytes. There were, however, no data available on the seasonality of epiphytes.
- (c) Field observations indicated that increased abundance of macroalgae and epiphytes would have affected seagrasses to a greater extent than increased turbidity in the water column since 1981.

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REFERENCES

Atkins, R.P., Iveson, J.B., Field, R.A. and Parker, I.N. (1980). A technical report on the water quality of Princess Royal Harbour, Albany. Bulletin No. 74 (Western Australian Department of Conservation and Environment, Perth). 67pp.

Cambridge, M.L. (1979). Cockburn Sound Environmental Study, Technical Report on seagrass. Technical Report No. 7 (Western Australian Department of Conservation and Environmental, Perth). 100pp.

Cambridge, M.L. and McComb, A.J. (1984). The loss of seagrasses in Cockburn Sound, Western Australia. I. The time course and magnitude of seagrass decline in relation to industrial development. Aquatic Botany 20:229-243.

Cambridge, M.L., Chiffings, A.W., Brittain, C., Moore, L. and McComb, A.J. (1986). The loss of seagrasses in Cockburn Sound, Western Australia. II. Possible causes of seagrass decline. Aquatic Botany (in press).

McKenzie, K.G. (1962). Oyster Harbour : A marginal marine environment. (Unpublished PhD thesis, University of Western Australia, Nedlands). 247pp.

Orth R.J. and Moore K.A. (1983). Submerged vascular plants : Techniques for analyzing their distribution and abundance. Marine Technology Society Journal 7(2),38-52.

Silberstein K. (1980). The effects of epiphytes on seagrass, (Unpublished MSc preliminary thesis, University of Western Australia, Nedlands). 97pp.

Silberstein, K. (1985). The effects of epiphytes on seagrasses in Cockburn Sound. Bulletin No. 135 (Western Australian Department of Conservation and Environment, Perth). 63pp.

Silberstein, K., Chiffings, A.W. and McComb, A.J. (1986). The loss of seagrasses in Cockburn Sound, Western Australia. III. The effect of epiphytes on productivity of Posidonia australis Hook. F. Aquatic Botany (in press).

Lands and Survey Department, aerial photographs:

W.A.477 Feb. 1943 Redmond Run 8 + 9 16000

W.A.480 Dec. 1943 Albany Run 1 + 10 16000

W.A.330 May 1957 Albany Run 3 + 4 7920

W.A.388 Nov. 1957 Redmond Run 9(5314-52) 7920

W.A. July 1977 Albany Run 16(5318-24) 1:25,000

W.A. July 1977 Albany Run 17(5325-33) 1:25,000

W.A.2036 Feb. 1982 - (5486-89) 1:25,000

W.A.2038 Feb. 1982 - (5034-39) 1:25,000

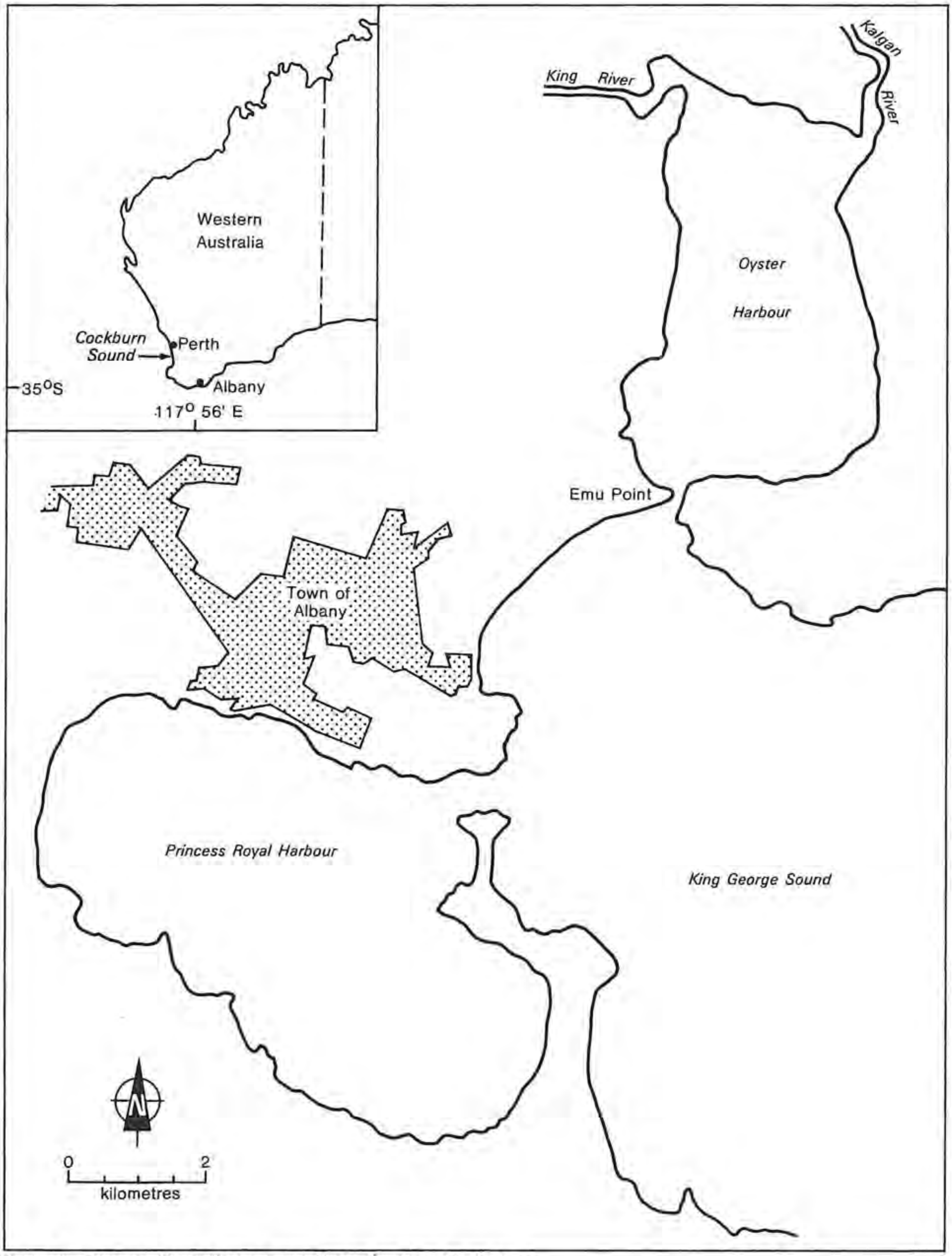

Figure 1 Princess Royal Harbour and Oyster Harbour Study Area.

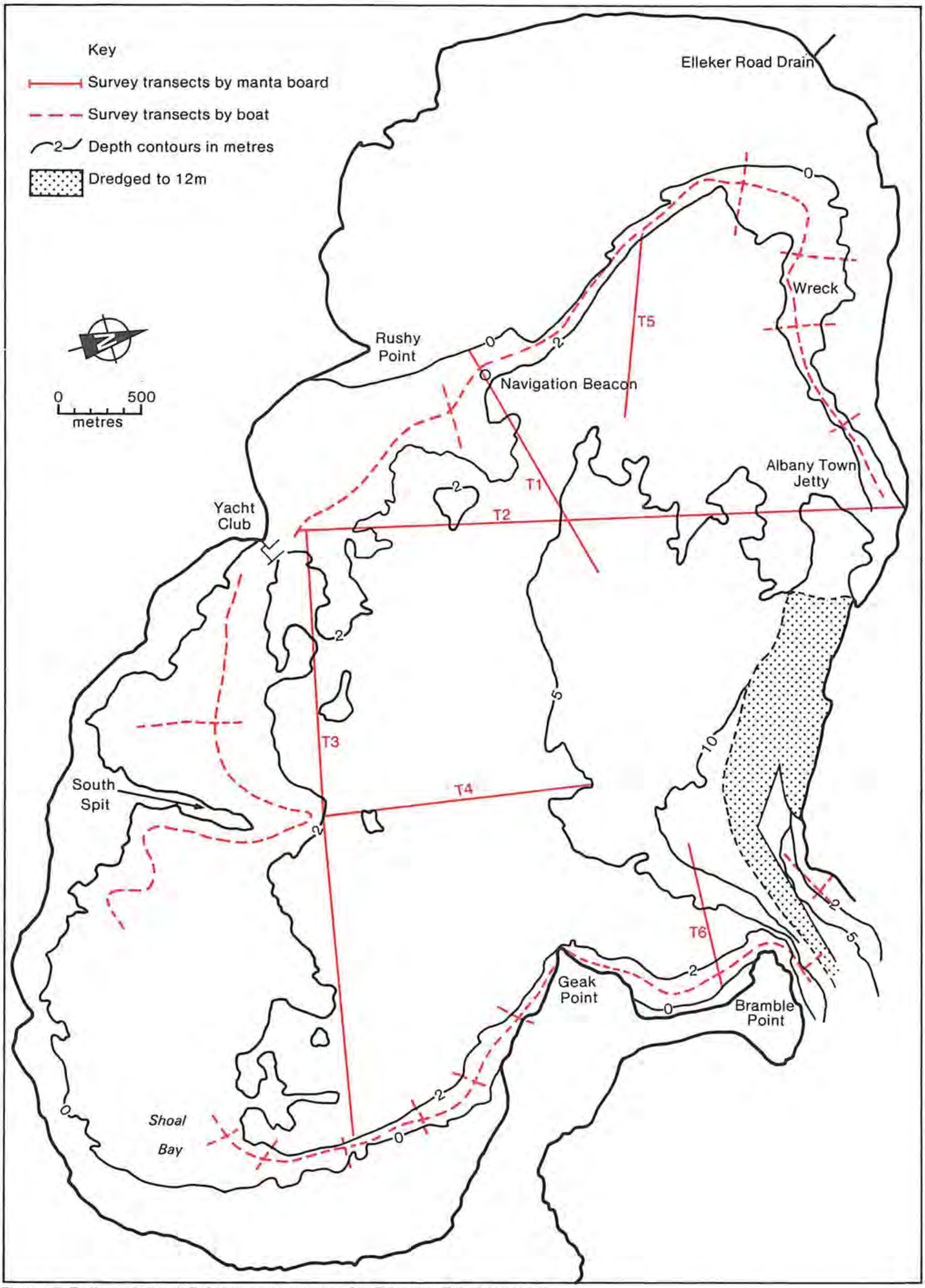

Figure 2 Bathymetry and field survey transects for Princess Royal Harbour.

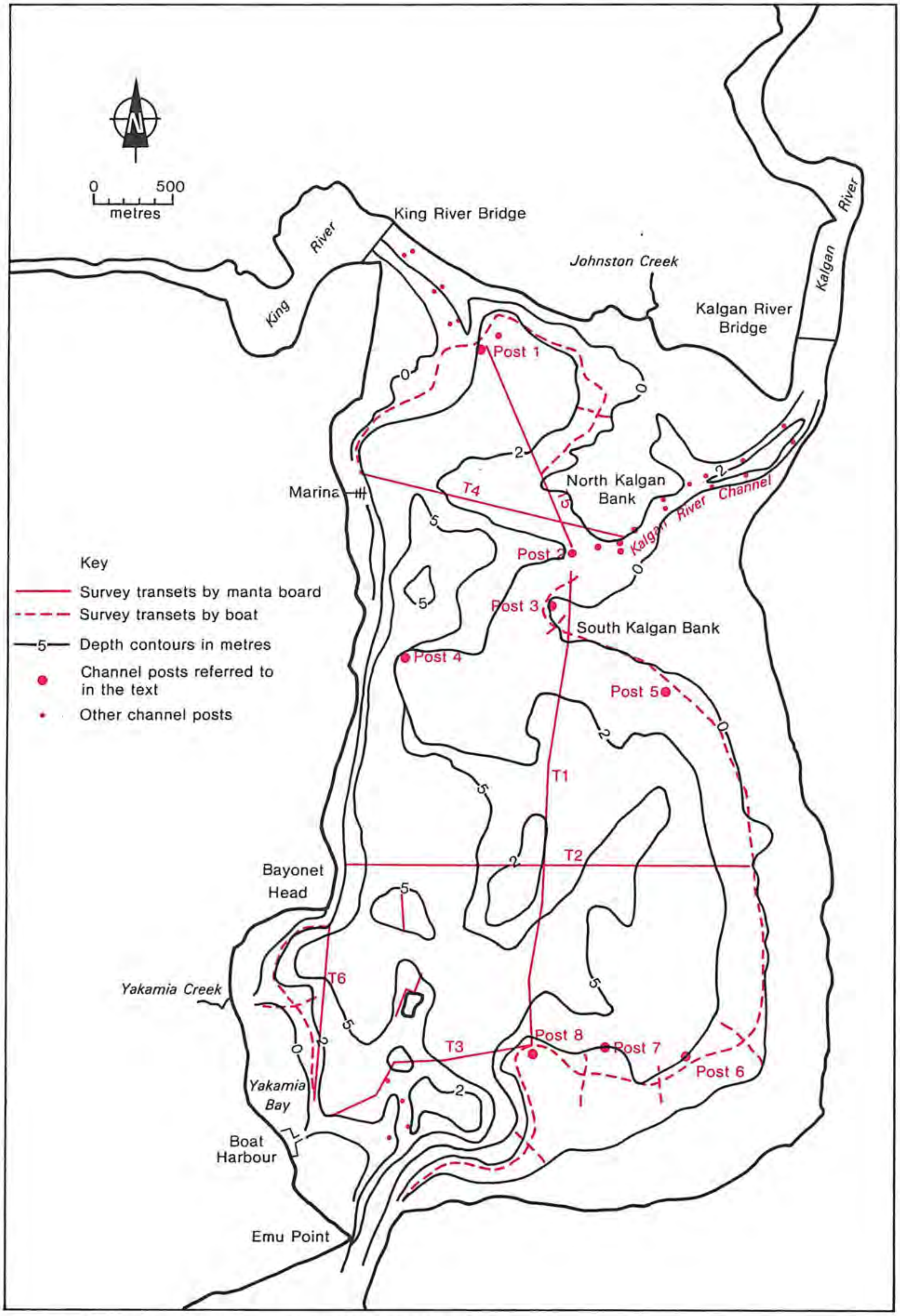

Figure 3 Bathymetry and field survey transects for Oyster Harbour.

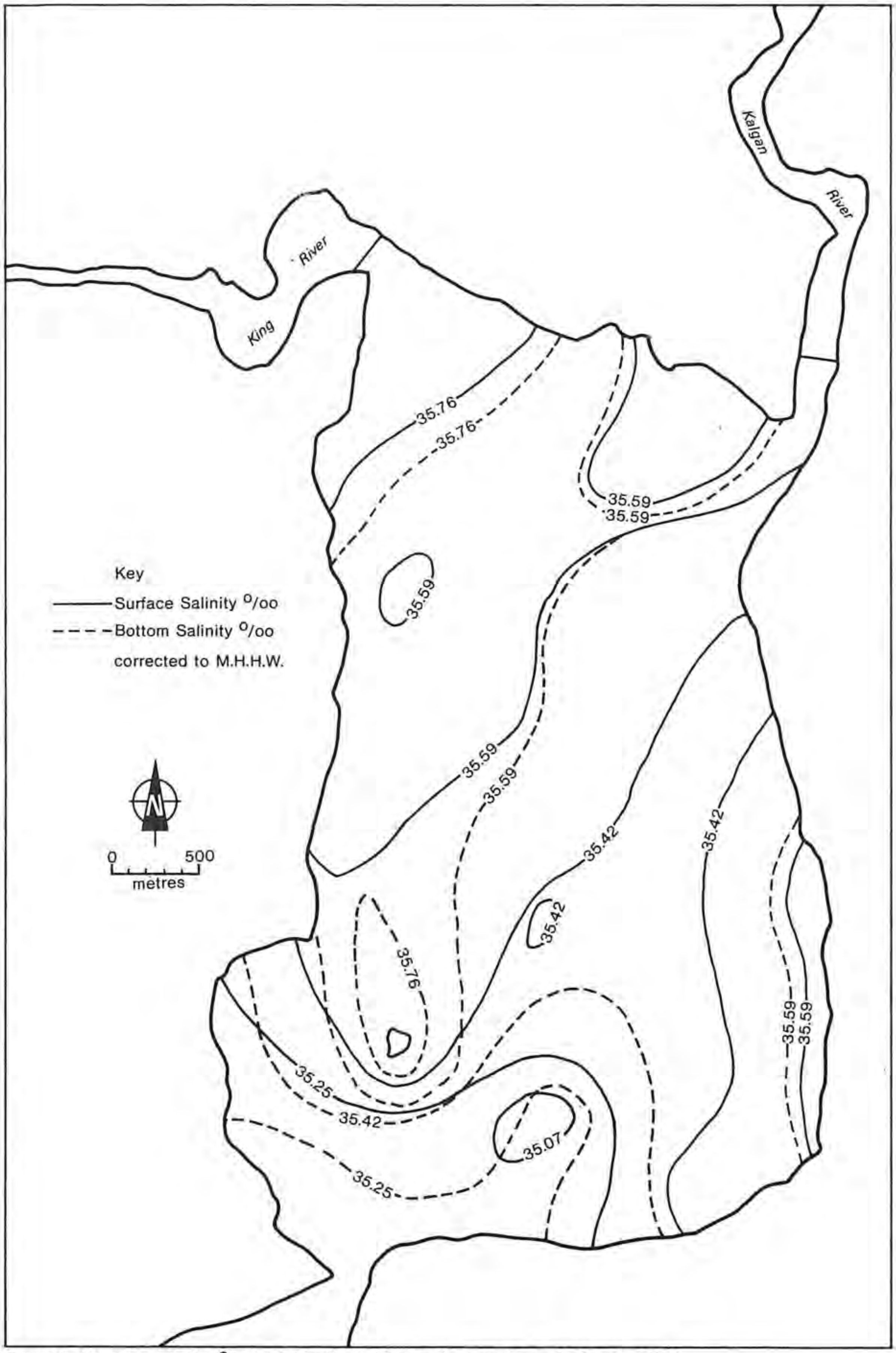

Figure 4 Summer salinity (⁰/oo) distribution in Oyster Harbour (From McKenzie 1962).

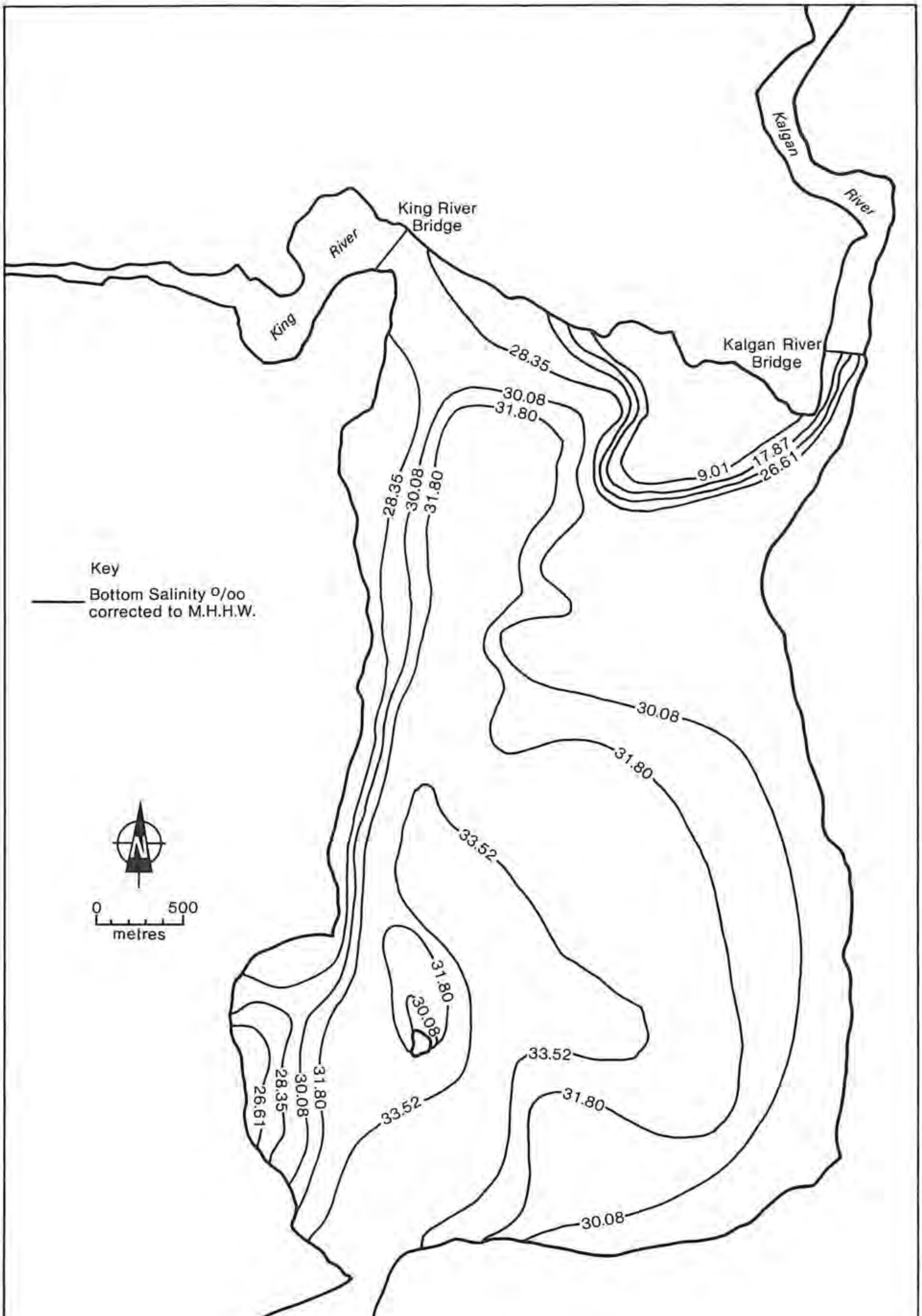

Figure 5: Winter salinity (°/oo) distribution in Oyster Harbour (From McKenzie 1962).

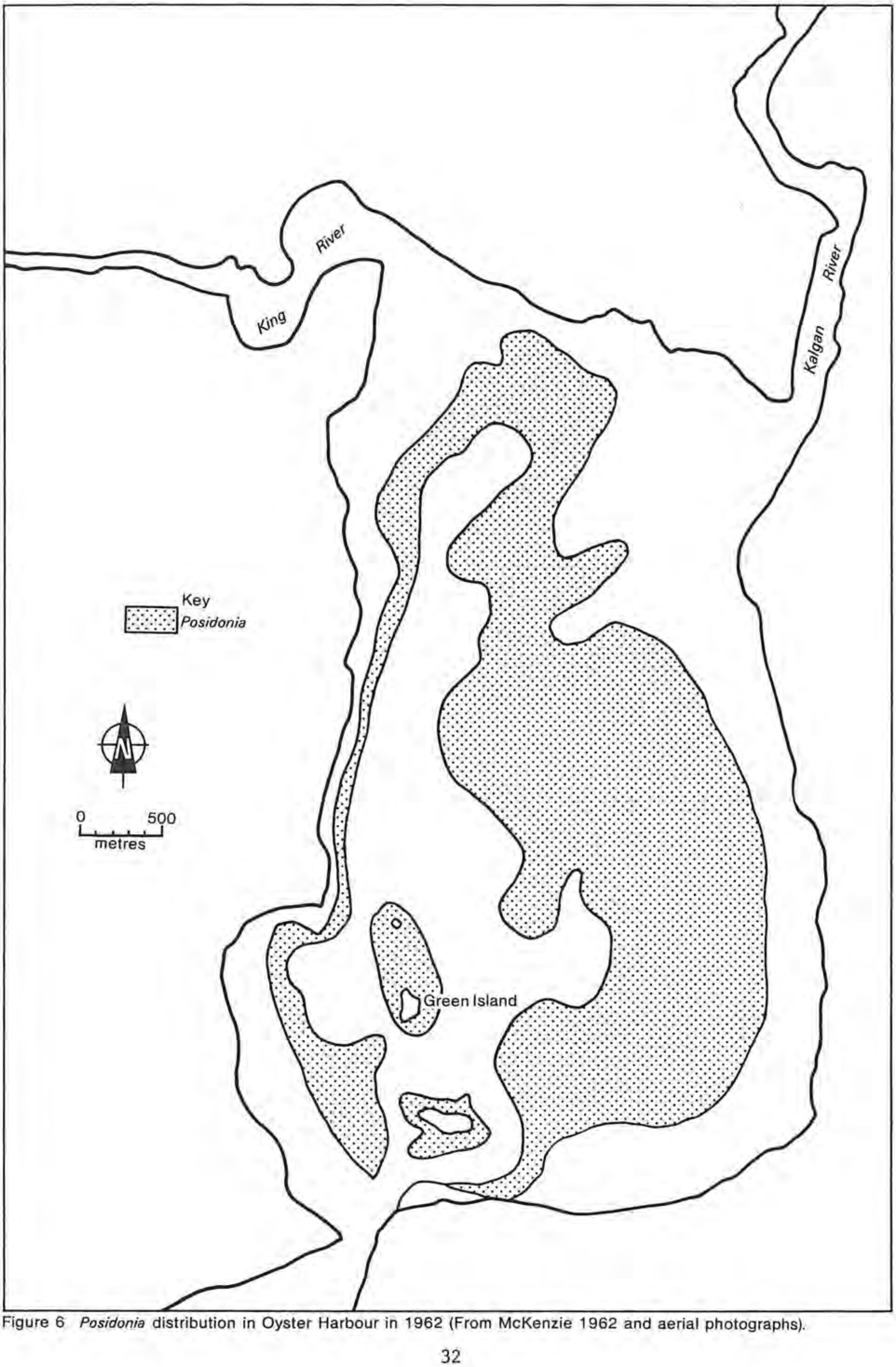

Figure 6 *Posidonia* distribution in Oyster Harbour in 1962 (From McKenzie 1962 and aerial photographs).

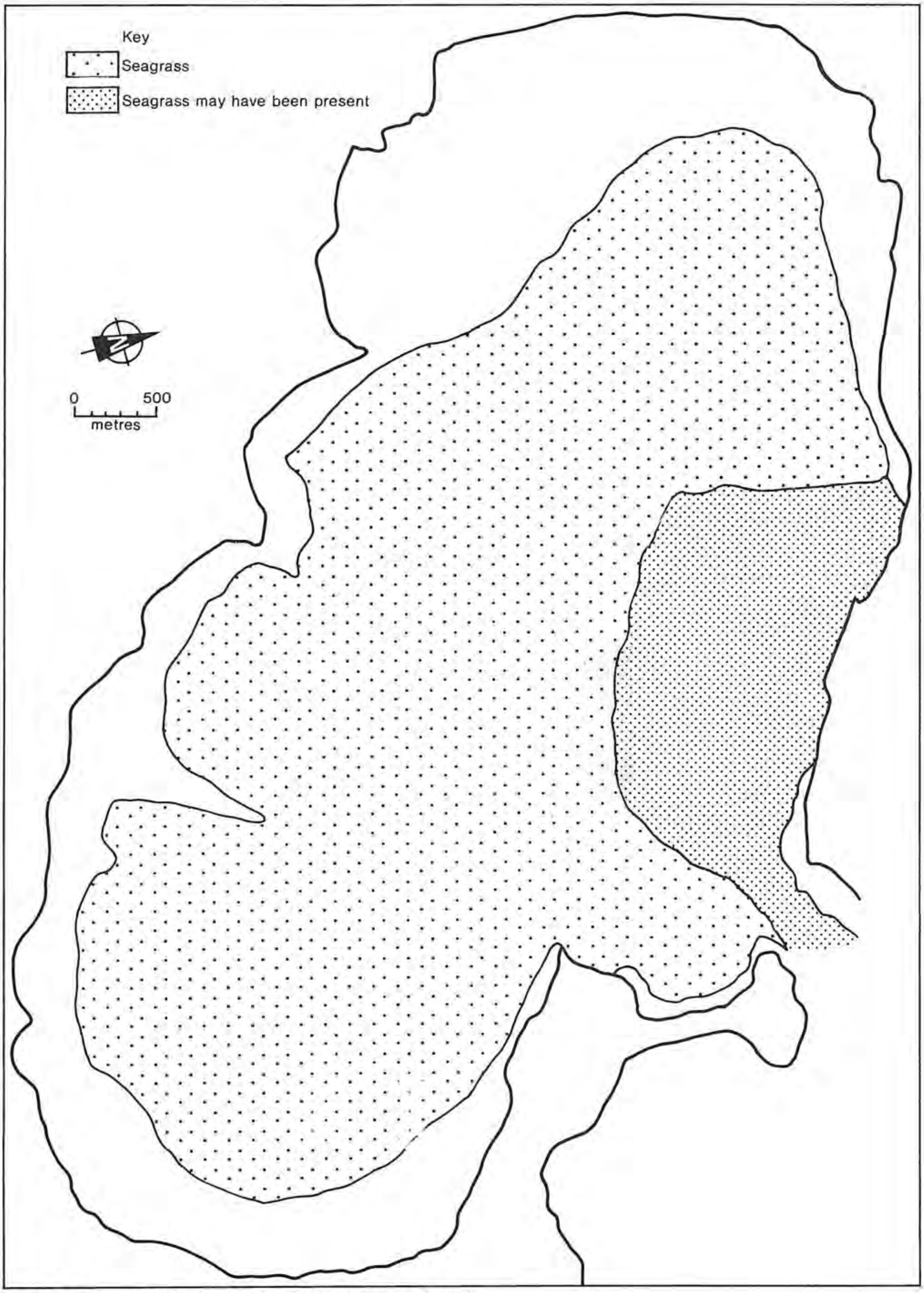

Figure 7 Seagrass distribution in Princess Royal Harbour in 1962
(Compiled from aerial photographs, evidence of rhizomes and Mckenzie 1962).

Key for Figures 8, 9, 11 and 12

Posidonia australis (seagrass) cover	*Posidonia sinuosa* (seagrass) cover	*Amphibolis griffithii (seagrass)* cover
100 - 75%	100 - 75%	100 - 75%
75 - 45%	75 - 45%	75 - 45%
45 - 15%	45 - 15%	45 - 15%
<15%	<15%	<15%

Cladophora (macroalga)

Epiphytes growing on *P sinuosa and A. griffithii*

0.5 m plant height

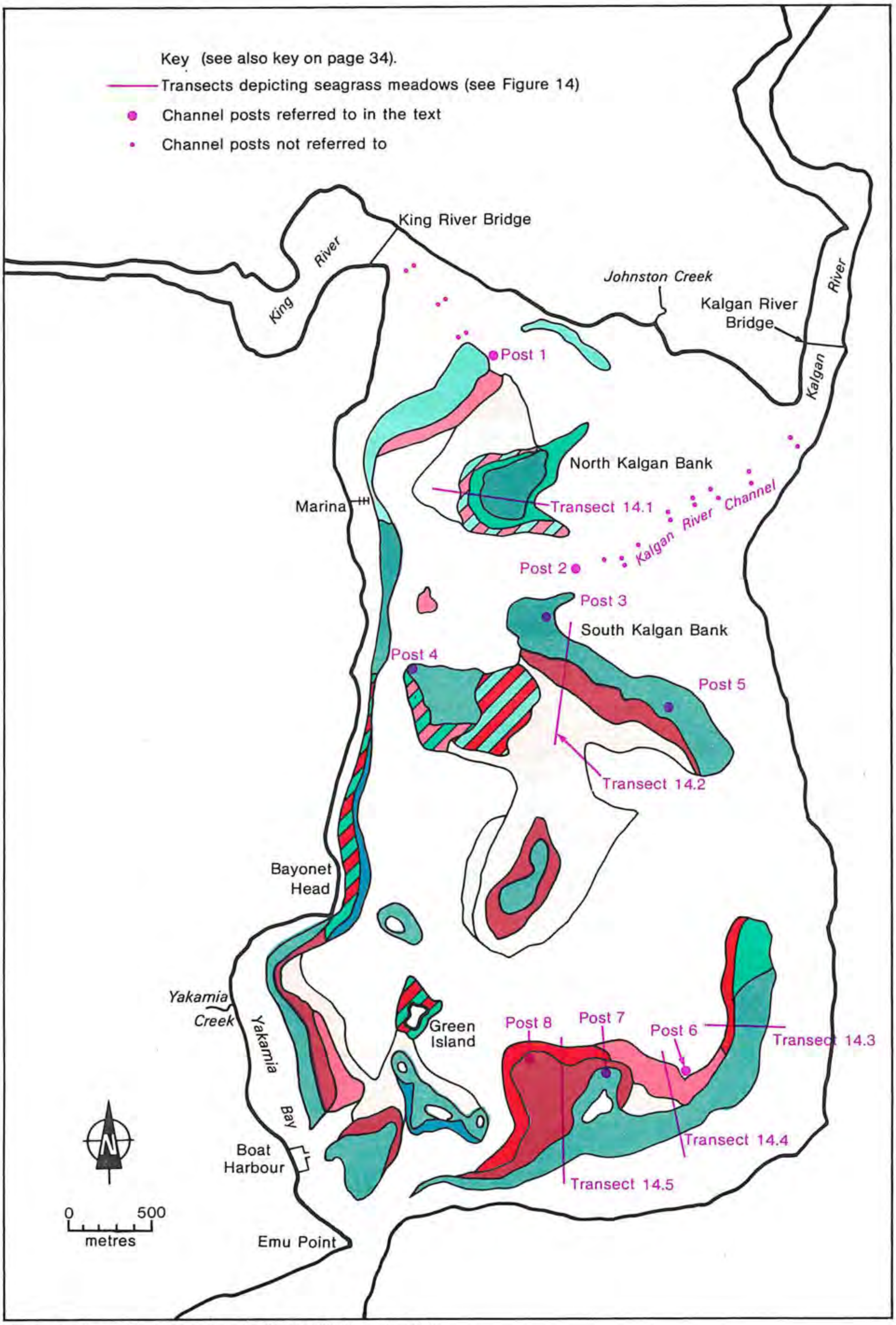

Figure 8 Seagrass distribution in Oyster Harbour in 1981.

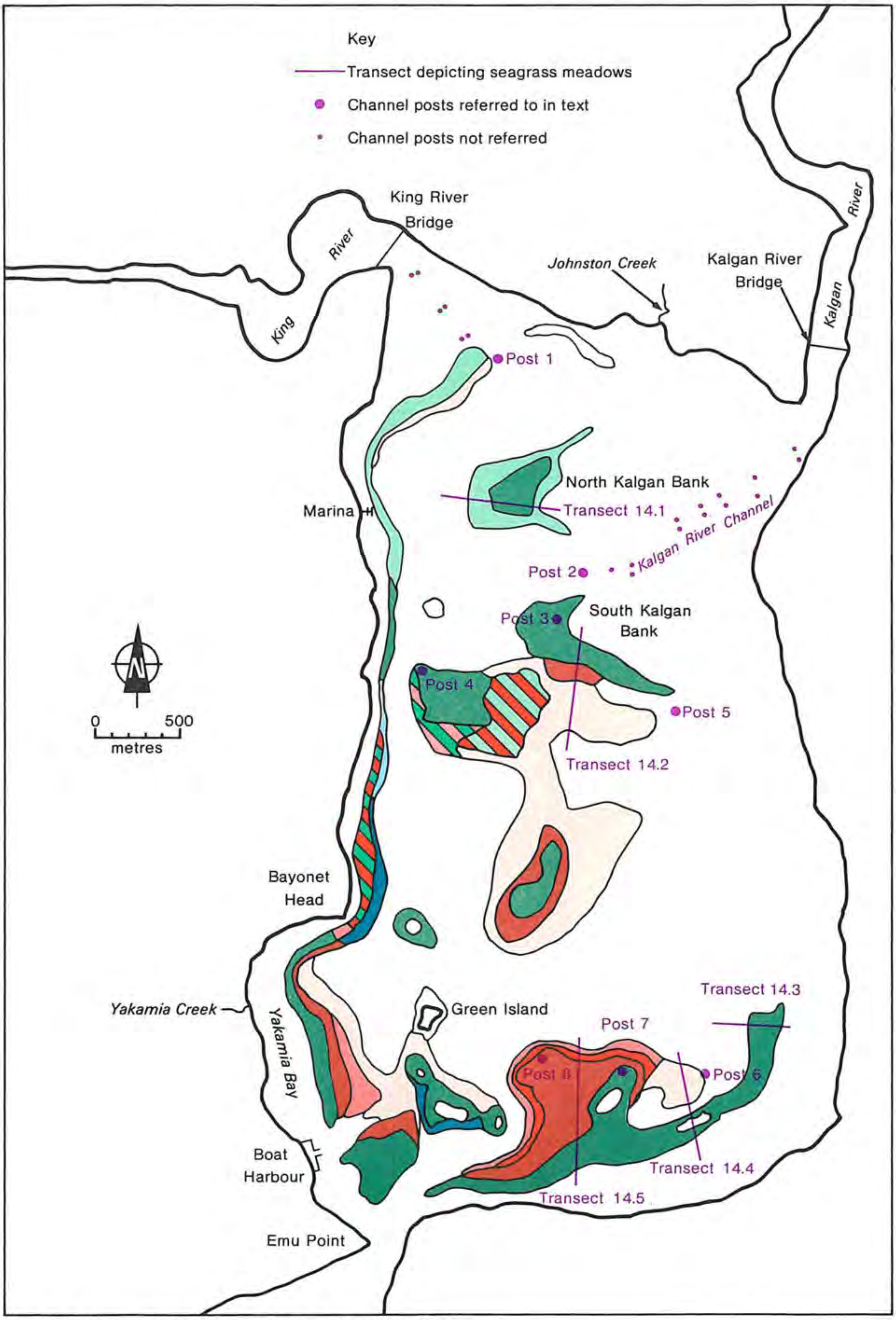

Figure 9 Seagrass distribution in Oyster Harbour in 1984.

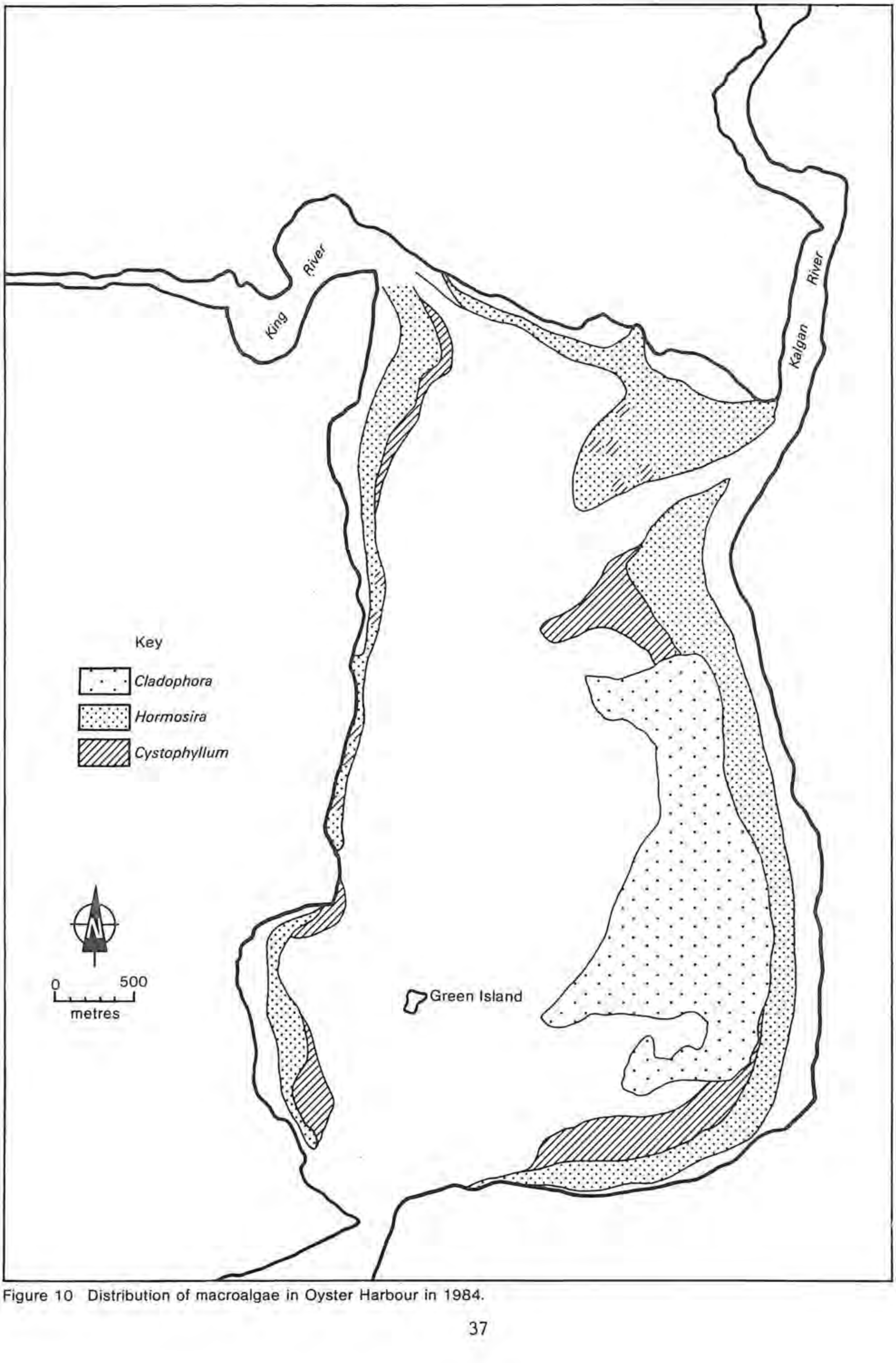

Figure 10 Distribution of macroalgae in Oyster Harbour in 1984.

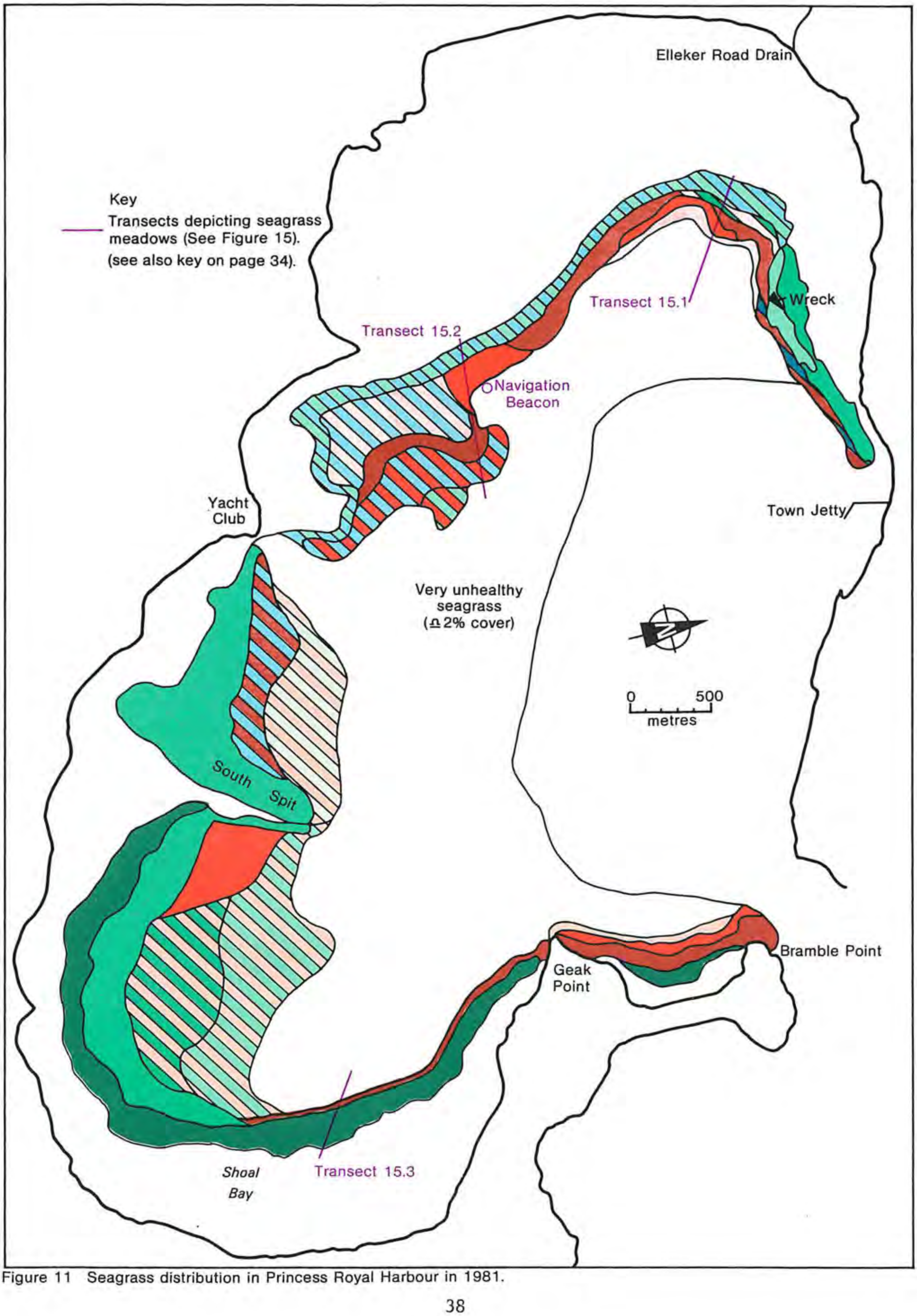

Figure 11 Seagrass distribution in Princess Royal Harbour in 1981.

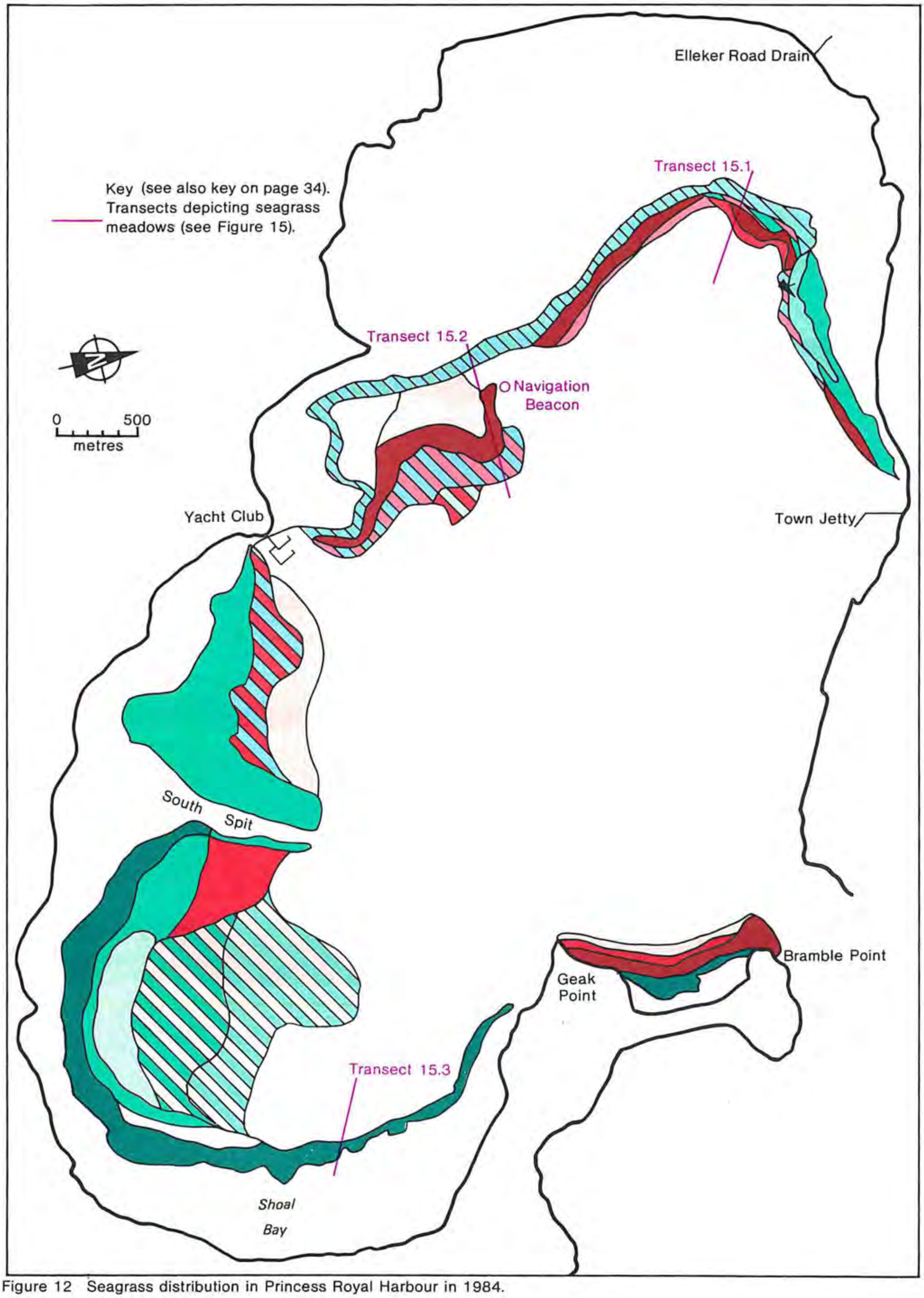

Figure 12 Seagrass distribution in Princess Royal Harbour in 1984.

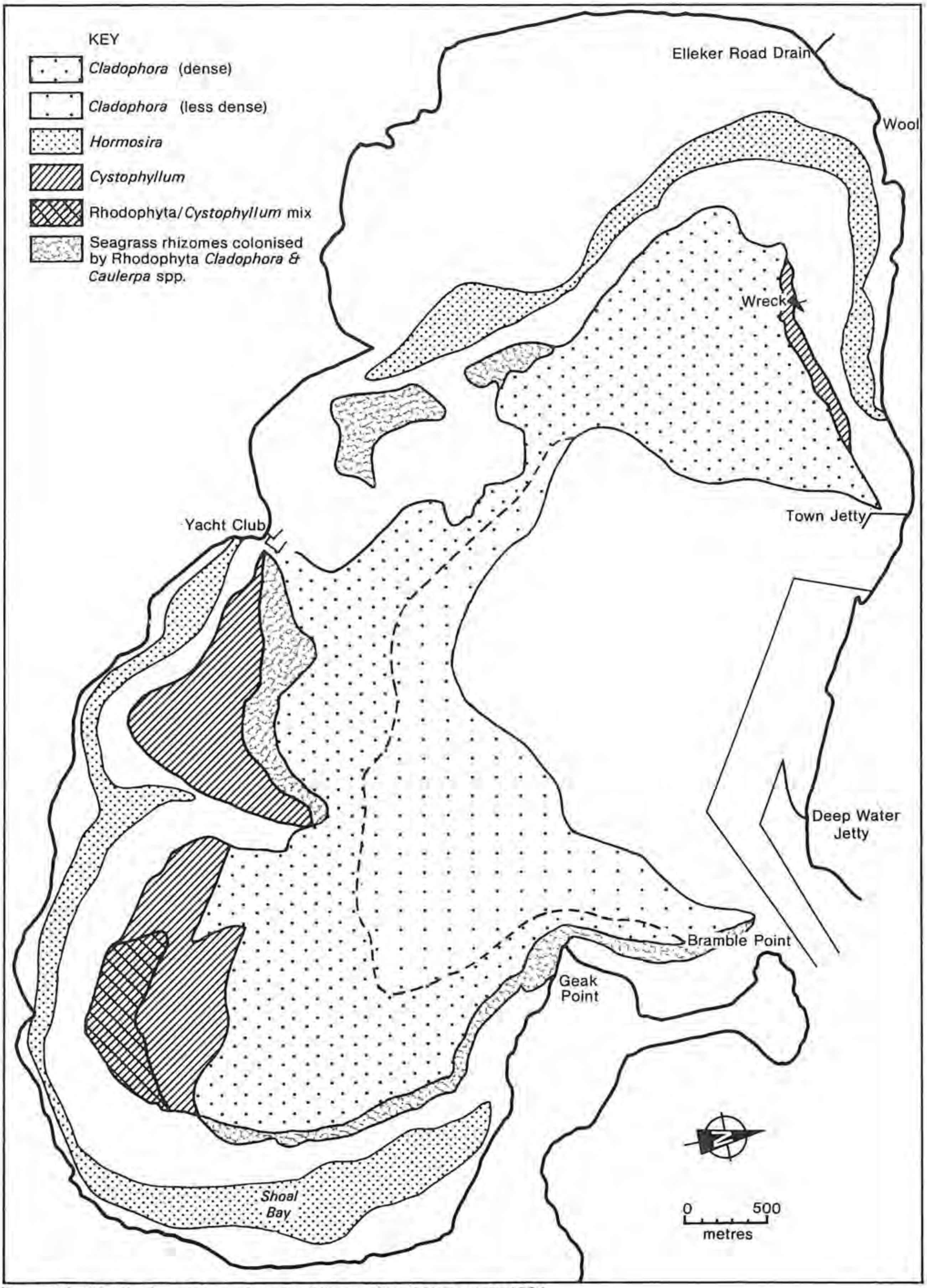

Figure 13 Distribution of macroalgae in Princess Royal Harbour in 1984.

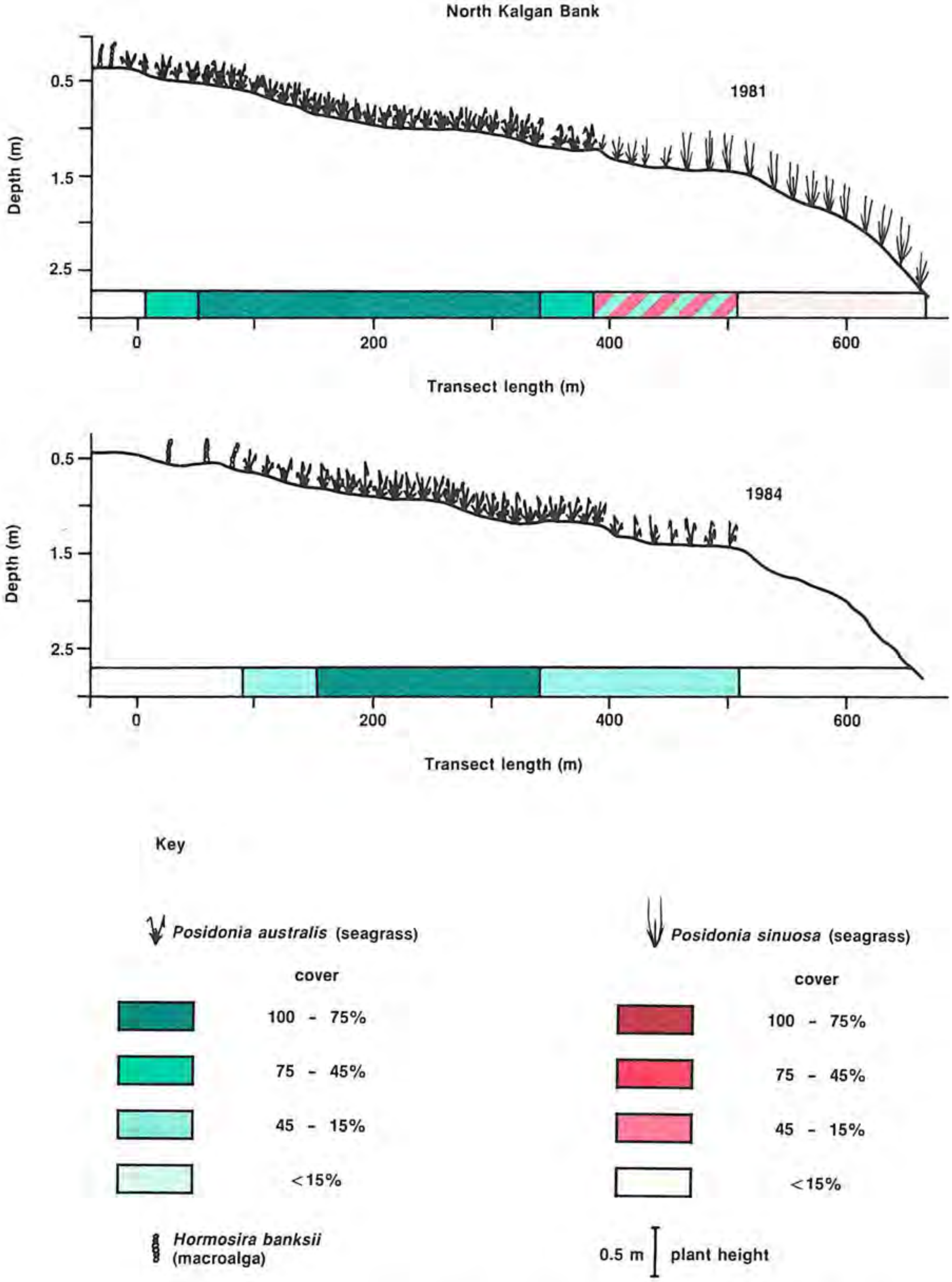

Figure 14.1 Cross section diagram of transect surveyed in 1981 and 1984 in Oyster Harbour. (Locations are shown in Figures 8 and 9.)

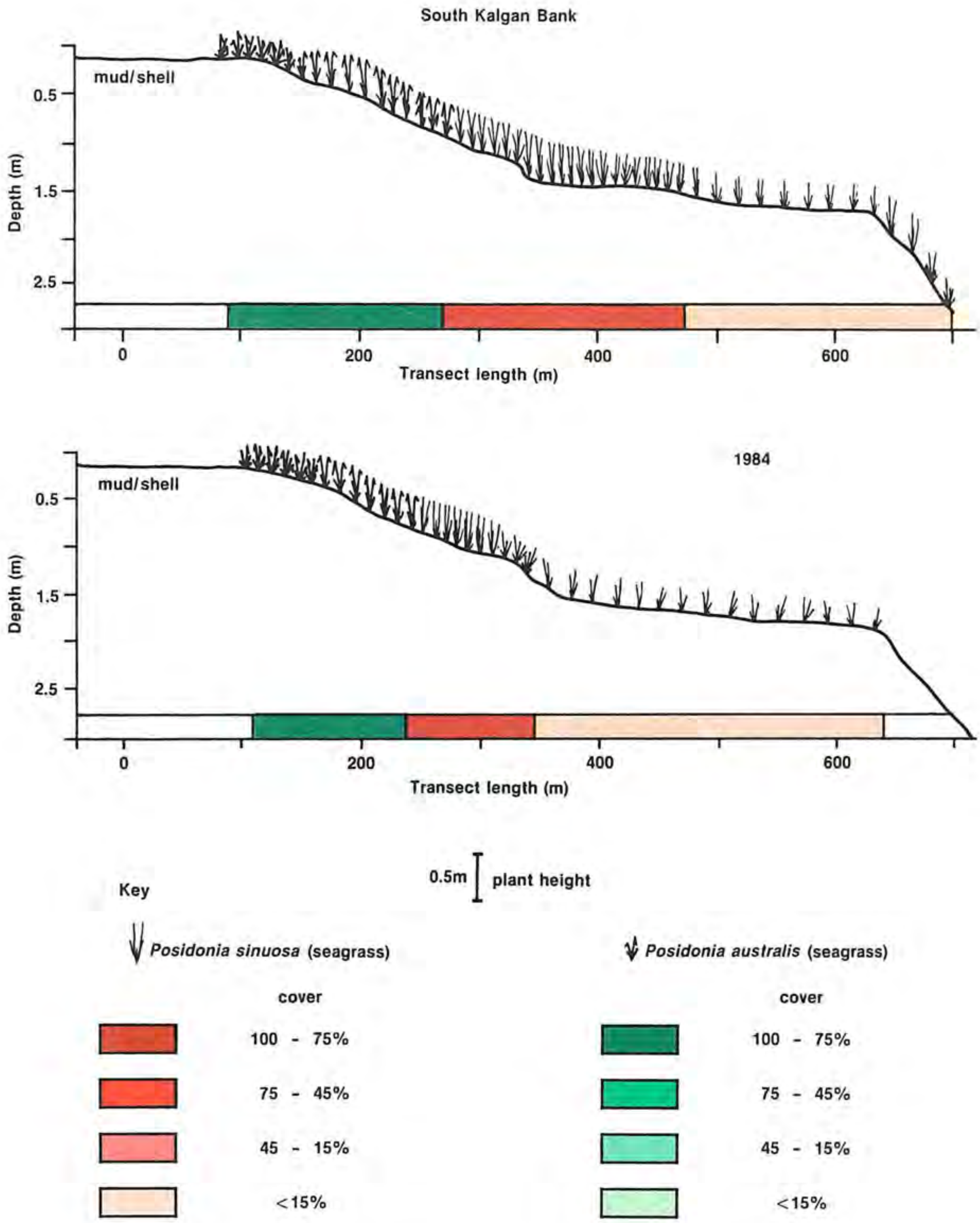

Figure 14.2 Cross section diagram of transect surveyed in 1981 and 1984 in Oyster Harbour. (Locations are shown in Figures 8 and 9.)

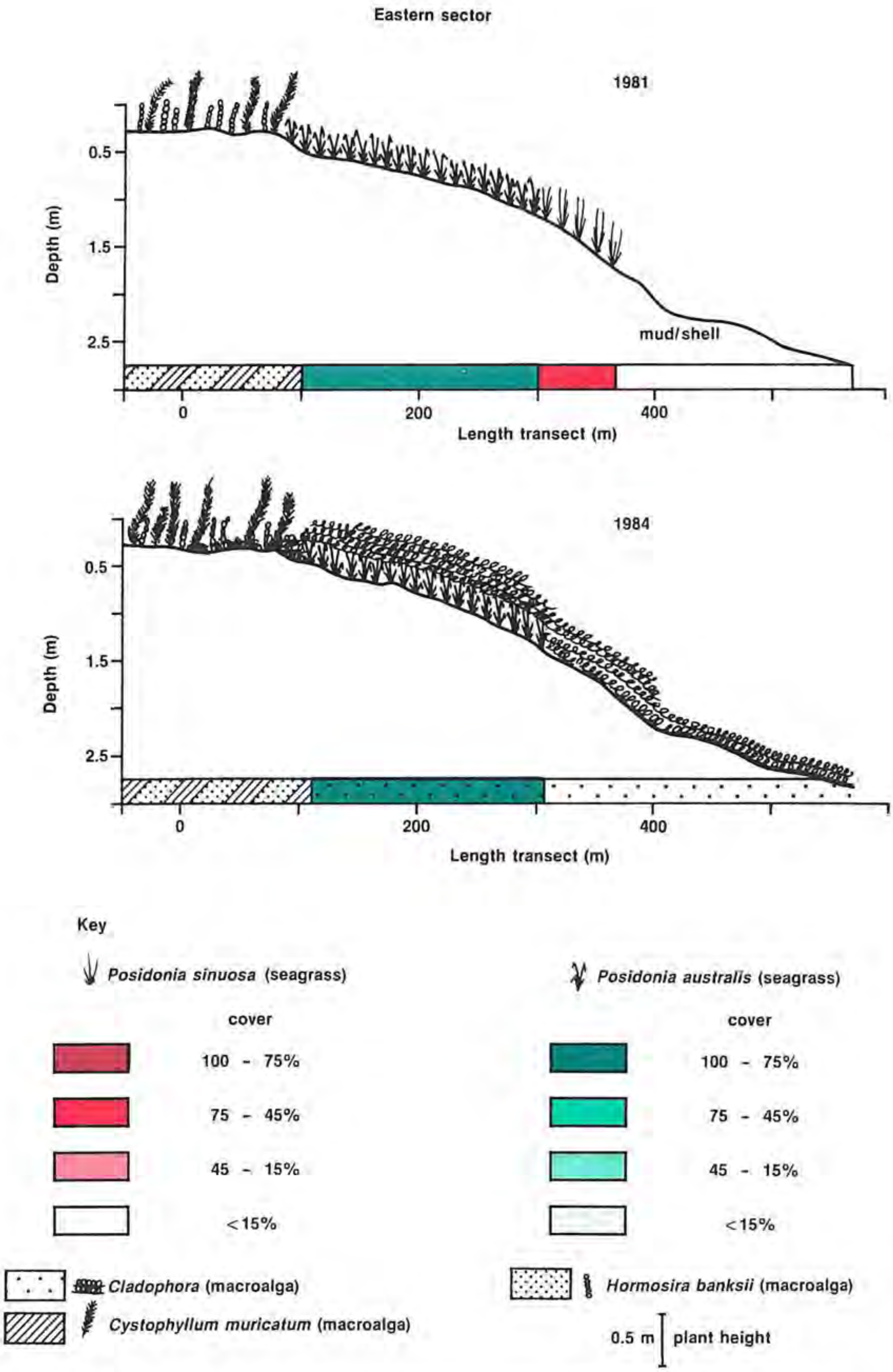

Figure 14.3 Cross section diagram of transect surveyed in 1981 and 1984 in Oyster Harbour. (Locations are shown in Figures 8 and 9.)

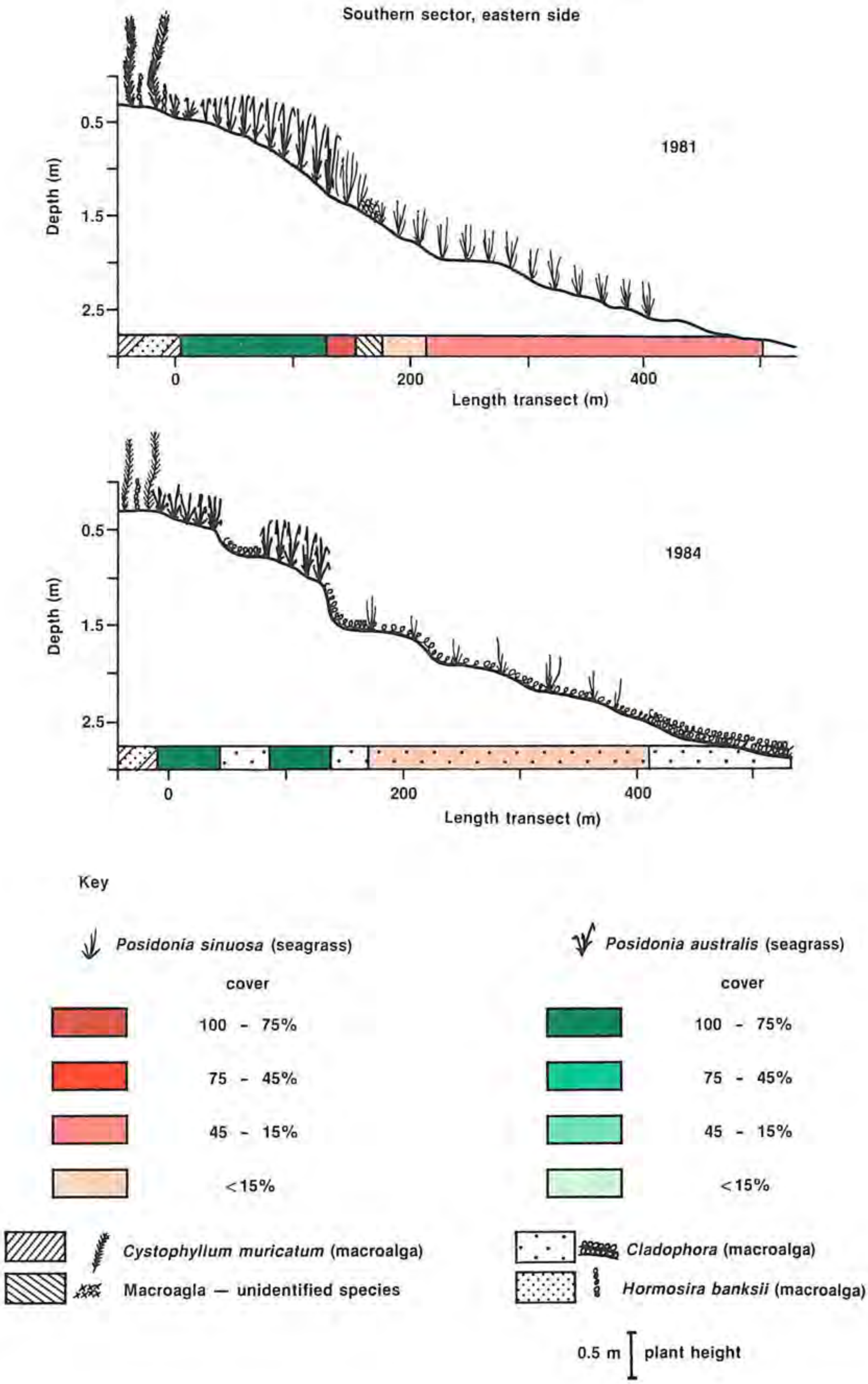

Figure 14.4 Cross section diagram of transect surveyed in 1981 and 1984 in Oyster Harbour. (Locations are shown in Figures 8 and 9.)

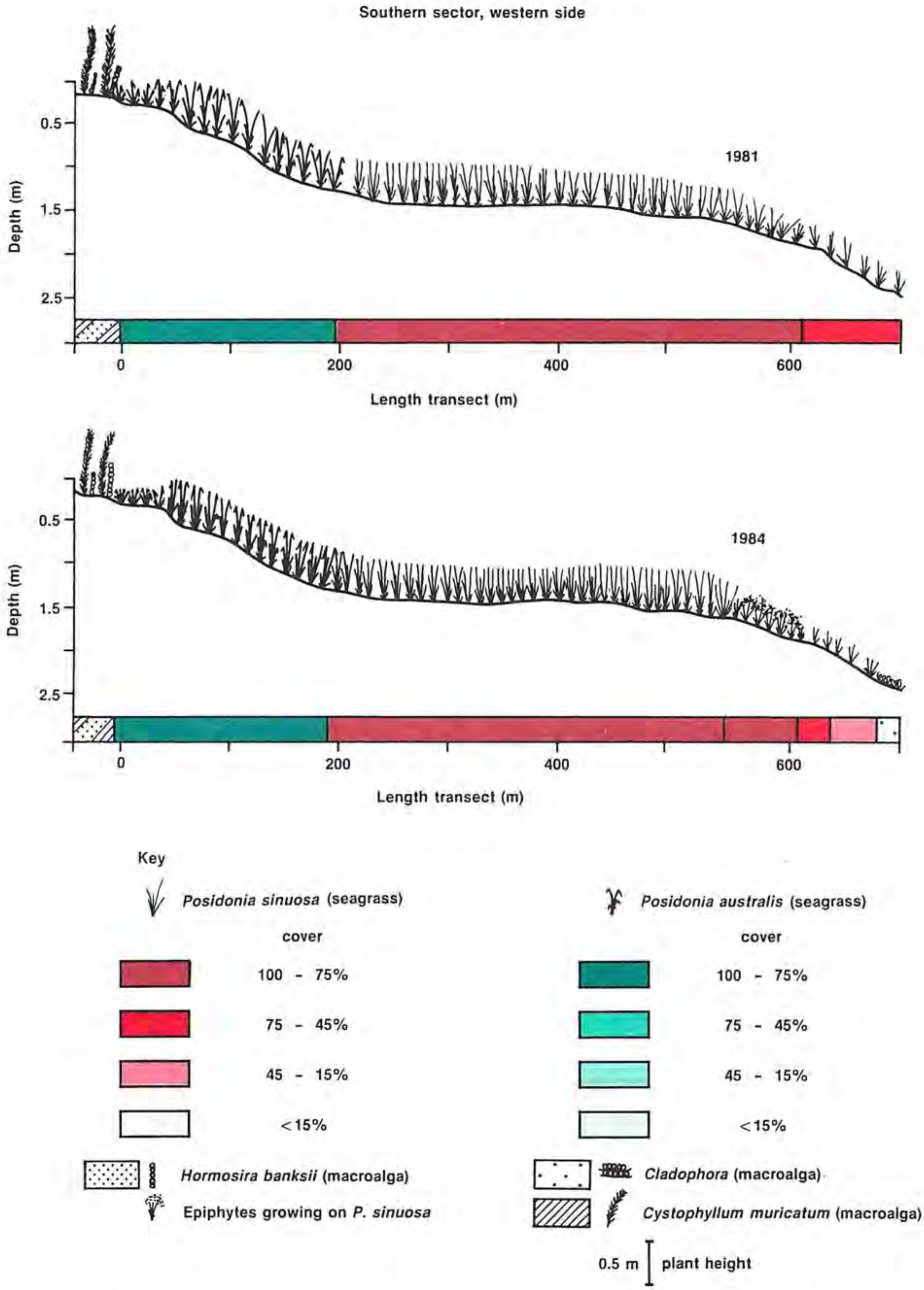

Figure 14.5 Cross section diagram of transect surveyed in 1981 and 1984 in Oyster Harbour. (Locations are shown in Figures 8 and 9.)

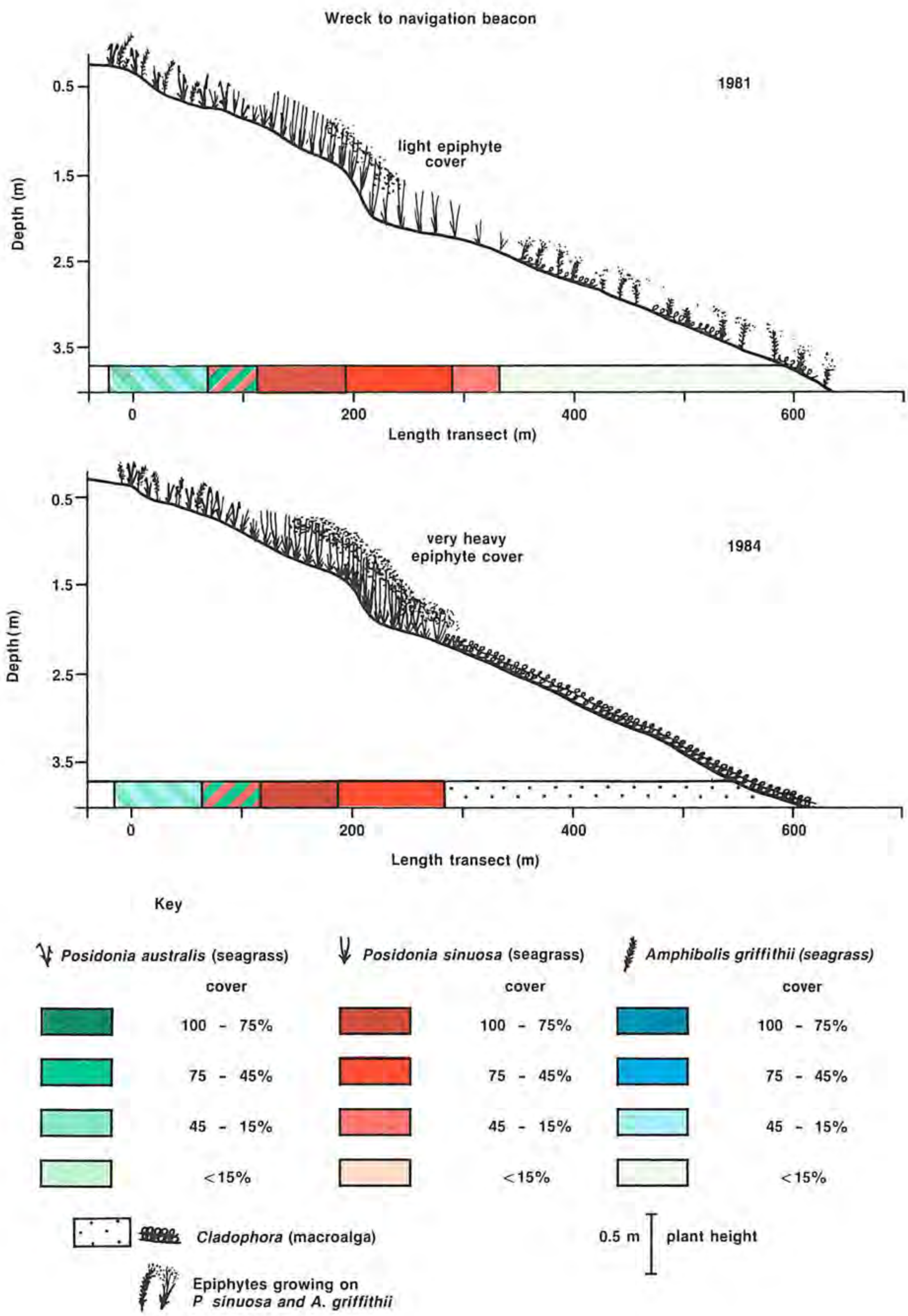

Figure 15.1 Cross section diagram of transect surveyed in 1981 and 1984 in Princess Royal Harbour. (Locations are shown in Figures 11 and 12.)

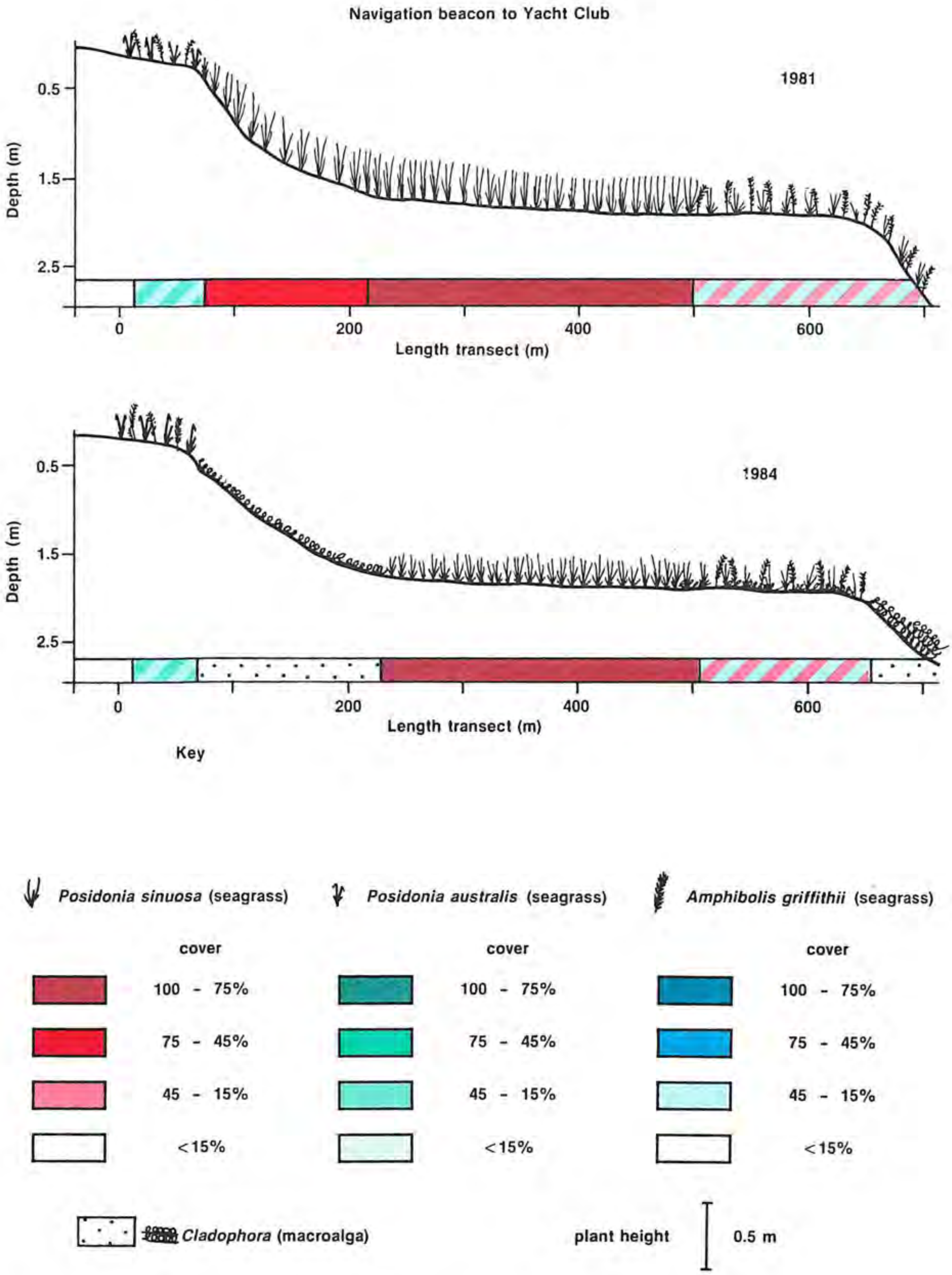

Figure 15.2 Cross section diagram of transect surveyed in 1981 and 1984 in Princess Royal Harbour. (Locations are shown in Figures 11 and 12.)

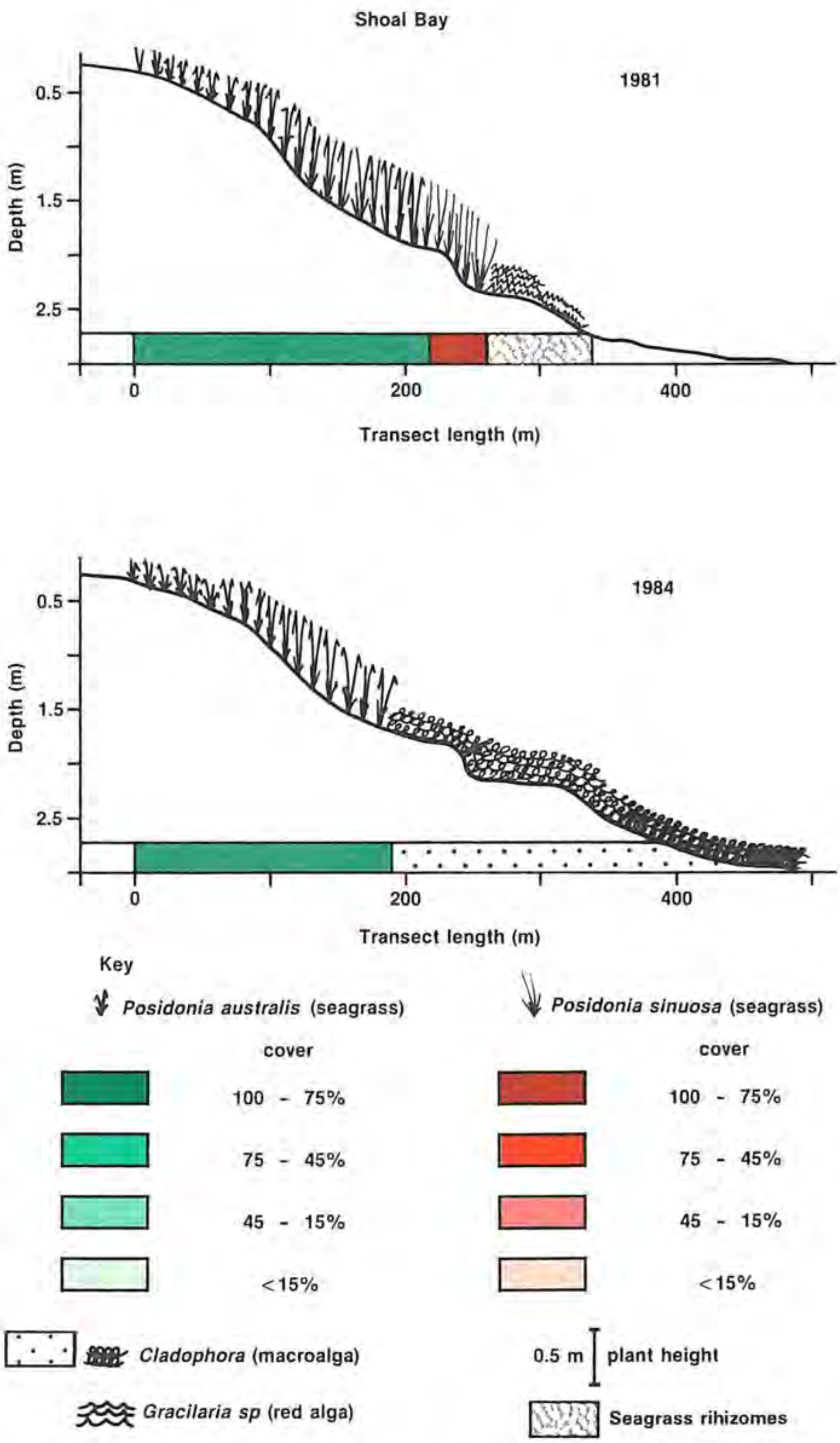

Figure 15.3 Cross section diagram of transect surveyed in 1981 and 1984 in Princess Royal Harbour. (Locations are shown in Figures 11 and 12.)

Figure 16 Stunted *Posidonia australis* from the north sector, Oyster Harbour (1.0 m deep).

Figure 17 Healthy *P. australis* from the South Kalgan Banks, Oyster Harbour (1.0 m deep).

Figure 18 *Cladophora* accumulations in Oyster Harbour, 1984.

Figure 19 Seagrass from Princess Royal Harbour covered with heavy epiphyte growth.

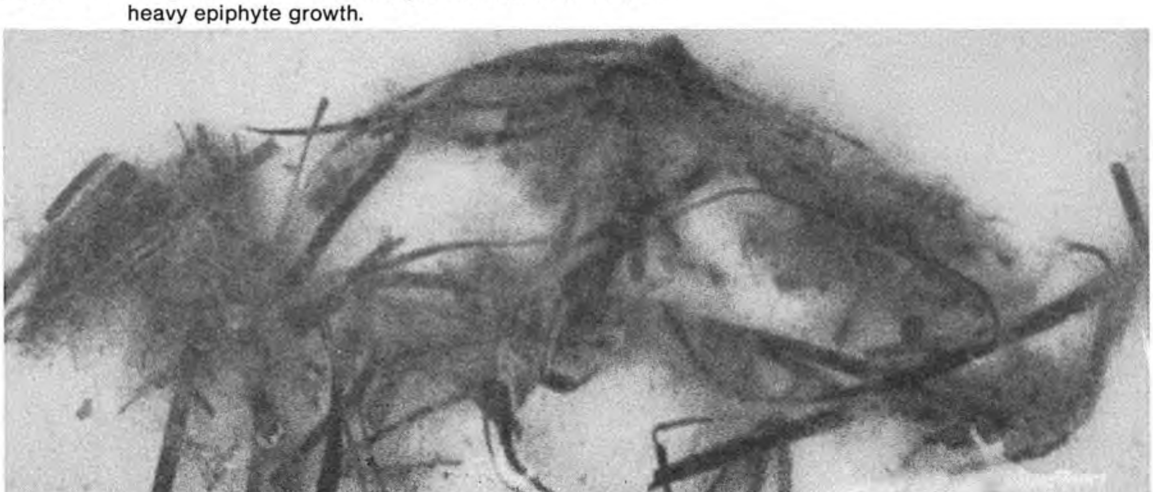

Figure 20 Impact of *Cladophora* accumulations on seagrass meadows in Princess Royal Harbour, 1984.