# NUTRIENT LOAD REDUCTION, WATER QUALITY AND SEAGRASS DIEBACK IN COCKBURN SOUND 1984-1985.



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Perth, Western Australia

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# NUTRIENT LOAD REDUCTION, WATER QUALITY AND SEAGRASS DIEBACK IN COCKBURN SOUND 1984-1985.

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# 1. INTRODUCTION

## 1.1 GENERAL

The 1976-79 Cockburn Sound study showed that massive dieback of seagrass in the Sound since the mid 1950's, and the subsequent appearance of phytoplankton blooms, occurred during a period of increased nitrogen loading associated with industrial development (Cambridge, 1979; Cambridge & McComb, 1984). Experimental evidence indicated that nitrogen levels limited the amount of phytoplankton (Chiffings, 1979; Chiffings & McComb, 1981), and influenced epiphytic growth on seagrasses, which led to seagrass dieback (Cambridge, 1980).

The Cockburn Sound Study Report (Anonymous, 1979) recommended that nitrogen loads to Cockburn Sound be substantially reduced to improve water quality, and arrest this seagrass dieback. The two principal nutrient sources to the Sound were identified as outfalls from the Kwinana Nitrogen Company/CSBP and Farmers Ltd (KNC/CSBP) and the Water Authority of Western Australia's wastewater treatment plant at Woodman Point (WPTP). Since then, both industry (KNC) and State Government (Water Authority of Western Australia) have taken active steps to reduce their respective nitrogen loads to the Sound. In late December 1982, KNC commissioned a steam scrubber designed to remove a large proportion of the nitrogen from the plant's effluent. On 12 July 1984, secondary treated effluent originally discharged from the WPTP outfall was diverted into a new pipeline which discharges into 20 m deep water 4 kms west of Cape Peron.

In order to assess the effects of the reduction in nitrogen loading from the KNC/CSBP outfall, a three-month study was carried out from mid-November 1982 to the end of February 1983 by the Department of Conservation and Environment in conjunction with the Centre for Water Research, University of

Western Australia (Chiffings & McComb, 1983). The study documented weekly changes in nutrient and chlorophyll 'a' levels and light attenuation in the Sound until the end of February 1983, when the ammonium stripping plant (steam scrubber) was expected to be operating at maximum efficiency. There were significant reductions in phytoplankton levels and light attenuation compared with previous years, and this was attributed to the reduction in nitrogen loading from KNC. The study noted, however, that effluent output from KNC was extremely variable, and recommended that a similar exercise be carried out over a subsequent summer after KNC had stabilised effluent output. The study also recommended investigation of the occurrence of macroalgae on shallow flats in the Sound, since macroalgal accumulations observed during the study period represented a potential management problem.

In view of these recommendations, and the further reduction in nitrogen loading to the Sound since July 1984 (with the diversion of WPTP secondary treated effluent), the sampling programme of the 1982/83 summer study was repeated during summer 1984/85 in order to re-assess water quality. In addition, it was deemed appropriate to re-assess the status of seagrass since the last (1977 - 1978) seagrass survey (Cambridge, 1979), to establish whether seagrass loss had ceased and whether there were signs of long-term recovery. A concurrent survey of macroalgae would also provide information on whether existing macroalgal levels represented a management problem.

Accordingly, water quality and seagrass/macroalgae distribution were studied from mid-December 1984 to the end of March 1985. The seagrass/macroalgae survey involved detailed examination of aerial photographs in conjunction with field surveys, and comparison with the original maps prepared during the Cockburn Sound study of 1976 - 1979.

## 1.2 OBJECTIVES OF THE STUDY

The water quality study was to document changes in phytoplankton levels and light transmission following further reduction of nitrogen loading to the Sound. These two parameters are closely related, since the turbidity of Cockburn Sound waters is largely determined by phytoplankton levels (Chiffings, 1979). Field work commenced on 21 December 1984, and continued weekly until 28 March 1985, for a total of 14 trips.

The seagrass/macroalgae survey examined the present distribution of seagrasses in relation to distribution in 1977, in order to determine whether seagrass dieback had ceased with improved water quality, and the distribution of macroalgae to determine whether they present a management problem. If large accumulations of macroalgae were observed during 'ground truthing' surveys, assessments of algal biomass were also envisaged. The field surveys, for "ground truthing" of distributions mapped from the aerial photographs, were carried out during March 1985.

# 2. NUTRIENT LOADS TO THE SOUND

## 2.1 CHANGES SINCE THE 1976-79 COCKBURN SOUND STUDY

As previously mentioned, the 1976-79 Cockburn Sound Study identified two principal nutrient sources to the Sound: the KNC/CSBP outfall, and the WPTP outfall (Chiffings, 1979; Chiffings & McComb, 1981). Both KNC and WPTP have continued to monitor daily nitrogen loads since 1979, but WPTP no longer discharges effluent into the Sound.

Mean daily loads (kg) of nitrogen for summer 1984/85 are compared with data for corresponding periods in previous years. As can be seen (Table 1), the combined nitrogen load of the two outfalls has fallen from about 4,500 kg/d in 1977/78 to 661 kg/d in 1984/85. It should be emphasized that the data in

Table 1 Changes in nitrogen loads to Cockburn Sound from WPTP and KNC/CSBP outfalls (loads in kg/day). Total nitrogen (TN) includes inorganic and organic nitrogen. Total inorganic nitrogen (TIN) includes ammonia-nitrogen ($NH_4$-N) and nitrate-nitrogen ($NO_3$-N).

| | WOODMAN POINT TREATMENT PLANT (WPTP) | | | | |
|---|---|---|---|---|---|
| | $NH_4$-N | $NO_3$-N | TIN | TN | Data Source |
| January to February 1978 | 1114 | 10 | 1124 | 1422 | 1 |
| March 1981 | 1557 | 4 | 1560 | - | 2 |
| November 1982 to February 1983 | - | - | - | 2004 | 4 |
| December 1984 to March 1985 | 0 | 0 | 0 | 0 | 5 |

| | KNC/CSBP EFFLUENT | | | | |
|---|---|---|---|---|---|
| | $NH_4$-N | $NO_3$-N | TIN | TN | Data Source |
| October 1977 | 2350 | 665 | 3015 | 3075 | 1 |
| March 1981 | - | - | 1593 | - | 2 |
| March 1982 | 237 | 20 | 257 | - | 3 |
| November 1982 to February 1983 | - | - | 563 | - | 4 |
| December 1984 to March 1985 | - | - | 661 | - | 5 |

1 Murphy (1979). Data for KNC are mean values from one week's intensive sampling at three-hourly intervals. Data for WPTP are mean values from a four week continuous sampling programme.

2 Mean values from one week's intensive sampling by DCE at three-hourly intervals.

3 Talbot (1983). Sampling carried out from 12/11-22/11/82.

4 Chiffings and McComb (1983). The load for KNC was calculated including days of no discharge. The average load from the plant on operating days was 1061 kg/d.

5 From KNC/CSBP and WPTP. The figure obtained was calculated including days of no discharge. The average load from the plant on operating days was 804kg/d.

Table 1 represent short, intensive periods of sampling, and therefore give no indication of the variability associated with these loads.

## 2.2 VARIABILITY OVER THE STUDY PERIOD

It is important to know the variability of nitrogen loads to Cockburn Sound, since extremes may be even more critical than average conditions in affecting biological processes such as phytoplankton response. Daily loads of total nitrogen from the KNC plant are shown for the study period (Figure 1). The contribution of nitrogen from CSBP is not shown, since KNC contributes about 98% of nitrogen load from the outfall (Murphy, 1979). Daily variation was considerable, ranging from 20-1810 kg/d; the latter figure approaches levels measured in 1977. This is due to variations in effluent concentration which, in turn, are due to both alterations in the production process and discontinuities in pumping of waste (Chiffings & McComb, 1983). There are 19 days for which no results are depicted (Figure 1) because the plant was not discharging. If the days for which there were no discharges are discounted, there were no periods of low discharge greater than one week.

## 2.3 LOADS SINCE THE COMMISSIONING OF THE AMMONIUM STRIPPER

During the 1982/83 summer, when the steam scrubber first became operational, the average daily nitrogen load from KNC on operating days was 1061 kg (Chiffings & McComb, 1983). During this study the corresponding figure was 804 kg, which represents a 24% reduction in average daily nitrogen load; however, comparisons are complicated because during the earlier exercise the plant was not operational for 39 days, giving an average daily nitrogen load for the entire study period (November 1982 to February 1983) of 563 kg. For this study (December 1984 to March 1985), the plant was not operational for

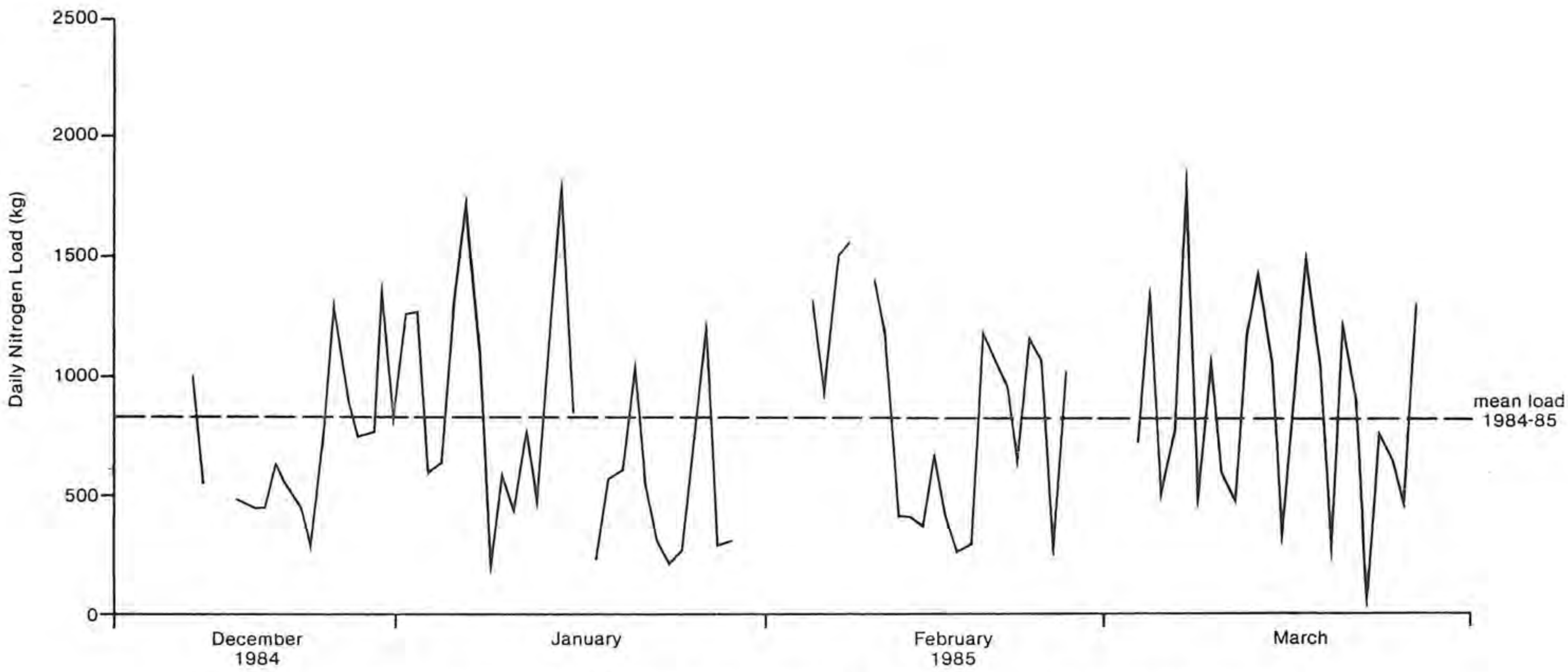


Figure 1 Daily nitrogen loads (kg) from KNC to the CSBP outfall over the 1984/85 summer period. The dashed line is the mean value of the daily loads.

19 days, giving an average daily nitrogen load for the entire study period of 661 kg. Thus, even though the average load during operating days was less in the 1984/85 exercise, the total nitrogen load from KNC to the Sound for the duration of the entire study was slightly higher.

For the purpose of comparing phytoplankton responses during the two studies, the lower total nitrogen load during the 1982/83 summer exercise is viewed as artificially low due to the abnormally high percentage (almost 50%) of days when the plant was non-operational.

## 3. PHYTOPLANKTON CONCENTRATIONS

### 3.1 INTRODUCTION

Between 1976 and 1979, phytoplankton concentrations in the Sound were found to be highly variable both spatially and temporally (Chiffings, 1979). To obtain maximum information from available time and resources, the 1982/83 summer exercise involved weekly sampling at 11 sites; eight sites within Cockburn Sound, two in Owen Anchorage, and one between Carnac Island and Garden Island (Figure 2). For the same reasons, and also to enable direct comparisons, the same sites were chosen for this study. Similarly, in view of the lack of vertical stratification in the Sound (Chiffings, 1979), the integrated sampling technique adopted in the 1982/83 exercise was also used. This technique reduced sampling effort and analytical costs, so allowing more sites to be visited on the day allocated to sampling, and achieving better characterisation of the Sound.

### 3.2 METHODS

Integrated samples were collected at each station using a plastic ten litre Niskin bottle, and sampling at three depths. The first sample was taken just below the water surface, the second sample was taken just above the

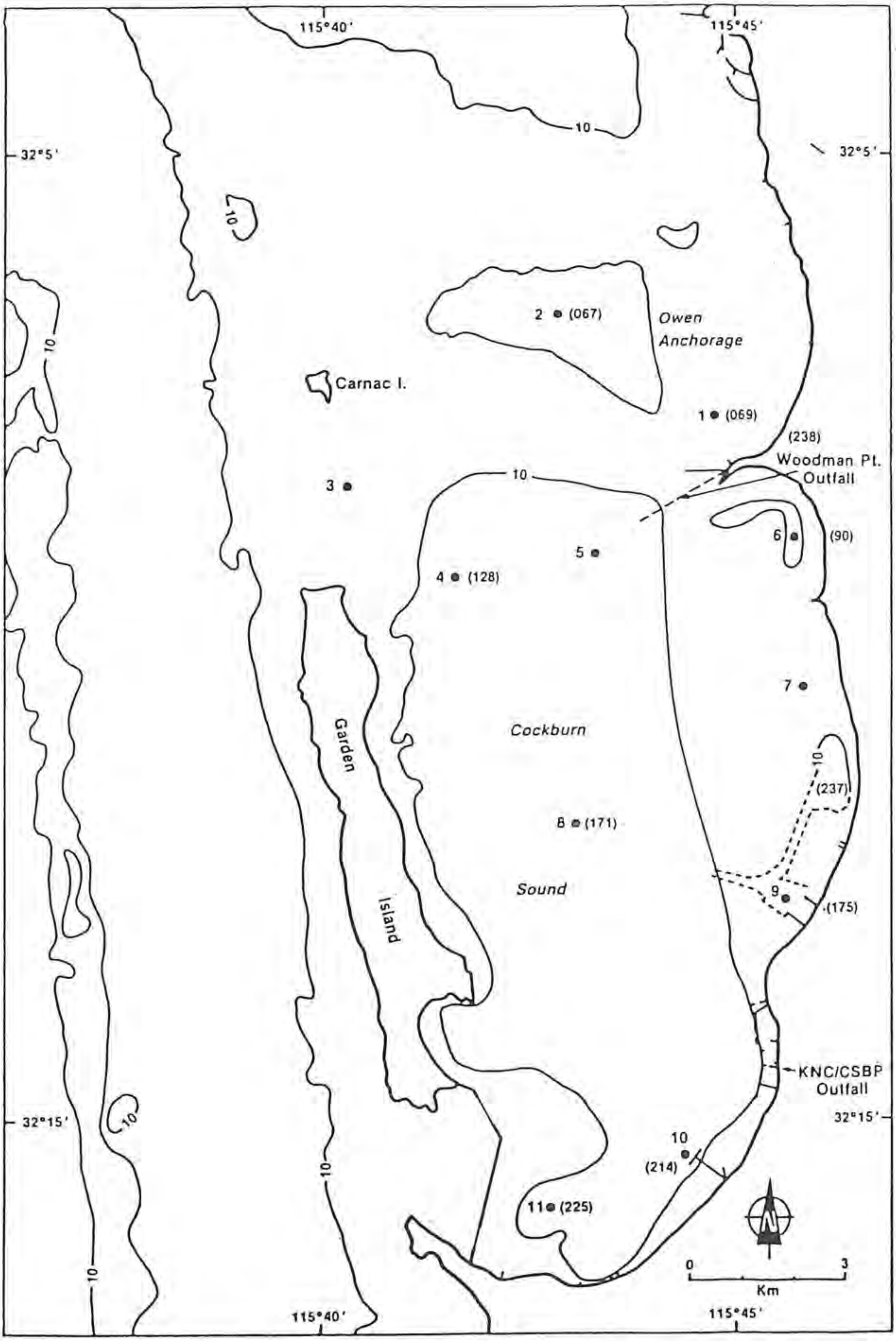


Figure 2. Location of sampling stations for the 1984-85 investigation in Cockburn Sound. The numbers in brackets are the original Cockburn Sound station numbers.

sediment/water interface, and the third was taken midway between the first two. The three samples were then mixed in a large plastic container and subsampled. Water samples were stored in 150 mL polyethylene bags ("Whirlpak", Nasco, Kansas, USA.) on wet ice, and upon return to the laboratory were deep frozen until analysed.

Samples of particulate matter were collected onto pre-combusted (1 hour at 450 $^{o}$C) GFC glass fibre filters by filtering a known volume of water (usually 1 L) using positive pressure not exceeding 10 mm Hg.

Salinity, temperature and light attenuation profiles were recorded at each station at 1 m intervals through the water column. Secchi depths were also measured.

Orthophosphate was analysed by the single solution method (Major et al, 1972); nitrate and nitrite after copper-cadmium reduction with a Technicon Autoanalyser II; and ammonia by the phenol-prusside method (Dal Pont et al, 1974). Total nitrogen and phosphorus were from sulphuric and perchloric acid digests respectively; followed by analysis for ammonia and phosphate by the methods given above. Chlorophyll 'a' was read after 24 hours in 90% acetone at 750, 664, 647 and 630 nm (Jeffrey and Humphrey, 1975).

## 3.3 RESULTS

Mean phytoplankton concentrations (as chlorophyll 'a') for the study period are compared with those for earlier studies (Figure 3). Results for the 1977/78, 1979/80 and 1980/81 studies were calculated for a set of eight stations similar to those used during the 1982/83 and 1984/85 studies, over similar summer periods (Anonymous, 1979).

Mean chlorophyll 'a' for the 1984/85 summer was not significantly different from the 1982/83 value, but both of these values were significantly less than mean values for the three earlier periods ($p < 0.05$; t test). This indicated that phytoplankton levels in the Sound have altered little since the improvement first noted in the 1982/83 study (Chiffings & McComb, 1983); however, this interpretation should be viewed with caution. Marked variation in chlorophyll levels did not occur in the present study (n = 154; mean: 1.06 μg chlorophyll 'a'/L; standard error: 0.06; range: 0.16-3.61), but samples were all in the one three-month period. Marked variation is apparent in the large standard error of the 1980/81 data: the four sampling cruises, each a month apart, yielded chlorophyll 'a' levels of 1.5, 1.5, 0.8 and 5.8 μg/L.

A corresponding comparison of light attenuation data for the five summer periods is presented (Figure 4). Results reflected trends observed for phytoplankton levels, which was expected since the turbidity of Cockburn Sound largely depends on attenuation of light by phytoplankton. The data indicate that water clarity has also not altered significantly since the marked improvement observed in the 1982/83 summer.

Average nutrient concentrations, chlorophyll 'a' concentrations and attenuation coefficients are shown for three sites (Table 2) during similar summer periods in 1977/78, 1982/83 and 1984/85. The 1977/78 data are for Cockburn Sound sites 238, 237 and 214 (see Figure 2); these are sites of the 1976-79 study for which suitable data were collected at weekly intervals, and which closely correspond to sites 1, 7 and 10 of the 1982/83 and 1984/85 studies (Chiffings & McComb, 1983).

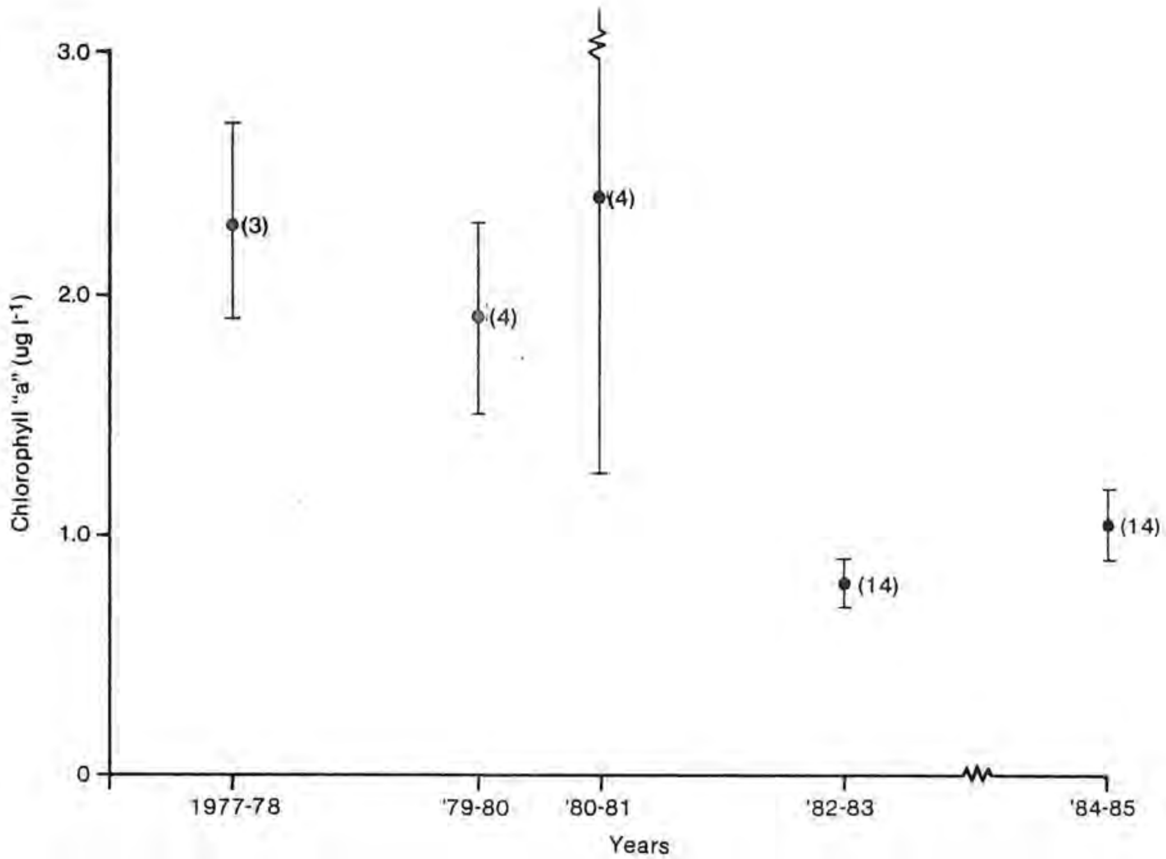


Figure 3 Mean chlorophyll 'a' concentrations for cruises made over summer periods in Cockburn Sound. Standard error bars are shown, and the number in brackets represents the number of cruises in the 'sample'. The 1977-78 sample is for 2 cruises in the 1978-78 summer and 1 cruise in November 1978. All other samples are for cruises during a single summer period. Note the break in scale on the horizontal axis.

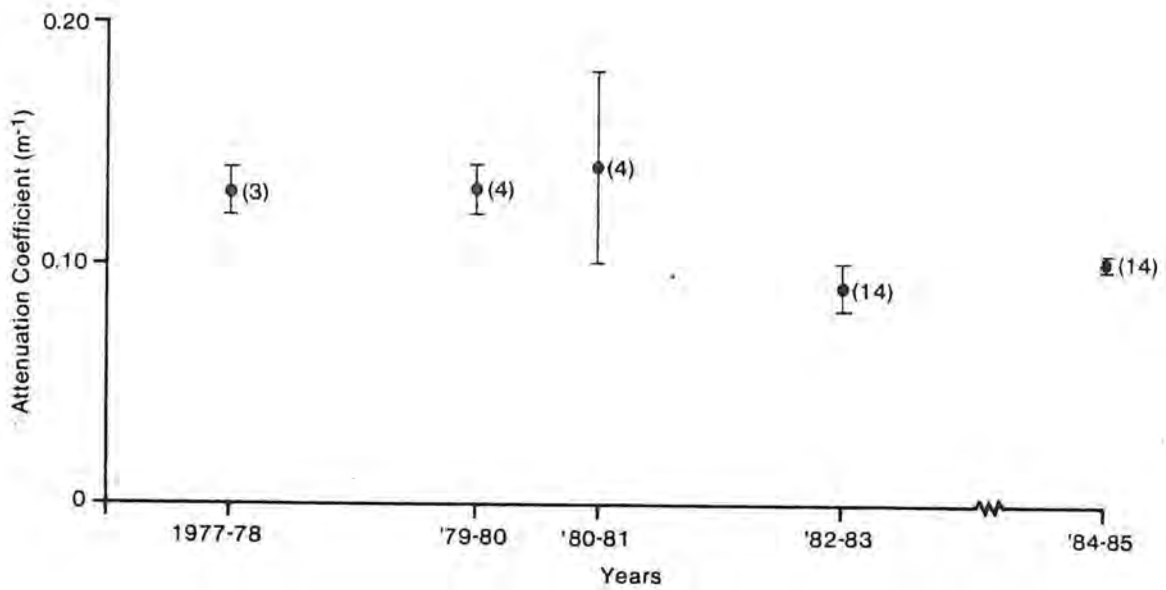


Figure 4 Mean light attenuation coefficients for cruises made over summer periods in Cockburn Sound. Details as for Figure 4.

Chlorophyll 'a' levels and attenuation coefficients appear to have changed little since the 1982/83 study, but chlorophyll 'a' values represent a considerable improvement over conditions of 1976-79 (Table 2). A similar change was apparent for inorganic nitrogen concentrations at all sites, which may reflect the sustained period of lower nitrogen loading to the Sound. In contrast, orthophosphate ($PO_4$-P) concentrations have continued to decline since 1982-83; the observed decline at site 7 (the site closest to the KNC/CSBP outfall) may reflect a reduction in nutrient input from the KNC/CSBP outfall, whilst sites 1 and 7 may reflect the diversion of phosphate-rich WPTP effluent from the Sound. It is worth noting, however, that despite decreased orthophosphate levels, the N:P ratios for all three sites during this study were still very low, suggesting that nitrogen continues to be the limiting nutrient in Cockburn Sound.

Trends in organic nitrogen and organic phosphorus levels were more obvious. At all three sites, organic phosphorus levels increased from 1977/78 to 1982/83, but returned to 1977/78 levels during this study. In contrast, organic nitrogen levels at all three sites remained high in 1982/83 and 1984/85, with an increase at site 10. The apparent rises at the other two sites are not statistically significant. There is no obvious explanation for the increased organic nitrogen levels, which greatly exceed those which might be accounted for by plankton. The organic nitrogen is presumably not in a form readily available for phytoplankton growth, since it would otherwise be quickly taken up in this nitrogen limited system. It would be useful to know more about the form of this nitrogen; for instance, whether it is particulate or dissolved.

Table 2 **Comparison of three individual stations during Cockburn Sound studies 1976-79, 1982-83 and 1984-85.**

$\bar{X}$ values are for 14 week summer periods. 1977-78 data from Chiffings (1979), 1982-83 data from Chiffings and McComb (1983), 1984-85 data from present study.

| Water quality parameter | Site 10 | | | Site 7 | | | Site 1 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1977-78 | 1982-83 | 1984-85 | 1977-78 | 1982-83 | 1984-85 | 1977-78 | 1982-83 | 1984-85 |
| | X (SD) | X (SD) | X (SD) | X (SD) | X (SD) | X (SD) | X (SD) | X (SD) | X (SD) |
| Orthophosphate phosphorus | 105 (45) | 56 (14) | 15 (9) | 72 (19) | 66 (22) | 12 (6) | 36 (7) | 39 (15) | 8 (5) |
| Organic phosphorus | 22 (20) | 29 (18) | 25 (11) | 25 (18) | 33 (18) | 26 (10) | 22 (12) | 45 (20) | 22 (8) |
| Total phosphorus | 119 (57) | 86 (15) | 40 (16) | 96 (28) | 99 (31) | 37 (11) | 74 (57) | 73 (31) | 30 (9) |
| Ammonia-nitrogen | 31 (30) | 16 (16) | 16 (7) | 12 (11) | 14 (12) | 9 (8) | 13 (6) | 14 (10) | 13 (10) |
| Nitrate-nitrogen | 7 (5) | 7 (3) | 6 (4) | 4 (3) | 7 (5) | 4 (3) | 3 (2) | 5 (3) | 4 (2) |
| Organic nitrogen | 142 (47) | 320 (103) | 476 (116) | 210 (79) | 409 (213) | 504 (178) | 150 (67) | 414 (159) | 478 (143) |
| Total nitrogen | 173 (61) | 339 (96) | 497 (119) | 208 (80) | 429 (217) | 517 (175) | 172 (58) | 432 (164) | 495 (144) |
| Chlorophyll 'a' | 5.2 (3.5) | 1.2 (0.8) | 1.9 (0.8) | 4.4 (2.6) | 0.9 (0.6) | 1.3 (0.5) | 3.2 (2.2) | 0.6 (0.2) | 0.6 (0.4) |
| Inorganic N:P ratio | 0.8 (0.5) | 0.7 (9.4) | 1.6 (0.6) | 0.7 (0.9) | 1.3 (1.0) | 1.4 (0.9) | 1.1 (0.6) | 1.0 (0.7) | 3.1 (3.0) |
| Attenuation coefficient | 0.14(0.03) | 0.09(0.01) | 0.11(0.02) | 0.16(0.02) | 0.11(0.02) | 0.11(0.02) | 0.16(0.03) | 0.13(0.06) | 0.11(0.02 |

No correlation was found between total chlorophyll 'a' in the Sound and average weekly nitrogen load. It is possible that this was due to the lack of sustained periods of uniform discharge. Alternatively, phytoplankton populations may well respond to short-term (less than one day) pulses of high nitrogen concentrations, but this could not be investigated with the available data.

## 3.4 DISCUSSION

Comparisons of the 1982/83 and 1984/85 results suggest that chlorophyll 'a' levels and turbidity levels in Cockburn Sound are at equilibrium, due to several years of similar nitrogen loading (the nitrogen load from KNC on operating days has only decreased slightly from 1982/83 to 1984/85, and overall there was a 17% increase). The recent (July 1984) reduction in nitrogen loading, due to the diversion of WPTP secondary treated effluent, did not produce a detected improvement in water quality, although the full effects of the diversion are possibly yet to be realised; it must be noted that the WPTP effluent was not diverted because it contributed a large proportion of nitrogen to the system in 1976-79, but because the amount of nitrogen was expected to increase substantially.

Data indicate that during days when the KNC plant was operational, nitrogen-loading has decreased since the 1982/83 study, but since the plant was non-operational for an unusually large number of days during the 1982/83 study, the total nitrogen load for the 1984/85 summer exercise was 17% higher than that of the 1982/83 summer exercise. Whilst it is clear that the installation of the steam scrubber at KNC has resulted in a considerable reduction in nitrogen-loading to the Sound since 1979, the expectation of a stabilised output of around 100 kg/d (Chiffings & McComb, 1983) has yet to be achieved.

On the basis of N:P ratios, it may be inferred that nitrogen remains the limiting nutrient in the Sound, but changes in phytoplankton levels did not correspond to measured variation in nitrogen loading from KNC during the study period. The lack of a clear relationship may have been due to the lack of sustained periods of uniform nitrogen loading, or to phytoplankton responding to short-term pulses of high nitrogen loads. It is also likely that correlations were not discernable because total amounts of chlorophyll 'a' in the Sound were examined, rather than amounts in the phytoplankton-rich waters near the nutrient point source (the KNC/CSBP outfall). Such phytoplankton-rich waters tend to be separated from low nutrient, low-chlorophyll waters by sharp vertical and horizontal boundaries (Chiffings & McComb, 1981). The amount of chlorophyll 'a' within these boundaries may be more closely related to nutrient loading; however, delineation of such boundaries would require more detailed study.

Other factors which influence phytoplankton levels include changes in water movements and flushing characteristics (Chiffings & McComb, 1983). In view of the relatively consistent physical conditions experienced during the 1984/85 sampling period, some of the measured variation in chlorophyll 'a' levels may have been caused by successional changes in plankton species and variations in nutrient cycling rates (Chiffings & McComb, 1983).

Overall, water quality in Cockburn Sound has improved significantly since 1979.

# 4. DISTRIBUTION OF SEAGRASSES AND MACROALGAE

## 4.1 INTRODUCTION

The massive dieback of seagrass recorded in Cockburn Sound, between 1954 and 1978, was attributed to shading from excessive growth of algae, epiphytic on the seagrass leaves, following nitrogen enrichment of Cockburn Sound. Dieback in deep water was partly attributed to reduction in light reaching the seagrasses, caused by phytoplankton blooms which also developed in response to nitrogen enrichment (Cambridge, 1979, 1980). Unlike seagrasses, which can tap sediment nutrient supplies through root systems, epiphytic algae depend on water column nutrients. Nutrient requirements for epiphytic algae are very similar to those of phytoplankton, and increased nitrogen loading to the Sound during industrial development led to increased growth (Cambridge, 1979, 1980).

With the improvement in water quality reported after the 1982/83 summer sampling, it seemed reasonable to predict a corresponding decrease in epiphytic algal growth, and therefore a decrease in the rate of seagrass dieback. There was some concern, however, about the reported appearance of large areas of macroalgae, during a flight over the Sound as part of the 1982/83 exercise. Although it was not determined whether these accumulations were drift material or benthic algae, the possibility of the latter reaching nuisance levels merited investigation.

Aspects of both seagrass and macroalgae distributions in Cockburn Sound were investigated during the present study, and are reported below.

## 4.2 METHODS

Seagrass distributions were mapped directly from 1:10,000 aerial photographs, and subsequently reduced to a scale of 1:25,000.

Distributions were verified during five days of field work (20.3.85 to 22.3.85, 26.3.85 and 27.3.85). Macroalgae distributions were observed at the same times, but not mapped because macroalgae were sparse.

## 4.3 RESULTS

### 4.3.1 SEAGRASSES

The distribution of seagrasses mapped during this study is shown (Figure 5). When compared with the seagrass distribution recorded in the 1977 survey (Figure 6), it is clear that seagrass dieback in Cockburn Sound has halted.

Little change was apparent in the seagrass distribution on Parmelia Bank when compared with the intensive survey of this region carried out in 1980 (Figure 7). Although there was no sign of seagrasses recolonising bare sand along the eastern shores of the Sound, the isolated patches of seagrass noted in 1977 have remained healthy and intact. It was also apparent that the heavy epiphytic loads described for eastern Parmelia Bank seagrasses in 1980 (Silberstein, 1980, 1985) were considerably less, although this was not quantified.

Seagrass populations have also remained healthy along the eastern shores of Garden Island, and there was evidence that meadows of *Posidonia sinuosa* have extended into deeper waters again, for example, off the north-eastern end of Garden Island (Figures 5 and 6). Furthermore, of particular note was a large area of healthy seagrass east of the main causeway bridge (Figure 5). The corresponding area on the 1977 map (Figure 6) is recorded as "*Posidonia* fibre mat, formerly *Posidonia* meadow", and it is concluded that seagrasses have recolonised the area since 1977. The status of seagrasses on Southern Flats has also improved: areas of "patchy mussels and seagrass fibre

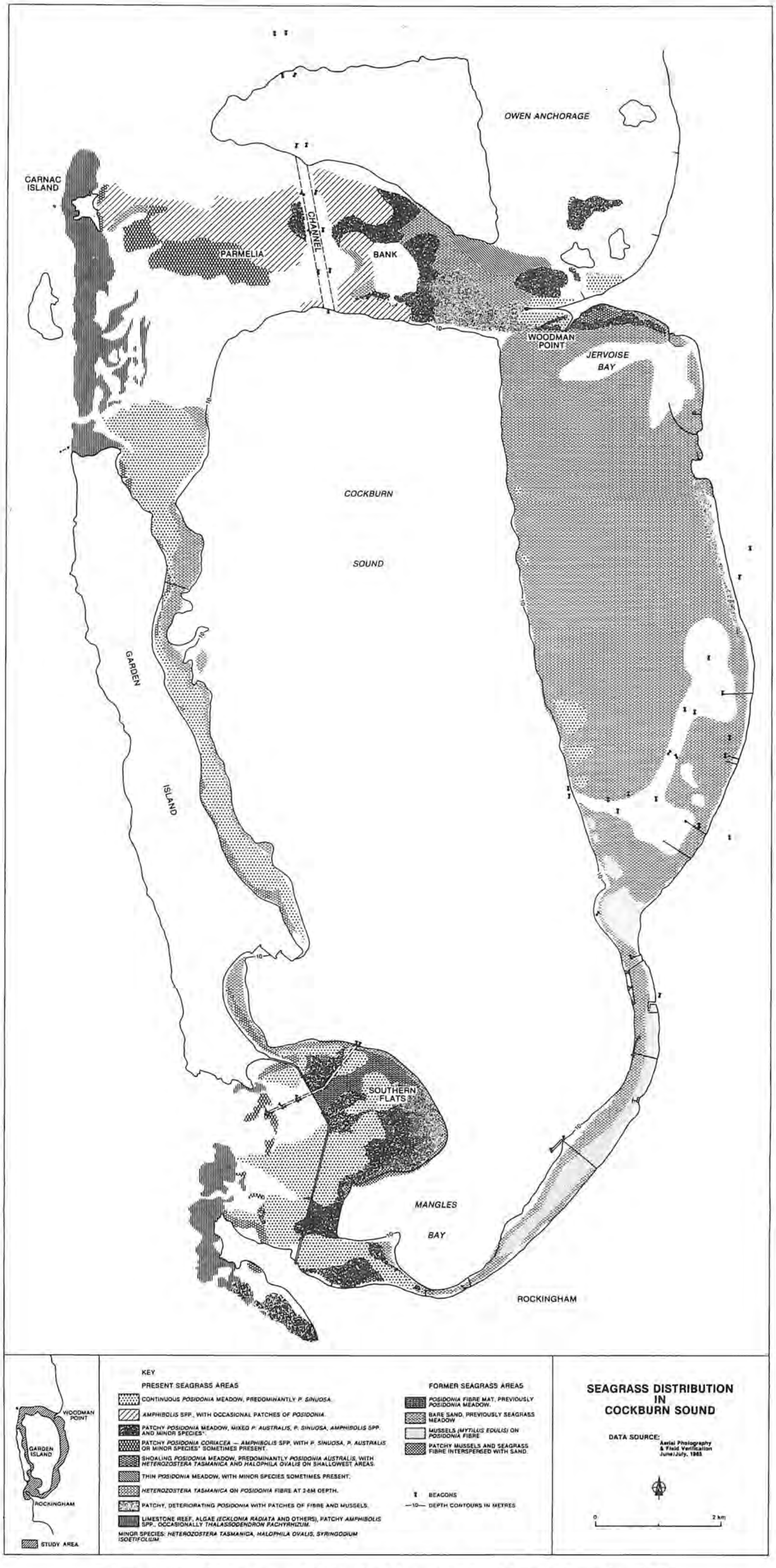


Figure 5 Seagrass distribution in Cockburn Sound, 1985.

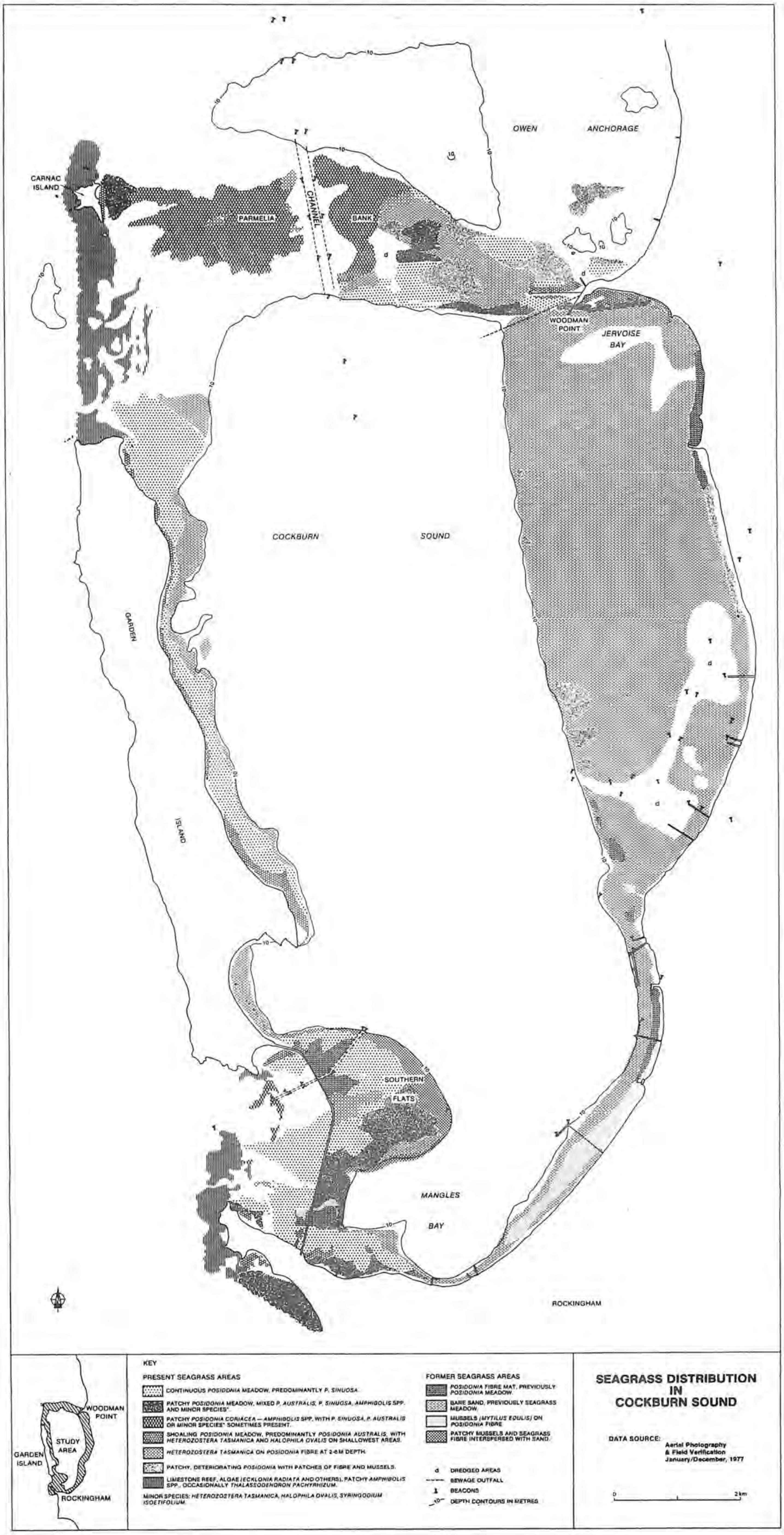


Figure 6 Seagrass distribution in Cockburn Sound, 1977.

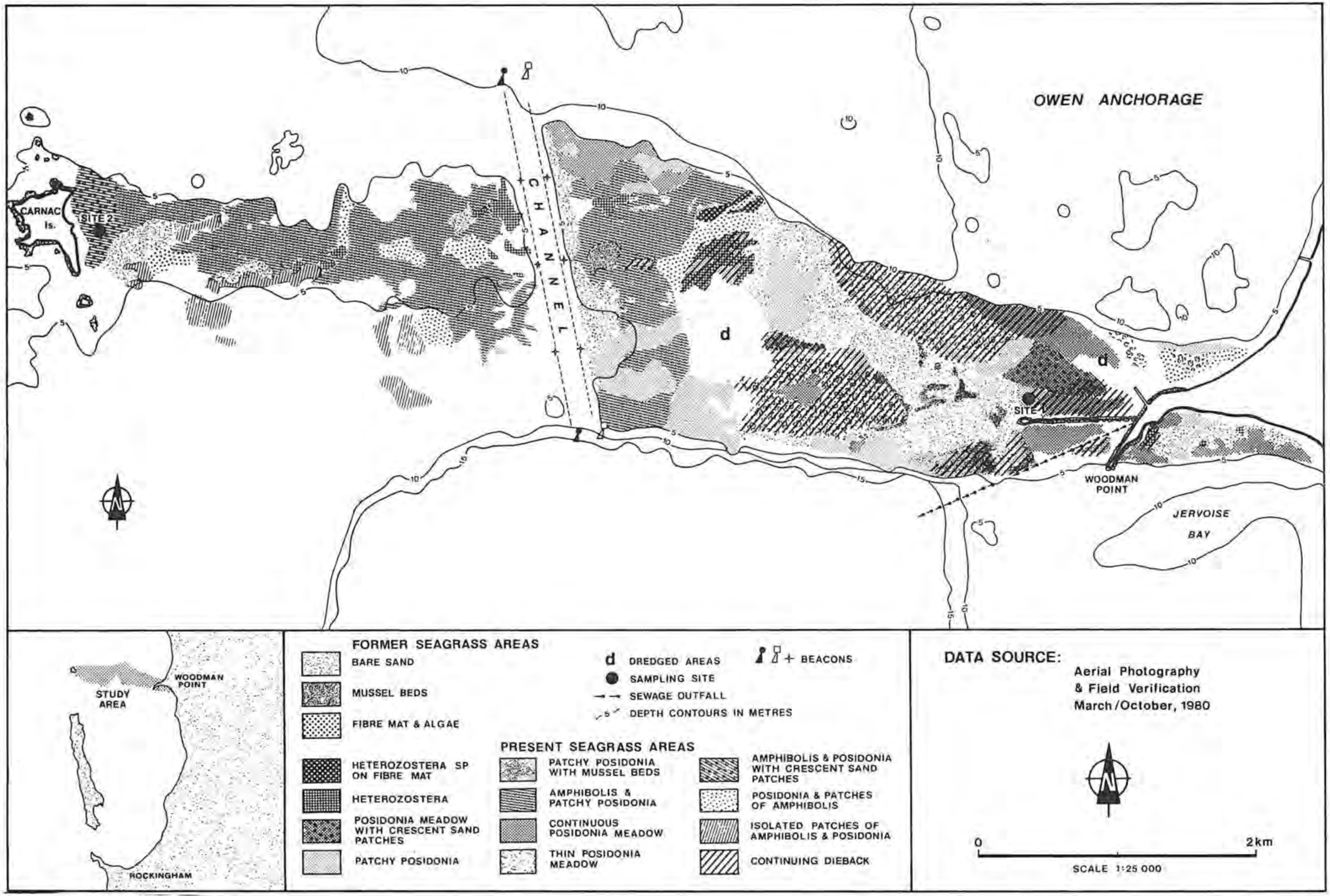


Figure 7 Seagrass distribution on Parmelia Bank, 1980. Reproduced from Silberstein (1985).

interspersed with sand" and "bare sand" have both decreased, and some areas previously "patchy Posidonia meadow" are now continuous Posidonia meadow.

### 4.3.2 MACROALGAE

Benthic macroalgae were not prominent in Cockburn Sound during the present study. No large accumulations of benthic macroalgae were encountered during the five days of field survey; only a few sparse patches of red algae (mainly Gracilaria and Polysiphonia spp) were observed in shallow water from just north of James Point (BP Refinery site) to the Rockingham jetty. Biomass measurements were not taken because the macroalgae were too sparse to justify such an exercise.

## 4.4 DISCUSSION

### 4.4.1 SEAGRASSES

The dieback of seagrasses in Cockburn Sound has clearly halted. There are definite signs of recolonisation in previously denuded areas, notably on Southern Flats and along the eastern shores of Garden Island. It seems reasonable to conclude that several years of reduced nitrogen loading and improved water quality have enabled existing seagrass meadows to stabilise and even extend their distribution in Cockburn Sound. This can be attributed to a decrease in growth of epiphytic algae and reduced phytoplankton blooms, due to nitrogen load reduction by KNC and WPTP, and therefore reduced shading stress on the seagrasses. It was apparent during this 1984/85 study that the heavy epiphytic loads noted previously (Cambridge, 1979, 1980; Silberstein, 1980) were not present. This was particularly obvious on Parmelia Bank, where seagrass dieback was caused by increased epiphyte loads, due to nutrient enrichment by the WPTP outfall (Silberstein, 1980, 1985; Silberstein et al, 1986). Heavy epiphytic loads described for eastern Parmelia Bank seagrasses, in 1980, were not apparent in the present study, although there was no sign of re-extension of seagrass meadows. Since the diversion of the WPTP effluent is relatively recent, it would be informative to re-examine Parmelia Bank seagrasses in 2-3 years. A considerable improvement is predicted in the status of seagrasses in this area, if nutrient loads remain low.

Thus, data indicate that seagrass meadows in Cockburn Sound are recovering, and will continue to do so provided nitrogen loading into the Sound remains at existing levels, or, ideally, is further reduced.

### 4.4.2 MACROALGAE

Benthic macroalgae were not found in the "large accumulations" reported in the 1982/83 study (Chiffings & McComb, 1983). On the basis of observations in the present study, macroalgae are not a potential management problem.

## 5. CONCLUSIONS AND RECOMMENDATIONS

1. Since the 1976-79 Cockburn Sound study, the inorganic nitrogen load entering the Sound from CSBP and the Woodman Point Treatment Plant has fallen almost seven-fold.
2. Ratios of N:P in the water, as inorganic forms readily available for phytoplankton growth, indicate that nitrogen continues to be the limiting nutrient for phytoplankton growth.
3. There has been a marked improvement in water quality since the reduction in nutrient loading, in terms of reduced phytoplankton levels and better light penetration. Similar values were recorded in the 1983/84 and 1984/85 summer exercises, but these are markedly improved over the measurements taken in 1976-79.

4. The total load of nitrogen entering the Sound was slightly higher during the summer exercise in 1984/85, than in 1983/84; the suggested stable output of about 100 kg/d from KNC has not yet been achieved. Further reductions should be encouraged.

5. Concentrations of organic nitrogen have continued to rise: this could be investigated further.

6. With improved water quality, seagrass dieback in the Sound appears to have ceased and there is evidence of recolonisation by seagrasses in some areas. Aerial photographs could be used to monitor seagrass distribution, possibly at regular intervals of 2-3 years.

7. In 1980, heavy epiphytic loads were found on seagrass leaves near the former effluent outfall on Parmelia Bank (Silberstein, 1980). These were not present in the 1984/85 study, but the extent of the seagrass meadows appears to have changed little since the detailed survey in 1980. A re-investigation should be made in 1986/87.

8. No large accumulations of benthic macroalgae were encountered during the present survey.

9. A further investigation into the nutrient loads, nutrient concentrations, and phytoplankton growth is recommended, to determine the effects of the reduction in nitrogen loading likely to be achieved by CSBP. The investigation should be carried out over the 1986/87 summer.

10. It would be useful to measure the 'epiphyte' loads carried on artificial (plastic) 'seagrass', to compare with similar data from 1980, as a check on the apparent improvement in environmental conditions for the survival of seagrass.

11. If conditions for seagrasses are sufficiently improved, it would be worth investigating the use of seagrass transplants to re-establish meadows.

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