Aquatic Botany, 20 (1984) 229—243
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

THE LOSS OF SEAGRASSES IN COCKBURN SOUND, WESTERN AUSTRALIA. I. THE TIME COURSE AND MAGNITUDE OF SEAGRASS DECLINE IN RELATION TO INDUSTRIAL DEVELOPMENT

M.L. CAMBRIDGE* and A.J. McCOMB

Botany Department, The University of Western Australia, Nedlands, W.A. 6009 (Australia)

(Accepted 14 June 1984)

ABSTRACT

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. *Aquat. Bot.*, 20: 229—243.

The areas of seagrass meadows in Cockburn Sound, a marine embayment in Western Australia, were estimated from historical aerial photographs supplemented by ground surveys, studies on meadows in adjoining areas, and coring for rhizome remains. Ten species of seagrasses with different habitat tolerances are recorded for the area, with *Posidonia sinuosa* Cambridge et Kuo forming the most extensive meadows. It is estimated that from 1954 to 1978 the meadow area was reduced from some 4200 to 900 ha. Based on measurements of aboveground productivity at several sites, this represents a reduction of leaf detritus production from 23 000 to 4000 t (dry wt.) y^{-1}. The major loss of seagrass occurred during a period of industrial development on the shore, and the discharge of effluents rich in plant nutrients.

INTRODUCTION

The seagrass meadows which occurred on the sublittoral sandbanks of Cockburn Sound, a marine embayment on the Western Australian coast (Fig. 1), have become much depleted since the commencement of industrial development on the shore in 1955 (Cambridge, 1975). The present paper firstly describes the time course of meadow deterioration, documented largely from aerial photographs; secondly, provides an estimate of the loss in seagrass meadow area and productivity; and finally, presents ecological information about the seagrasses. In this ecological work, the distribution of seagrasses was examined in areas remote from industrial development, so that a study of habitats in the Sound would provide circumstantial information about the communities which were presumably once supported there. There was very

*Present address: Department of Systematic Botany, Biological Centre of the State University, P.O. Box 14, 9750 AA Haren, The Netherlands

0304-3770/84/$03.00

little direct evidence available concerning the previous distribution of the seagrasses with the exception of a localised survey of benthic fauna in 1958–1960, which included seagrass meadows on the eastern shelf (Marsh and Devaney, 1978).

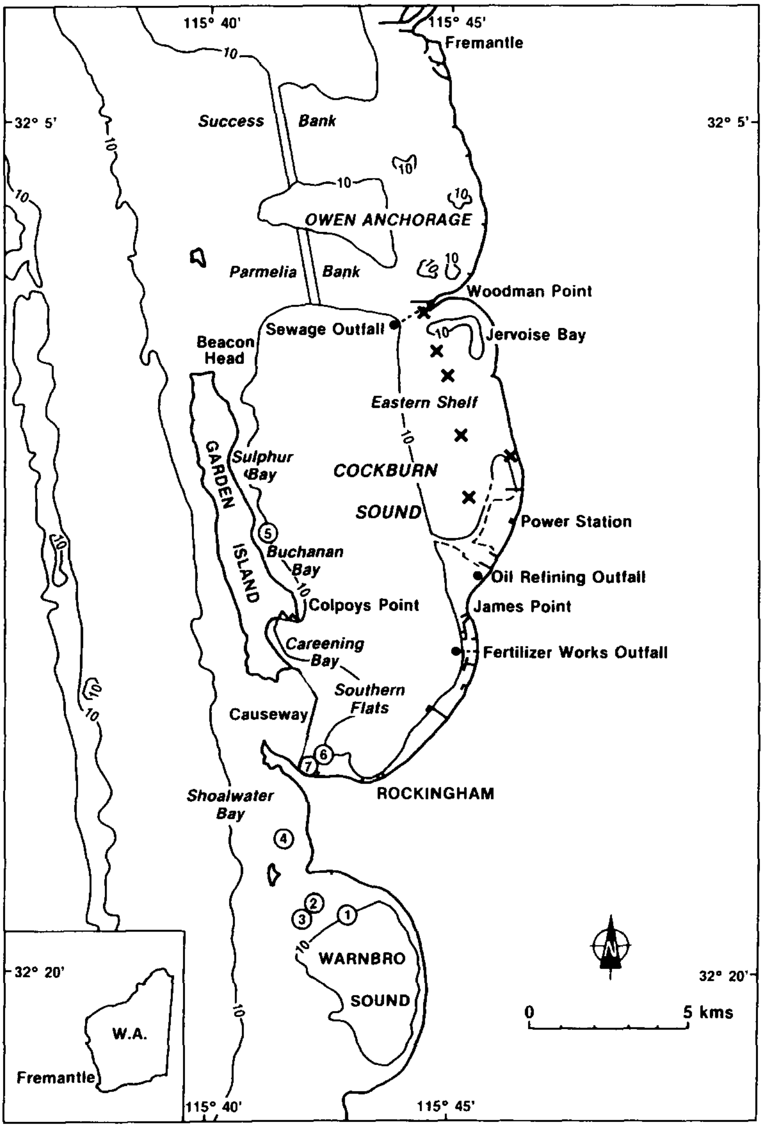


Fig. 1. Cockburn Sound, Western Australia. The numbers 1—7 indicate the sites at which seagrass productivity was measured, and crosses show the sites at which coring was carried out to seek fibrous remains of seagrass rhizomes.

MATERIALS AND METHODS

Mapping of seagrass depletion

Aerial photographs of the coast had been taken routinely each year from 1954, and these fortuitously included the eastern shore of Cockburn Sound, extending on occasions some 4 km offshore. These surveys provided some information about the distribution of seagrasses before and after industrial development began in 1955, but records for the remainder of the Sound are much less complete; for example, for the banks forming the northern and southern boundaries of the Sound. The photographs were from 1:4000 to 1:16000, of variable quality, and taken on days of differing water clarity. Some areas of the Sound were not included at any time in useful aerial photographs, and so substrate coring was carried out on sandbanks which did not have seagrasses at the time of the study, to check for the fibrous remains of seagrass rhizomes. Replicate cores were taken by divers using perspex tubing 3 cm in diameter and 50 cm long, and *Posidonia* remains were identified from their characteristic rhizome fibres (Kuo and Cambridge, 1978).

Standing crop and species composition

Plant material was collected at 16 sites (Fig. 2) from December 1970 to January 1971, at stations along transects run from the shoreward margin of a meadow, to either the deepest limit of *Posidonia* or, where the meadow covered a wide bank, to water 2—4 m deep. Three replicate quadrats, each of 0.1 m^2 and 1 m apart, were harvested at each station along the transect, and leaf lengths and widths recorded.

Standing crops were measured at 21 sites (Fig. 2) in 1977 on the three remaining extensive meadows of seagrass, from a few deteriorating stands in Cockburn Sound, and from a nearby embayment, Warnbro Sound, which had no industry but was in a residential area. The areas were chosen from aerial photographs. Harvests were made in early December, near the time of maximum standing crop. At each sampling site, two 10-m ropes were attached to a stake and run north and west. A wire frame, 0.33 m^2 in area, was placed sequentially at 12 regularly spaced stations along the ropes, and the seagrass in each harvested at the sand surface. Mussels, heavy growths of epiphytes, etc., were removed, the material sorted into species, wet-weighed, decalcified with 10% v/v HCl and dried to constant weight at 80°C. Weights of *Amphibolis* included the stems.

Primary productivity

Samples were taken at seven sites on the sublittoral sandbanks, three from Cockburn Sound, three from Warnbro Sound, and one in Shoalwater Bay

(Fig. 1). Six of these were selected to include pure stands of *Posidonia sinuosa* Cambridge et Kuo at a range of habitats (sites 4, 5 and 7 in Fig. 1), mixed-species stands (sites 2 and 3) and deteriorating areas (site 6). Two of the sites (3 and 1) were chosen because one was at the upper (0.5 m) and the other at the lower (~10 m) limit of the *Posidonia* meadow in Warnbro Sound.

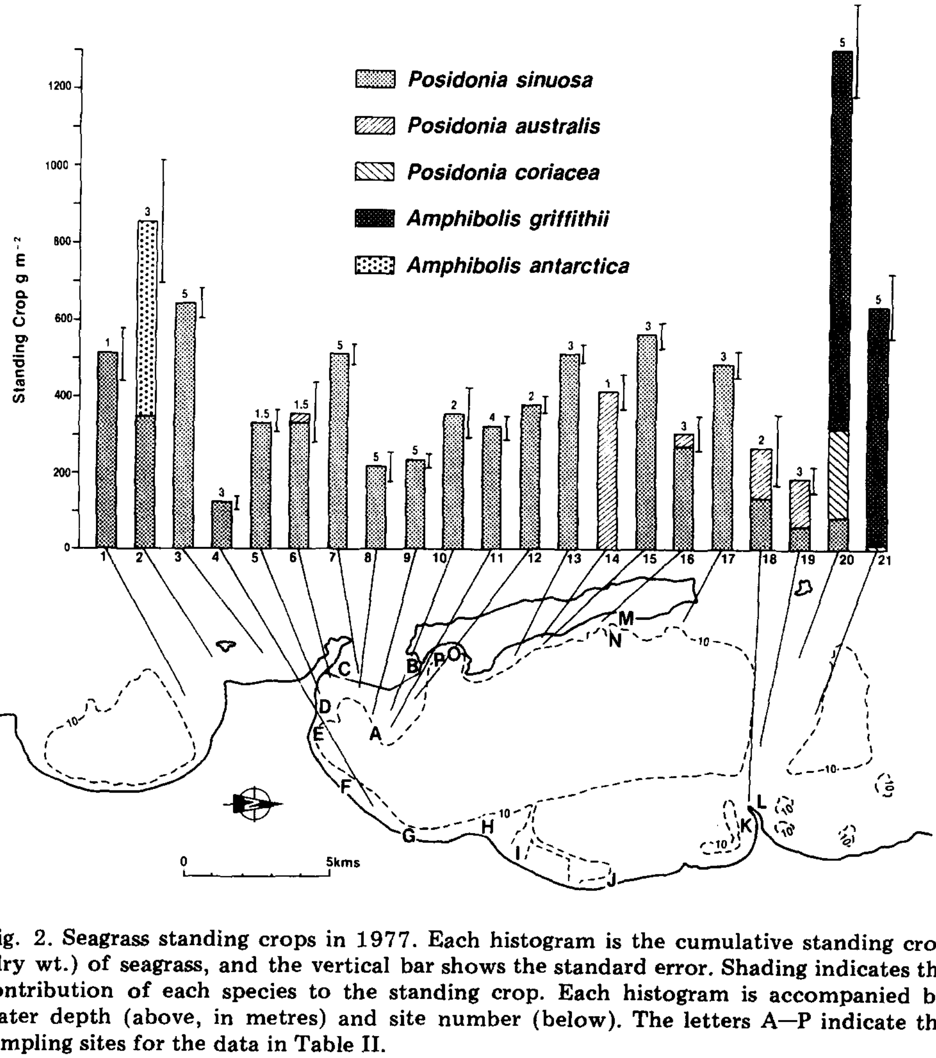


Fig. 2. Seagrass standing crops in 1977. Each histogram is the cumulative standing crop (dry wt.) of seagrass, and the vertical bar shows the standard error. Shading indicates the contribution of each species to the standing crop. Each histogram is accompanied by water depth (above, in metres) and site number (below). The letters A—P indicate the sampling sites for the data in Table II.

Quadrats (0.1 m^2) for leaf growth measurements were marked by a frame of plastic-coated steel rod, anchored level with the substrate by four steel spikes welded to the frame. Primary production was measured approximately each month from May 1977 to November 1978 by stapling near the base of each leaf blade within the frame, and harvesting one month later (Zieman, 1974). The frame was then moved to another area, where leaves were stapled for the following month's harvest. Any new leaves which had emerged between stapling and harvest were included in the production measurements.

The leaves were dipped in HCl (10% v/v, 10 s) to remove calcareous epiphytes and sediment, and lightly scraped. Staples were removed and each leaf cut level with the base of the staple, giving an "increment" and "remainder". The increment was dried to constant weight at 80° C.

On one occasion shoot densities were estimated at each site by harvesting all shoots from transects of 15 contiguous quadrats, each of 0.1 m^2, adjacent to a line running north from each growth plot.

Primary productivity was calculated by converting the length and weight increments to increment per hectare, using the shoot density estimates; the data were then summed for all growth intervals over a year.

RESULTS

Seagrass species present

Further species of seagrass have been described since the paper of Cambridge (1975), bringing the total number in Cockburn Sound to 10. Among the more recently described species is *Posidonia sinuosa* Cambridge et Kuo (Cambridge and Kuo, 1979), which is the main meadow-forming species in the Sound, formerly included in *Posidonia australis* Hook. f. *Posidonia australis*, *Amphibolis antarctica* (Labill.) Sonder et Aschers. and *A. griffithii* (J. M. Black) den Hartog are important either on the edges of meadows of *P. sinuosa* or in turbulent, disturbed areas. The smaller seagrasses *Halophila ovalis* (R.Br.) Hook. f., *Halophila decipiens* Ostenfeld, *Syringodium isoetifolium* (Aschers.) Dandy and *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog also occur in disturbed areas or beneath the main canopy-forming genera, *Posidonia* and *Amphibolis*. Voucher specimens of all species are housed in the Western Australian Herbarium (PERTH) and the University of Western Australia Herbarium (UWA).

Posidonia sinuosa is at present the most common species, and was presumably the most common before seagrass deterioration took place. This is concluded from the present distribution of the plant, an assessment in 1977 of the standing crop, and from remains of rhizomes in cores from areas presently lacking living seagrass. This species and *P. australis* display different habitat tolerances with respect to sediment supply; *P. sinuosa* forms almost pure stands on those areas of the fringing and barrier banks with low sediment accretion, whilst *P. australis* forms almost pure stands on the much smaller areas of higher sediment accretion such as sand spits, and on the margin of meadows adjacent to the beach (Cambridge and Kuo, 1979). This distribution of species in relation to sedimentation can still be seen on the Garden

Island fringing bank (Fig. 1), and was observed on the eastern bank from Rockingham to James Point before the recent loss of seagrass meadows. Other species, such as *Heterozostera tasmanica*, *Halophila ovalis*, and occasionally *Amphibolis antarctica*, were found only at the upper and lower borders of the *Posidonia* meadows on the fringing banks. *Halophila dicipiens* occurs at one location in Cockburn Sound beyond the lower limit of the *Posidonia* meadow. *Posidonia angustifolia* Cambridge et Kuo is included tentatively, as it was probably the species observed in the restricted habitat formed by occasional limestone outcrops along the outer boundary of the eastern shelf. No collections were made while the species still grew there, and before 1974 it was undescribed and included in *P. australis*. However, *P. angustifolia* has been collected from a similar habitat at North Fremantle, a few kilometres north of Cockburn Sound.

A greater diversity of species is present on Parmelia Bank, the northern barrier bank, than in other regions of Cockburn Sound. Here wave energy is diminished as westerly swell trains move across the sand bank, creating a wider range of physical environmental conditions, in which the interplay of wave energy and sediment deposition are of paramount importance. *Posidonia coriacea* Cambridge et Kuo (previously included in *P. ostenfeldii* den Hartog) (Kuo and Cambridge, 1984) and *Amphibolis* spp. are dominant at the more exposed western zone, giving way to *P. sinuosa* meadows. A few small seagrasses, including *Heterozostera tasmanica*, *Halophila ovalis* and *Syringodium isoetifolium*, occur grouped around or amongst the stands of *Posidonia* and *Amphibolis*, and in many cases seem to be eroded and torn out during storms each year, regenerating from rhizome fragments or perhaps, in the case of *Halophila ovalis*, from dormant seeds.

Seagrass standing crop, 1971 and 1977

Table I provides data for seagrass meadows at 16 sites in 1971, and records the appearance of the same sites in 1977; by that time a significant loss had taken place. Standing crops at 21 sites in 1977 are given in Fig. 2. The data may be divided into six groups on the basis of location. The standing crop of pure stands of *P. sinuosa* was consistently between 500 and 600 g (dry wt.) m^{-2} (stations 1, 3, 13, 15 and 17).

The Garden Island stations (13, 15 and 17) sampled within the mid-depth range of 2—3 m had similar values of standing crop to Shoalwater Bay (13) and Warnbro Sound (1). *Posidonia australis* is a subordinate species in the seagrass communities of the study area. The maximum standing crops of pure stands of *P. australis* were in all cases lower than those of *P. sinuosa*, and *P. australis* also occurred far less often in the samples, tending to be restricted to habitats where sand is accreting.

The highest total standing crop (1300 g m^{-2}) was measured on the western sector of Parmelia Bank (station 20) in the *Amphibolis—Posidonia* community; most of the weight was contributed by *Amphibolis*, in part because the lignified erect stems were included in the standing crop.

Stations where the standing crop of *P. sinuosa* fell below 500 g m^{-2} may be divided into two groups; those where *Posidonia* meadows had recently deteriorated, and those where *Posidonia* was growing in habitats where natural factors are unfavourable. Stations at which *Posidonia* had recently

TABLE I

The status of seagrass meadows at particular sites in 1971, and their general appearance in 1977

Site[a]	Measurements in 1971					Appearance in 1977[d]
	Water depth (m)	Number of station samples	Leaf length (m) (mean ± S.E.)	Leaf area index[b]	Taxa with *P. sinuosa*[c]	
A	3—5	6	40 ± 18	4.0		Leaf bases with mussels and bare sand
B	1—2	5	20 ± 9	2.9		Narrow band in shallows
C	0.5—1	5	32 ± 15	3.5		Causeway construction caused sand erosion; patches remaining to 1 m of water
C	1—2	5	34 ± 16	4.3	*P. australis*	
D	1—1.5	5	33 ± 15	1.2	*P. australis*	Meadow present
E	0.5	3	27 ± 11	3.2	*P. australis*	A few patches remaining in bare sand
F	2—4	6	27 ± 12	4.1	*P. australis*	As above
G	2—3	2	18 ± 6	1.8		As above
H	1—3	4	13 ± 6	0.5		Bare sand or mussels and algae on leaf bases
I	1	3	15 ± 6	0.4	*P. australis*	Bare sand
J	2—4	2	26 ± 12	2.6		A few patches around rocks in bare sand, mussels and algae on leaf bases
K	0.5—10	5	32 ± 15	4.2	*P. australis*, *Amphibolis*, *Heterozostera*	Bare sand, mussel on fibre; a few patches in shallows
L	1—5	6	34 ± 17	0.5	*P. australis*	Meadow present
M	1—3	4	39 ± 18	5.2		Dredged
N	4—5	2	36 ± 15	1.5		Dredged
O	0.5—6	8	42 ± 15	3.4		Patches in shallows, later dredged
P	0.5—5	8	40 ± 17	3.0	*P. australis*	Dredged

[a] Sites shown in Fig. 2.
[b] Area of leaf per unit area of substratum.
[c] All quadrats contained *P. sinuosa*.
[d] Leaf bases refers to fibrous remains of dead seagrass.

deteriorated included 18 and 19 on Parmelia Bank, where a plume of enriched water from the Woodman Point sewage outfall passed over the bank; 16, where dredging activity had destroyed the meadows in Sulphur Bay; 8 to 12 on the section of Southern Flats separated from the ocean by the causeway; and 5, where a few remnants of the *P. sinuosa* survived as sparse patches with evidence of sea-urchin and fish grazing on the leaves. In contrast, natural factors limit *Posidonia* at station 2 in Warnbro Sound at the interface of the seagrass meadow and unvegetated, rippled sand, where *P. sinuosa* forms a mixed community with *Amphibolis antarctica*. These factors include instability of the substrate, wave action and interspecific competition.

Stations 7 and 8 were sites 500 m apart on the eastern and western sides respectively of the causeway, and were sampled to provide a comparison for the *P. sinuosa* meadow on the oceanic and leeward sides. Examination of aerial photographs prior to the construction of the causeway shows the meadow to have been continuous across and beyond the intervening area between these stations.

Evidence for loss of seagrass in regions not covered by aerial photography or standing-crop surveys

One portion of the eastern shore, a 4-km-wide shelf from 3 to 10 m deep, was included in the aerial photographs for only ~1 km of its width. However, the presence of *Posidonia* meadows had been noted on this shelf in the 1958 survey (Marsh and Devaney, 1978), while in 1976 only a few small patches remained near the outer edge of the shelf adjacent to limestone outcrops. Six cores taken in this study from sandy substrates at 5—10 m depth (Fig. 1) contained the fibrous remains of seagrass (Table II).

Evidence for the recession of the deeper limit of the remaining meadows was also provided by cores downslope of the remaining seagrass, which in 1978 extended down to 4 m. Fibrous material derived from *Posidonia* rhizomes was found in cores down to 10 m.

From the results of the coring, the similarity in depth and substrate between areas of coring and those of the eastern shelf, and the field observations recorded by Marsh and Devaney (1978), it is inferred that seagrass meadows were present in this area until at least 1960. It is assumed that the whole shelf was sparsely vegetated between the 1- and 10-m isobaths; the area was calculated from Admiralty Chart AUS 117, "Gage Roads and Cockburn Sound".

Field observations on deteriorating meadows

Field observations were used to help in the interpretation of the aerial photographs. In healthy meadows the seagrass generally forms a continuous cover which produces a dark, dense tone in an aerial photograph. Areas of bare sand do occur in healthy meadows in turbulent areas, but have a regular shape in the form of crescents aligned with the predominant wave direction.

As the meadow deteriorates, the once continuous cover is reduced to a patchy leaf canopy. In these areas sediment is scoured out during storms.

TABLE II

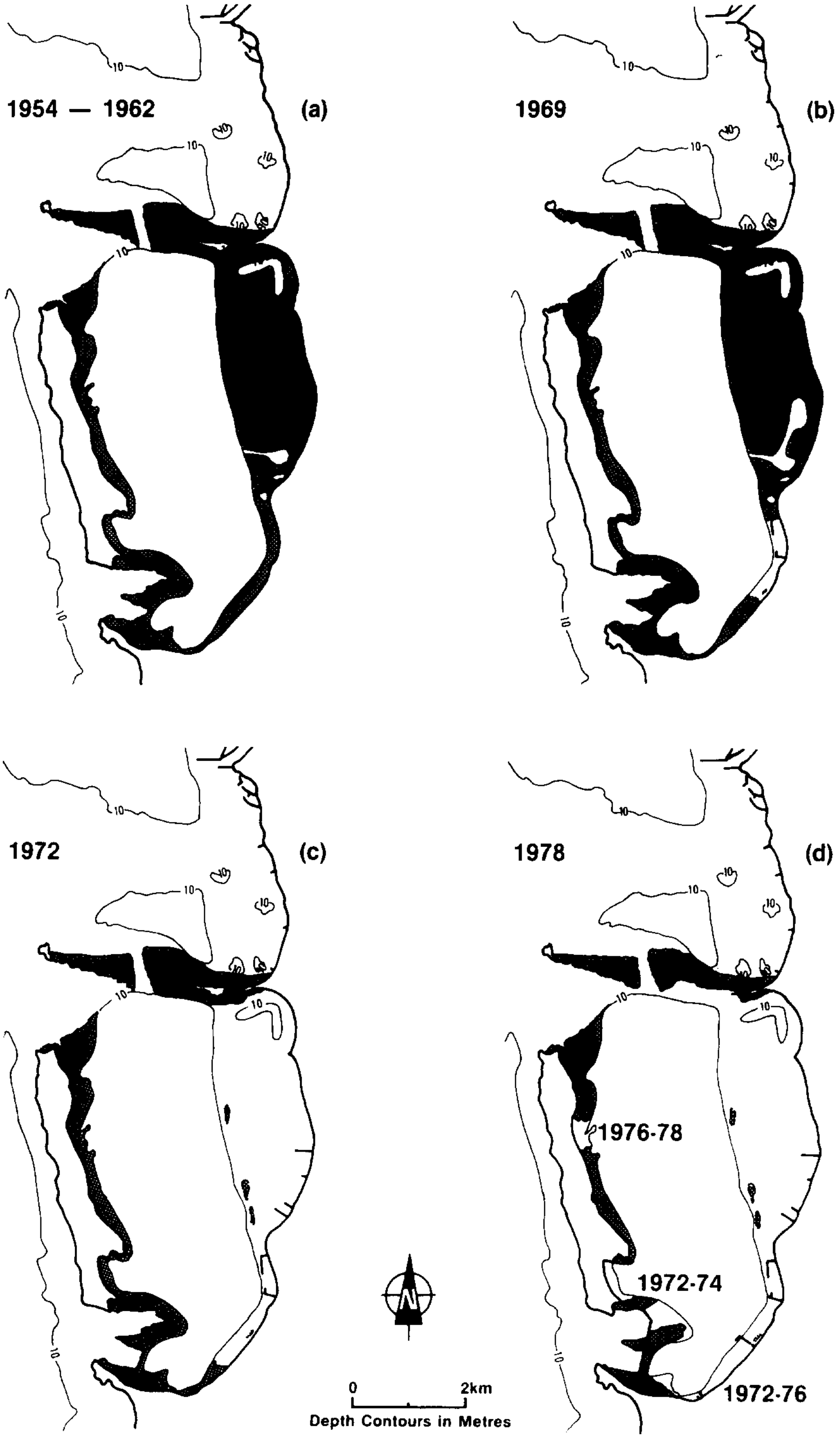
Description of sediment cores containing remains of seagrass rhizomes taken from the eastern shelf, Cockburn Sound, December 1977[a]

Water depth (m)	Core depth (cm)	Sediment profile
10	0—5	Sand and rhizomes with a thin layer of detritus
	5—13	Sand/silt mixture
10	0—5	Thin layer of worm tubes and detritus over fine sand
	5—12	Sand/silt
	12—24	Sand/seagrass rhizome material
9	0—5	Thin layer of detritus on sand
	5—15	Sand/silt with shell fragments
	15—20	Sand with rhizome material
9	0—3	Sand with detrital layer
	3—12	Light-grey sand and silt
	12—17	Sand/silt
	17—22	Coarse sand/silt, shell fragments and rhizome material
5.2	0—2	Algae and detritus with some sand
	2—15	Sand/silt layer with rhizome material
9	0—3	Fine sand/silt
	3—12	Light-grey silt
	12—17	Silt and rhizome material

[a]Sites shown in Fig. 1, and presented in this Table from north to south.

Some patches remain as islands of seagrass bounded by bare sand or rhizome mesh, their plateau-like appearance marking them as remnants of more extensive meadows. These remnants finally disappear and only an eroding fibre-bed remains as evidence of a once vigorous meadow.

In some cases, once the fibre mesh beneath the meadow has been exposed, mussels settle and algae such as *Polysiphonia* and *Ulva* form a sparse, temporary cover which may sometimes be torn loose during strong wave action. These and other species of algae sometimes form a coating 0.5—1.0 cm thick on the seagrass leaves, often extending to the leaf bases. Large *Ulva* plants were often present on deteriorating seagrass collected on the central eastern shore, adjacent to the industrial complex. These epiphytes differ from the encrusting calcareous epiphytes, and much sparser filamentous ones, which are usually present on the older one-third or one-half of the length of *Posidonia* leaves in other areas.



1954 — 1962
(a)
1969
(b)
1972
(c)
1978
(d)
1976-78
1972-74
1972-76
10
0
2km
Depth Contours in Metres
N

Time-course of meadow depletion

Using the aerial photographs and the supplementary evidence on seagrass distribution, four composite interpretations were produced of the progressive changes in seagrass distribution from 1954 to 1978. These are presented in Fig. 3, and details of the sources of information are given in the figure caption.

The major events in the sequence of dieback are summarised in Table III. The first detectable loss was a patch of 4 ha from James Point, southwest of the oil-refinery outfall, between 1961 and 1962. A narrow strip of seagrass was also lost from the northern edge of the James Point bank at some time between 1960 and 1962. Rapid depletion of seagrass then occurred on the central eastern shore, south of James Point, first detected in aerial photographs in late 1968, and spreading rapidly in the next two years along some 5 km of the coast, from north of James Point south to Rockingham. Seagrass was eliminated from the eastern shelf between 1960 and 1976; the dates cannot be specified more precisely in the absence of aerial photographic records. The meadows on Southern Flats were lost between 1970 and 1976.

There is a clear distinction between the dieback which extended rapidly along the eastern shore from 1969, and localised losses which can be related to specific events, especially after 1970 when construction of the causeway across the southern entrance of the Sound began. Losses were associated with causeway construction, including scours around breakwaters from funnelling of waters through restricted openings in the solid-fill causeway. Seagrass cover has also been removed directly by dredging; from Woodman Point along a sewage pipeline, along a shipping channel through Southern Flats, from the Stirling Channel north of James Point, and from Sulphur Bay and Parmelia Bank. Dredging for limesand along the route of a proposed shipping channel on Parmelia Bank removed some 400 ha of seagrass. There are also losses from boat moorings, and anchor-drag scars. However, at all of these sites, apart from localised effects, there have been no further losses in adjacent meadows.

The Garden Island bank now supports the last remnant of the extensive *P. sinuosa* meadows which once covered the western and eastern shore, and portions of the Southern Flats. These meadows appear to have survived because of the prevailing water-circulation pattern, which results in ocean water being drawn south along the Garden Island shore (Steedman and Craig, 1983; Chiffings and McComb, 1981). *Posidonia* meadows in Careening Bay

Fig. 3. Distribution of seagrass meadows in Cockburn Sound at different times. Each representation is a composite based mainly on aerial photographs. Figure 2(a) is based on those of 1954 for the eastern shore, 1967 for the Garden Islandshore, and 1970 for Southern Flats. The dating of the loss of seagrass meadows from the northern part of the eastern shore cannot be given precisely, because of poor aerial photographic coverage. Dates within (d) show the time during which seagrass depletion took place in localised regions.

TABLE III

Summary of dates of main events in seagrass decline, and of industrial and port development

Date	Seagrass meadows	Industrial and other developments
1955	Seagrass meadows in undisturbed state	Oil refinery begins discharging cooling waters at James Point
1961—1962	4 ha seagrasses lost on James Point near to oil-refinery outfall	
1966	No photographs or observations	Sewage-treatment plant begins discharging southwest of Woodman Point
1968	No photographs or observations	Blast furnace begins discharging cooling water coloured with black particulates
1968	No photographs or observations	Nitrogen-fertilizer plant begins discharging
1969	First signs of main seagrass loss, later to become the major depletion along the eastern shore	Phosphate-fertilizer plant begins discharging
1970		Power station releases cooling water
1971—1973	Localised losses due to scouring beneath bridges and dredging; loss of seagrass south of Woodman Point	Construction and dredging of a solid-fill limestone causeway across the southern entrance, with two bridges allowing access to open ocean; dredging associated with building and launching an oil-rig platform at Woodman Point
1974—1976	Loss of seagrass on Southern Flats in the lee of causeway	
1976—1977	Localised losses due to dredging and dumping of dredge spoil	Construction and dredging for access jetty at Sulphur Bay, Garden Island

were reduced from a continuous band extending from low water to 6 m in 1971, to a few patches in the shallows 0.5—1 m deep by 1977.

Changes in meadow area and aboveground production

The area covered by seagrass was estimated to have been 4195 ha in 1954, and 889 ha in 1978. The annual production of *P. sinuosa* and *P. australis* at the sampling stations is shown in Table IV. A detailed analysis of the differences between the sites in relation to environmental variables and season will be published elsewhere. In the present context the data provide a basis upon which estimates of aboveground productivity before and after loss of meadows can be based. In 1954, it is estimated that 4000 ha of *Posidonia* produced almost 23 000 t (dry wt.) of leaf material each year. By 1978, with less than 900 ha of seagrass remaining and a number of areas showing decreased productivity, the total production had fallen to 4000 t (Table V).

TABLE IV

Annual production of *Posidonia sinuosa* and *Posidonia australis*

Station[a] and depth	Annual increment of leaf area (m^2 (leaf) m^{-2})	Aboveground productivity t (dry wt.) ha^{-1}
Posidonia sinuosa		
Warnbro Sound		
1 11 m	2.8 ± 0.21	1.0 ± 0.1
2 2.5 m	12.8 ± 0.78	5.4 ± 0.3
3 5 m	16.3 ± 2.62	8.0 ± 1.3
Shoalwater Bay		
4 3.5 m	13.9 ± 0.18	6.67 ± 0.86
Cockburn Sound		
5 2.5 m	11.1 ± 1.14	5.15 ± 0.52
6 2 m	1.5 ± 0.24	0.70 ± 0.11
7 1 m	15.8 ± 1.40	8.06 ± 0.71
Posidonia australis		
Warnbro Sound		
2 2.5 m	24.2 ± 2.54	11.4 ± 1.2
3 0.5 m	2.6 ± 2.96	1.3 ± 0.2

[a]Stations shown in Fig. 1.

DISCUSSION

The depletion of seagrass from Cockburn Sound occurred as the area changed from one visited by relatively few holiday-makers, to an industrial centre and port. Studies of degraded ecosystems are often undertaken only when their deterioration is well advanced, so that assessment of the pristine condition presents some difficulties. Cockburn Sound was no exception. Nevertheless, some general trends are clear, and, as pointed out above, it is possible to distinguish between what appear to have been localised events, and the more massive loss of seagrasses on the eastern shore beginning in late 1968 and continuing over an extensive area and throughout the period of the investigation.

Included in Table III is a summary of the main industrial developments which have taken place in the Sound. Construction of the complex began in 1954, with the establishment of the oil refinery, and with the successive establishment of steel works, fertilizer factories, sewage-treatment works and a power station there has been an increasing amount of industrial effluent discharging into the waters (Murphy, 1979). These effluents have included wastewater contaminated with hydrocarbons, nitrogen compounds and phenolics, and, immediately preceding and during the period of rapid decline, effluents rich in nitrogen and phosphorus from the fertilizer works. Studies on nutrients and phytoplankton in the waters of the Sound suggest strongly that of the two nutrients, nitrogen is likely to be limiting for algal

TABLE V

Estimation of seagrass aboveground primary productivity in Cockburn Sound, 1954 and 1978

Location	1954			1978		
	Area (ha)	Primary productivity (t ha^{-1} y^{-1})	Total production (t (dry wt.) y^{-1})	Area (ha)	Primary productivity (t ha^{-1} y^{-1})	Total production (t (dry wt.) y^{-1})
North of Garden Island	73	6.67	487	73	6.67	487
Garden Island shore (Beadon Head—Colpoys Point)	324	5.15	1 669	300	5.15	1 545
Careening Bay	4	5.15	21	<0.1	3	<0.3
Rockingham Bank (Palm Beach—north of James Point)	440	5.39	2 372	<1.0	0.7	<0.1
Nearshore eastern shelf	124	5.39	668	<0.1	0.7	<0.1
Eastern shelf	2 350	5.15	12 103	5	0.7	3.5
South of Woodman Point	23	7.99 5.39	92 62	10	0.7	7
Parmelia Bank	300	5.39	1 617	200	5.39	1 078
Totals	4 196		22 813			4 021

productivity, since phosphorus is present at high levels (Chiffings and McComb, 1981). It is not the purpose of this paper to review the mechanisms which may have been responsible for the decline; these will be examined in a subsequent paper. Suffice to say at this stage that there appear to be a general correlation between the main process of loss, and the discharge of effluents rich in plant nutrients.

Ecologically, the loss of seagrass has brought about a change in the main primary producers from benthic to planktonic, a loss in leaf detritus production accompanied, presumably, by changes in food chains (e.g., Lenanton et al., 1982), and a loss of large areas with considerable structural diversity as compared to the bare sand which has remained after the death of the seagrass meadow. There has been a change in fish fauna, as some species are exclusive to either seagrass meadows or a sand substrate (Dybdahl, 1979). The habitat of the black mussel *Mytilus edulis* L. has expanded greatly, as the fibrous rhizome mesh left behind after the loss of seagrass provides a substrate for settlement, and beds of mussels many hectares in area grow until removed by storms. With the loss of seagrass meadows, changes in beach morphology may be expected because of enhanced erosion during storms (France, 1978).

ACKNOWLEDGEMENTS

We are indebted to the Department of Conservation and Environment, Western Australia, for financial support, and to other members of the Cockburn Sound Study Group for their help and advice.

REFERENCES

Cambridge, M.L., 1975. Seagrasses of south-western Australia with special reference to the ecology of *Posidonia australis* Hook. f. in a polluted environment. Aquat. Bot., 1: 149—161.

Cambridge, M.L. and Kuo, J., 1979. Two new species of seagrasses from Australia, *Posidonia sinuosa* and *P. augustifolia* (Posidoniaceae). Aquat. Bot., 6: 307—328.

Chiffings, A.W. and McComb, A.J., 1981. Boundaries in phytoplankton populations. Proc. Ecol. Soc. Aust., 11: 27—38.

Dybdahl, R.E., 1979. Cockburn Sound study technical report on fish productivity. Rep. No. 4, Department of Conservation and Environment, Western Australia, 96 pp.

France, R., 1978. The sedimentology of barrier and fringing banks in Cockburn Sound and the effect of industrial development on sedimentation. Department of Geology, University of Western Australia, 105 pp.

Kuo, J. and Cambridge, M.L., 1978. Morphology, anatomy and histochemistry of the Australian seagrasses of the genus *Posidonia* König. Aquat. Bot., 5: 191—206.

Kuo, J. and Cambridge, M.L., 1984. A taxonomic study of *Posidonia ostenfeldii* (Posidoniaceae), with description of four new Australian seagrasses. Aquat. Bot., 20: 267—296.

Lenanton, R.C., Robertson, A.I. and Hansen, J.A., 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. Mar. Ecol. Prog. Ser., 9: 51—57.

Marsh, L.M. and Devaney, D.M., 1978. The benthic fauna of Cockburn Sound, Western Australia. Parts II—IV. Western Australian Museum, Perth, Western Australia, 23 pp.

Murphy, P.J., 1979. Cockburn Sound study technical report on industrial effluents. Rep. No. 6, Department of Conservation and Environmental, Western Australia, 297 pp.

Steedman, R.K. and Craig, P.D., 1983. Wind-driven circulation of Cockburn Sound. Aust. J. Mar. Freshwater Res., 34: 187—212.

Zieman, J.C., 1974. Methods for the study of the growth and production of turtle grass (*Thalassia testudinum*). Aquaculture, 4: 139—143.