



Seagrass loss associated with boat moorings at Rottneest Island, Western Australia

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(Received 25 July 1994; accepted 30 November 1994)

ABSTRACT

Loss of seagrasses caused by mooring damage at Rottneest Island, Western Australia, was studied using aerial photographs taken between 1941 and 1992. The temporal decline of seagrass beds damaged by moorings was studied by comparing areal coverages of seagrasses and sand patches, and increases in the length of the exposed seagrass edge within seagrass beds. The study concentrated on Rocky Bay and Thomson Bay where the bulk of permanent moorings are located. Rocky Bay is more exposed to the prevailing westerly swell direction and Thomson Bay is a protected east facing bay. The loss of seagrasses associated with moorings in Rocky Bay has been dramatic, with 18% of seagrass area lost between 1941 and 1992, and 13% between 1981 and 1992. The exposed edge of the beds increased by 230% between 1981 and 1992. Sand patches associated with moorings have coalesced in the shallow central west part of the bay. The change from single weighted swing moorings to three chained cyclone moorings has resulted in greater loss of seagrasses. Single cyclone moorings produce three circular holes in the seagrass bed. The areal loss recorded from Thomson Bay was less than 5%, yet the exposed edge of the seagrass beds doubled between 1941 and 1992. Fragmentation of the bed was visible near heavy use areas. Some regrowth was recorded to the north of the main ferry jetty where the sedimentary environment is depositional. The effects of moorings on seagrasses at Rottneest Island varied from devastating in Rocky Bay to small in Thomson Bay. The differences seem to be related to exposure to prevailing swell and

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whether the environments are erosional or depositional. Thus a single management protocol, such as cyclone moorings versus swing moorings, is inappropriate. Physical environments need to be assessed before determining the number and types of moorings allowable in bays at Rottnest Island.

1. INTRODUCTION

This study documents the temporal course of damage to seagrass meadows by boat moorings at Rottnest Island, Western Australia. Seagrasses in southwest Western Australia have been identified as being sensitive to physical disturbances^{1,2} as well as nutrient enrichment.^{3,4} According to Kirkman,¹ seagrass beds do not regrow or recolonise areas where seagrasses including their rhizomes have been removed.

A regional study of the effects of boat moorings on seagrass beds in the Perth metropolitan area concluded that boat moorings were responsible for the loss of 5.4 ha or <2% of the total seagrass cover in the region.^{5,6} In comparison, seagrass loss associated with eutrophication within the Cockburn Sound region of the Perth metropolitan area was 3300 ha or 78% between 1954 and 1978.³

Despite the small amounts of seagrass lost due to moorings in a region-wide context, the losses are concentrated in local areas and have considerable visual impact in these areas. Walker *et al.*⁶ reported that in the Perth region, most damage to seagrasses caused by moorings had occurred at Rottnest Island. Rottnest Island has a significant proportion of the permanent moorings within the greater Perth region with 917 private moorings distributed between 8 bays (Table 1).

TABLE 1
Number of moorings in bays at Rottnest Island, 1992

<i>Bay</i>	<i>Number of moorings</i>
Thomson Bay	330
Longreach Bay	77
Geordie Bay	94
Catherine Bay	34
Stark Bay	97
Narrow Neck	193
Marjorie Bay	63
Porpoise Bay	29
Total	917

The boat mooring study of Walker *et al.*⁶ addressed the condition of seagrass meadows observed in 1987. They did not study the rate of loss of seagrasses caused by boat moorings. In this paper we further investigate the effects of moorings on seagrass beds at Rottnest Island by studying the temporal changes in area of seagrasses and sand patches, and in the exposed edge of seagrass beds. The temporal course of seagrass change (mostly loss) was studied by mapping and comparing aerial photographs taken in 1941, 1966, 1972, 1981 and 1992. The study is concentrated on the bays with the greatest number of moorings at Rottnest Island—Rocky Bay and Thomson Bay.

2. THE STUDY AREA

Rottnest Island lies 18 km off the coast of Perth, Western Australia. It is an intricately shaped island with an area of approximately 1900 ha and an east–west orientation (Fig. 1). The island is composed of geologically young (late Pleistocene to Holocene), lithified, aeolian calcarenites and is surrounded by both dune limestone reefs and platforms, modern living coral reefs, and extensive sand and seagrass habitats. It has a Mediterranean climate. Tides are microtidal, the maximum daily range being approximately 1 m and the extreme range being 1.5 m.⁷⁻⁹

Rottnest Island is an A Class Reserve for recreation and is managed by the Rottnest Island Authority (RIA). The RIA provide mooring sites for boats in many of the bays around the island. The mooring gear is privately owned but the mooring sites are leased from, and managed by, the Rottnest Island Authority, who attempt to make sure moorings are maintained and are of the correct design.⁹

Rocky Bay is situated on the north coast at the west end of the island, fronting a narrow isthmus known as Narrow Neck (Fig. 1). It forms a shallow, arcuate bay containing numerous aeolianite reefs and it receives significantly greater wave energy than Thomson Bay. At Rottnest, a high proportion of swell waves arrives from the southwest and west while there is negligible swell from the east (Table 2). Maximum deepwater wave heights at West End are around 1.4–2.5 m and there is minimal refraction of S, SW and WSW waves into Rocky Bay.⁹ Wave, wind and topographically induced currents can be strong in the bay and may trend both obliquely ENE and WNW out of the bay depending on swell and weather conditions.

Thomson Bay is a long, sheltered bay facing ENE (Fig. 1). There is little to no easterly swell (Table 2) and other swell that enters the bay

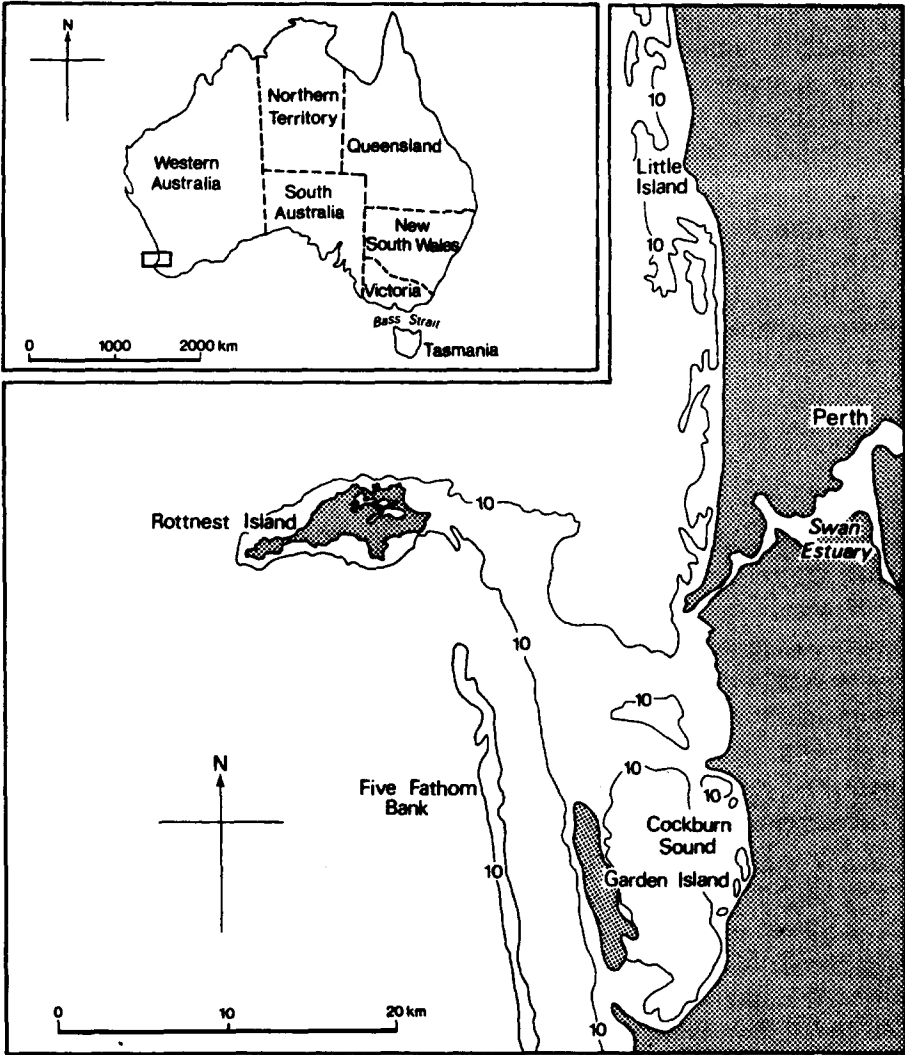


Fig. 1. Location of Rottneest Island.

is highly refracted and generally of low energy. Easterly wind waves can be significant at times within Thomson Bay but wave heights seldom exceed 0.5–0.8 m. Wave and wind induced currents can be strong particularly in the southeastern part of the bay where they typically trend east to WNW.

TABLE 2
Percentage frequency of occurrence of swell direction and amount observed in the Perth region¹⁰

<i>Time</i>	<i>Direction</i>	<i>All swells</i>	<i>Heavy swell</i>
Summer (Jan.)	South	29%	3.5%
	Southwest	46%	6%
	West	4%	1%
Winter (July)	South	8%	3%
	Southwest	44%	1.6%
	West	31%	14%
	Northwest	8%	1.5%

3. MATERIALS AND METHODS

Vertical aerial stereo photographs dating from 12 June 1941 were used to map the extents of seagrasses, sand and aeolianite reef at Narrow Neck and Thomson Bay (Table 3). Aerial photographs were chosen on the basis of their availability, and the depth penetration and contrast of the photographs. The seagrass meadows in both Rocky Bay and Thomson Bay are predominantly dense monospecific meadows of *Posidonia sinuosa*, *Posidonia australis*, *Amphibolis antarctica* and *Amphibolis griffithii*. These seagrass species were indistinguishable from each other in the aerial photographs.

The photographs were scanned, converted to a common scale and the scanned images analysed in two ways. The changes in the areas of sand and seagrasses within bays were determined by mapping the margins of the sand patches and reefs which were clearly visible on the scanned photographic images. These hand drawn maps were then placed on a

TABLE 3
Aerial photographs used in interpretations (Western Australian Lands and Surveys Department)

<i>Series</i>	<i>Date</i>	<i>Area</i>	<i>Run</i>	<i>Scale</i>
WA	12/6/41	Rottnest	1-2	1:12 500
WA 991	13/11/66	Rottnest	1	1:4800
WA 1420(C)	16/10/72	Rottnest	1-2	1:15 840
WA 2013(C)	18/10/81	Rottnest	1-2	1:10 000
WA 3077(C)	10/5/92	Rottnest	1-2	1:5000

1:5000 bathymetric map base so that land margins and reef areas were standardised, and northings and eastings could be established. The data were then input into ARC-INFO, a Geographic Information System (GIS) software package, and a series of ARC-INFO coverages were produced. Summary statistics of areal change in sand and seagrass were computed within ARC-INFO, and a coverage was produced from this software illustrating the spatial changes in sand and seagrass cover over the 51 year period. Also, the circumferences of sand patches that were associated with moorings within the seagrass meadows were determined using a separate image analysis program (NIH Image 1.44). The circumferences of sand patches were added together to measure the length of the exposed edge of the seagrass meadow, and to supply information on the fragmentation of the seagrass meadow independent of changes in area of seagrasses and sand patches.

3.1. Methodological errors

There were a variety of methodological errors possible in the way in which the mapping was carried out. These are briefly addressed here.

Firstly, the photographs were uncorrected aerial photographs which meant there was some distortion of the image, particularly at the edges. We therefore only mapped from the middle of stereo pairs of photographs.

Secondly, the photographs were taken at widely varying scales ranging from 1:5000 to 1:50 000 so the degree of error was different between different photographs. We attempted to minimise this by scaling all images to a similar scale (1:5000) to closely match an enlarged standard bathymetric map overlay (PWD WA 54153).

Thirdly, the quality of the images varied and hence the ability to distinguish sand patches varied. Some photographs had part or all of the area of interest affected by flaring of the image by the sun, change in the contrast caused by clouds, and reflection from algal blooms in the surface waters which led to difficulties in interpretation and image analysis. The area of sand and the circumference of the sand patches within bays are not presented for some dates (e.g. Thomson Bay) because we were not confident in our interpretation, due to one or more of these factors. In the case of the GIS method, the varying quality of the images (particularly the black and white images) meant that there was some observer bias in determining whether a sand patch (particularly a small one) was present. We attempted to overcome this by having all three of the authors independently map the images.

Overall, we do not believe that the error is greater than 5% on any one mapped year, and in many cases is considerably less than this.

Finally, we analysed the length of the exposed edge of seagrasses that are only associated with moorings within the ARC-INFO mapped areas and make comparisons with areal coverages difficult. We did not map the edges of the seagrass beds not associated with moorings, as was done in the ARC-INFO coverages. The exposed edges of seagrasses associated with moorings were determined using NIH Image 1.47 on 300 dpi scanned images. The analysis of exposed edges is included, not for comparison with areal coverages, but to look more closely at the specific damage associated with moorings.

4. CHANGES IN SEAGRASS AND SAND AREAS

4.1. Rocky Bay

Moorings have had a demonstrable impact on the seagrass meadows in Rocky Bay opposite Narrow Neck (Fig. 2). The areal extent of seagrasses has decreased by 18% since 1941 with most of the loss (13%) recorded between 1981 and 1992 (Fig. 2, Table 4). Sand patches within the seagrass meadows have increased by at least 36 000 m² between 1941 and 1992, and most of the increase has occurred between 1981 and 1992 (26 819 m²). This represents an increase of approximately 2500 m² year⁻¹, 10 times greater than the annual increase recorded between 1941 and 1972. Numbers of moorings in Rocky Bay increased from 81 in 1977 to 196 in 1985, then decreased to 191 by 1992. Combined with the increase in the number of moorings over these years was an increase in the size of the boats frequenting the bay (P. Hesp, personal observation).

The losses of seagrasses in Rocky Bay have been in the western and northwestern parts of the bay where irregular sand patches associated with moorings have coalesced and enlarged along their edges (Fig. 3: 1941 and 1992 ARC-INFO coverages). Interestingly, there are some small areas of 'positive' change where seagrass has re-established. These areas are chiefly in the westernmost tip of the study area, and near and along the beach. In the latter case, Fig. 2 shows that the seagrass is quite dynamic along the outer margin of the narrow surf zone.

The seagrass beds within Rocky Bay have undergone visible fragmentation since 1981. The length of exposed edges of seagrass beds has increased by almost 260% since 1981. Increases in the length of

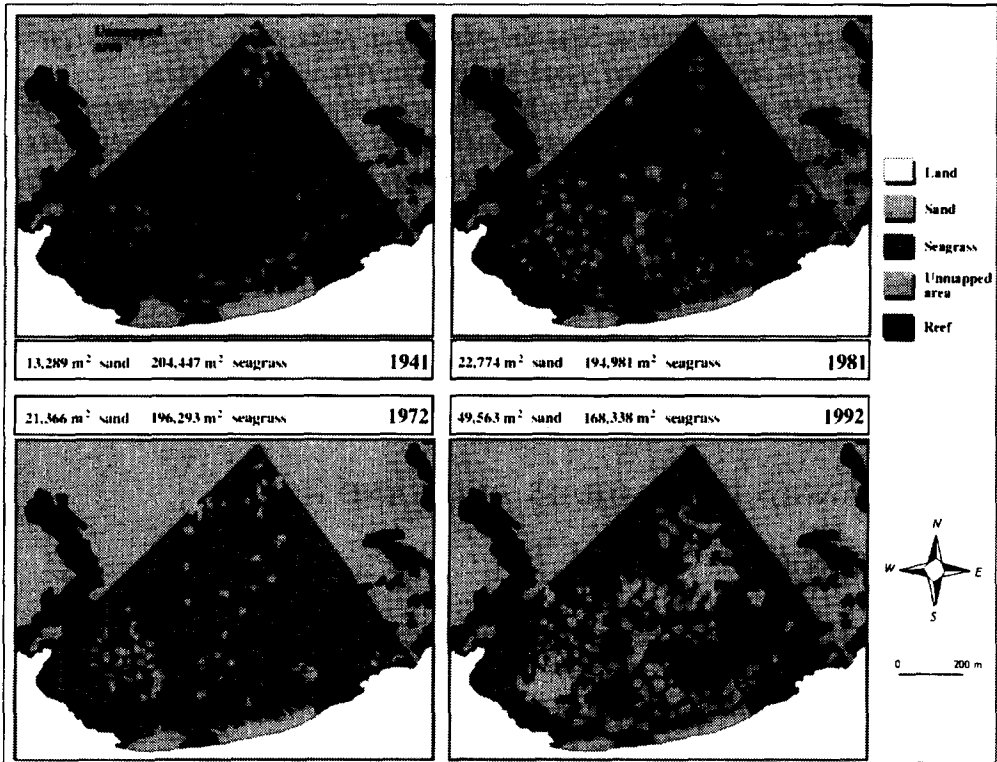


Fig. 2. ARC-INFO images of the Rocky Bay area, Rottneet Island, for four photographic periods. The areal extent of sand (white areas) and seagrass (dark grey within survey triangle) is indicated for each period.

TABLE 4

Area of sand and seagrass (m²) determined from ARC-INFO database for period between 1941 and 1992 for Rocky Bay, Thomson Bay South and Thomson Bay North

Bay	Year	Area of sand	Area of seagrass
Rocky Bay	1941	13 289	204 447
	1972	21 366	196 293
	1981	22 774	194 981
	1992	49 563	168 338
Thomson Bay South	1966	112 703	340 203
	1992	119 078	333 358
Thomson Bay North	1966	43 466	101 159
	1992	47 533	97 003

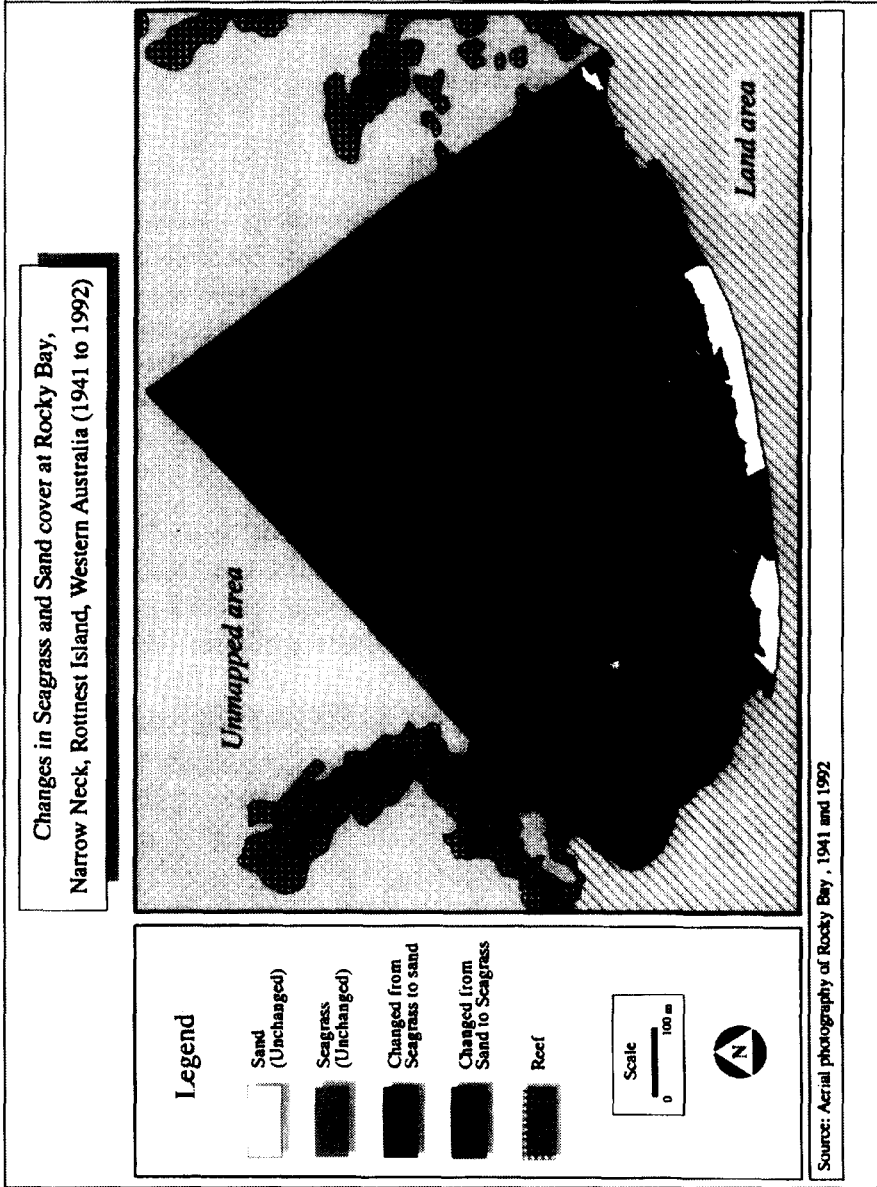


Fig. 3. ARC-INFO/MIRAGE overlay map generated from the 1941 and 1992 data illustrating changes in seagrass and sand habitats within Rocky Bay, Rottnest Island. Significant loss of seagrass meadow has occurred within the 51 year period. (Created by Chang Chew Hung and Kathleen Hastings.)

exposed edges of less than 50% were observed from 1972–1982 and 1941–1972. The large increases in exposed edges of seagrass beds in Rocky Bay suggest fast rates of fragmentation, and the stabilities of these beds are in question given the direction and size of change in just over 10 years.

The Rottneest Island Authority implemented a change in the type of mooring gear around 1986. Moorings were switched from a single leg (one chain) type to a 'cyclone' mooring, which comprises a three leg chain system joined to an upper single chain for craft above 12 m length (two chains or legs for craft below 12 m). The cyclone mooring is held on the bottom by railway wheels or track sections, concrete blocks or other heavy items. The change from swing to cyclone moorings occurred because of perceived seagrass losses associated with swing moorings. Walker *et al.*⁶ found the mean size of scour from swing moorings to be 39 m² whereas for cyclone moorings the scour was 3 m². Figure 4 demonstrates that this is not necessarily the case. A careful examination of the 1992 photograph reveals that instead of one scoured sand patch around a mooring, there are often three, 10 m diameter, circular sand patches in a triangle (Fig. 4B). Diver observations on several of these 'tri-circle' patches revealed that the lower anchor chains were scouring the seabed and seagrasses. The sand patches associated with moorings have also coalesced in the shallow central area of the

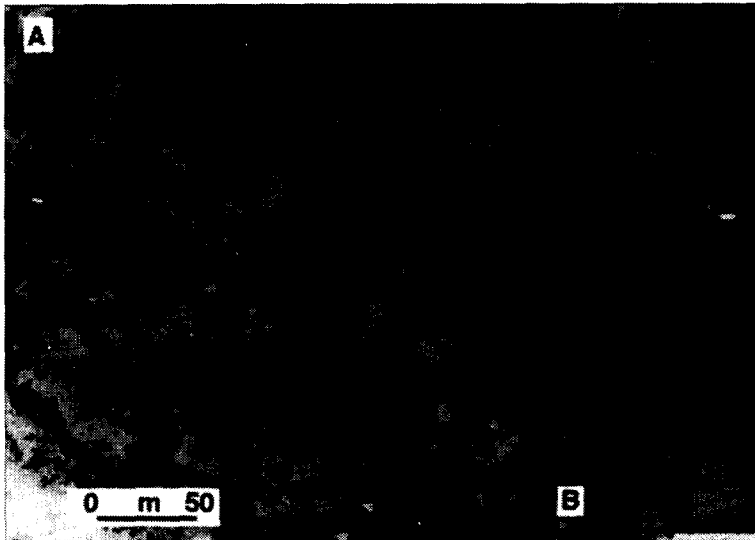


Fig. 4. (A) A portion of the 1992 photographic image showing the nature and distribution of sand patches, seagrass and reef within Rocky Bay. (B) An enlarged view of the portion marked, illustrating the 'tri-circle' sand patches which have developed as a result of the incorrect construction of three legged cyclone moorings.

bay, the total impact being greater than that of a single mooring (Fig. 4).

4.2. Thomson Bay

Thomson Bay south of the main ferry jetty (Thomson Bay South) has been analysed separately from the area to the north of the main jetty (Thomson Bay North). Thomson Bay South extends from the natural jetty (a linear, aeolianite intertidal and subtidal reef) to the main jetty. Our mapping extends to within around 400 m of the natural jetty. Medium term beach erosion is taking place along the central part of the bay south of the main ferry jetty, while beach accretion is occurring to the north.

4.3. Thomson Bay South

4.3.1. *Historical background*

The nearshore areas of this seagrass meadow have been impacted since the 1840s, when Rottneest was initially a penal colony and later a summer holiday resort. In the 1930s the Army constructed a line of barge moorings trending south–north about 300 m WNW of the Army jetty (Fig. 5). In addition, the Army established several lines of equally spaced moorings along the bay and parallel with the beach. These lines of moorings are just visible in 1941 aerial photographs, and the sand patches created in the seagrass meadow have persisted to the present day (Fig. 5). It was not possible to accurately map from 1941 to the early 1960s due to poor photographic quality, but it is critical to realize that the impacts on seagrasses in Thomson Bay date back to the 1930s.

In more recent times, but again primarily in the period prior to 1966, the nearshore areas in Thomson Bay South have been altered by boat mooring, marine dredging, construction and enlargement of the main jetty, and use of this jetty in recent years by large, high powered ferries (see the Main Jetty area on Fig. 5).

4.3.2. *1966 To the present*

There has been little change in the area of seagrass within Thomson Bay South between 1966 and 1992 (Fig. 6). Loss of area of seagrasses through mooring damage (2%) between 1966 and 1992 has not been as great as observed in Rocky Bay. It is also within the measurement error associated with the interpretation of an aerial photograph from a single year (5%).

In the case of the north–south Army barge mooring line, the large

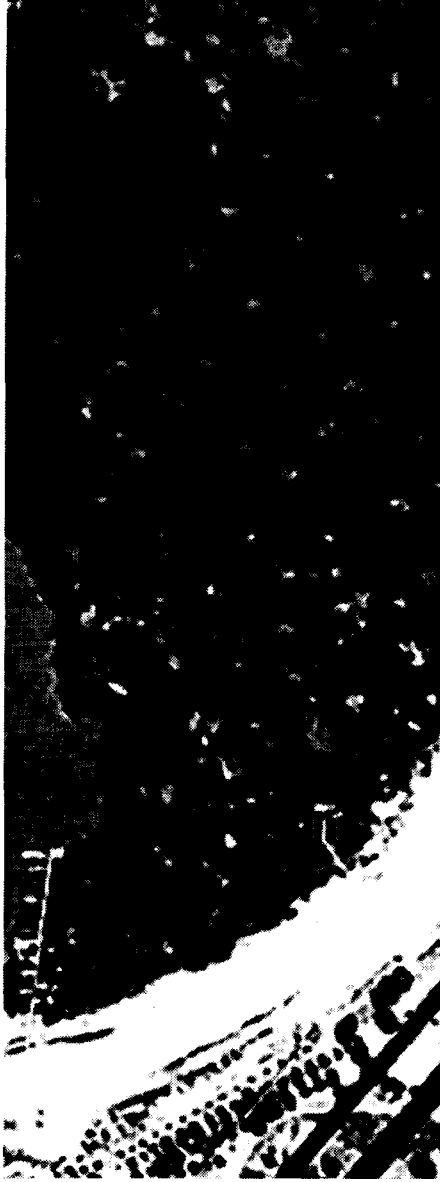


Fig. 5. A section of Thomson Bay South lying between the Fuel Jetty and south of the Hotel Jetty indicating the lines of original army moorings (trend indicated by arrows) established prior to 1941 (A) and still visible in 1966 (B) and 1992 (C).

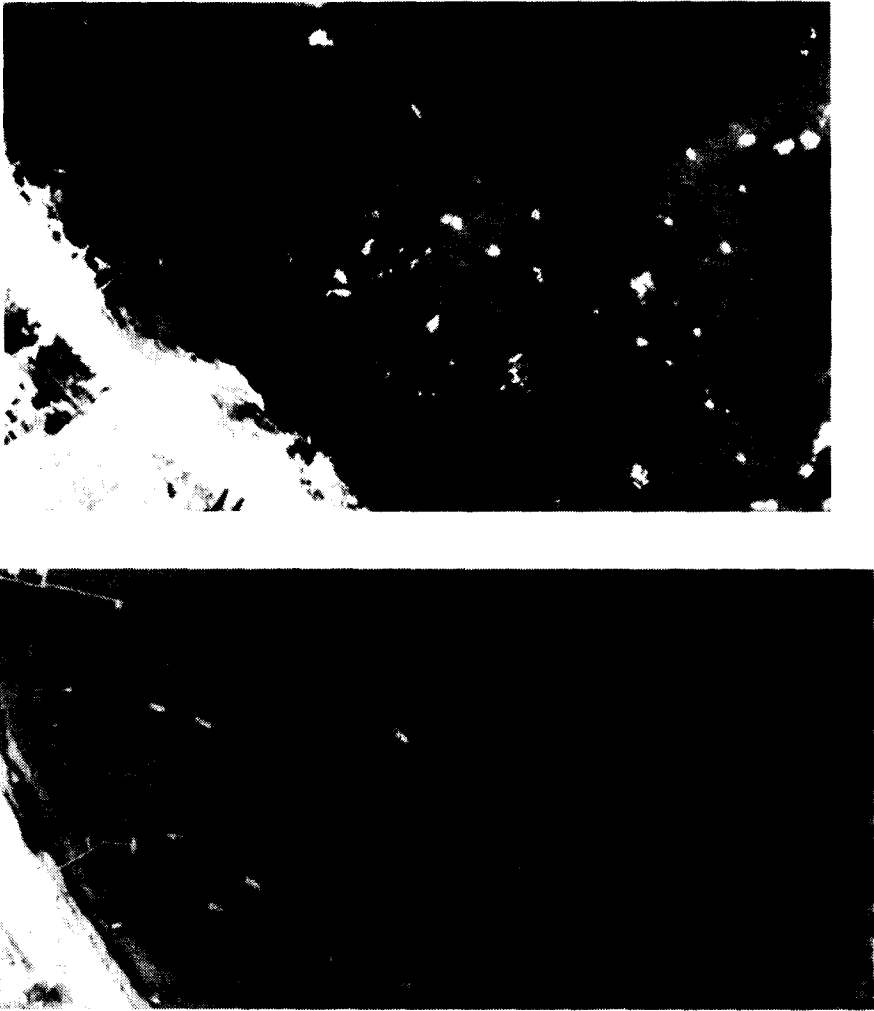


Fig. 5. (*Continued*).

sand patches and defined eastern edge are readily observable on the 1966 photographs (Fig. 5). This line of sand patches has persisted through to 1992 (Fig. 5 and Fig. 6) although the defined edge is less obvious and parts of the patches have been recolonised with seagrass. Similarly, the alignment and placement of moorings, and their associated sand patches, in an ESE-WNW direction within the northern section of Thomson Bay South, remain much as they were in 1941, although they are gradually becoming less obvious as other sand

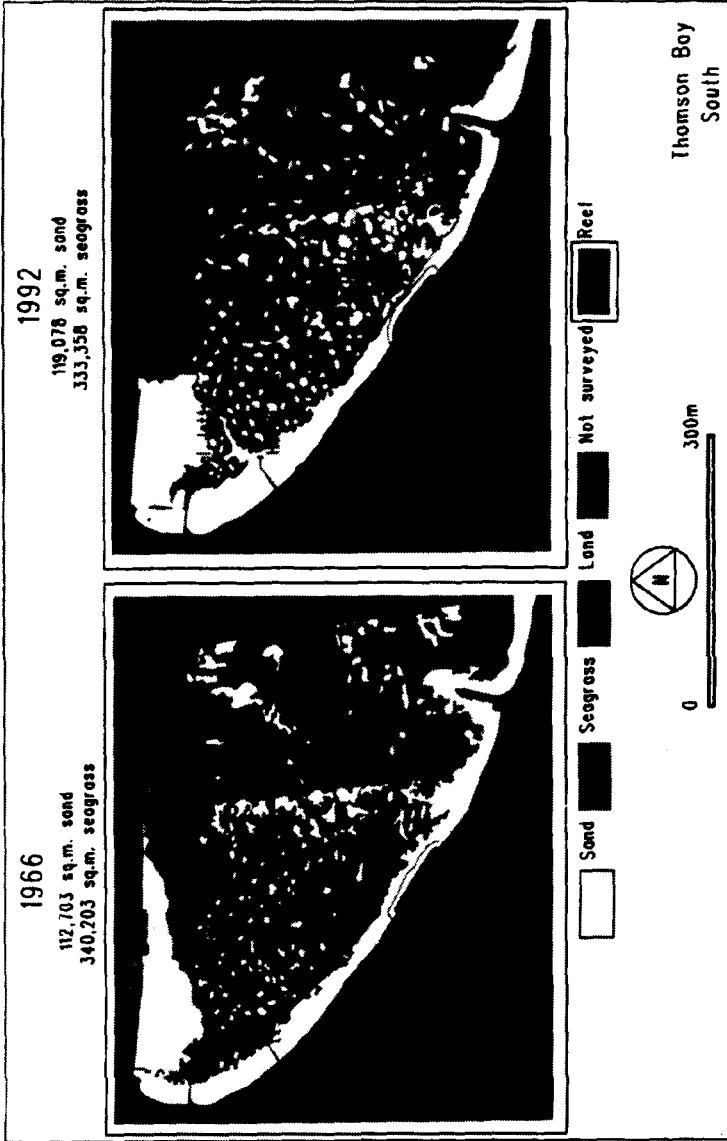


Fig. 6. ARC-INFO images of Thomson Bay South, Rottneest Island, for two photographic periods. The areal extent of sand (white areas) and seagrass (dark grey within the survey triangle) is indicated for each period.

patches are generated within and around the original Army mooring lines (Figs 5 and 6).

Boat traffic and mooring is high within Thomson Bay South and seagrass has receded away from the jetties and mooring areas around the northern section of the bay. This loss is evident as an increase in the length of the exposed edge of the seagrass within the bay. The edge of seagrass exposed within meadows where moorings are located has almost doubled between 1966 and 1992 (Table 5). Again, fragmentation of the seagrass meadow is occurring around mooring areas. Numbers of moorings within Thomson Bay South have increased from 183 in 1977 to 249 in 1992, an increase of 26% compared with the doubling in numbers of moorings that occurred in Rocky Bay during the same time period.

4.4. Thomson Bay North

The area of seagrass meadow in Thomson Bay North has decreased by 4% since 1966 (Table 4). Again, this loss in area of seagrasses is within the measurement error associated with the interpretation of an aerial photograph from a single year (5%). Loss of seagrasses and increase in area of sand has been localised around the northern section of the main ferry jetty, and is not associated with moorings in the post-1966 period (Fig. 7). The size and location of sand patches within Thomson Bay North was different for the years 1966, 1972, 1981 and 1992 (Fig. 7), suggesting that regrowth and recolonisation of sand patches has occurred within the bay. There appeared to be more, but smaller, sand patches in the seagrass meadow in 1966 compared with 1992. Whilst we were ground-truthing aerial photograph interpretation in September 1992, we found that large sand patches visible in 1981 had been recolonised by *Posidonia sinuosa* (Fig. 7).

The increase in the exposed edge of the seagrass beds associated with boat moorings doubled between 1972 and 1981, and has remained at similar levels since (Table 5). Why there has been no further increase in the exposed edge over the last decade, as documented in Thomson Bay South and Rocky Bay, is not known, but deserves intensive study. One hypothesis is that the nearshore environment is depositional versus erosional (as is Thomson Bay South) and growth of edges of seagrass beds equals seasonal losses due to mooring damage. The number of moorings in Thomson Bay North had increased by 67%, from 49 in 1977 to 82 in 1985. Between 1985 and 1992 numbers of moorings decreased to 79.

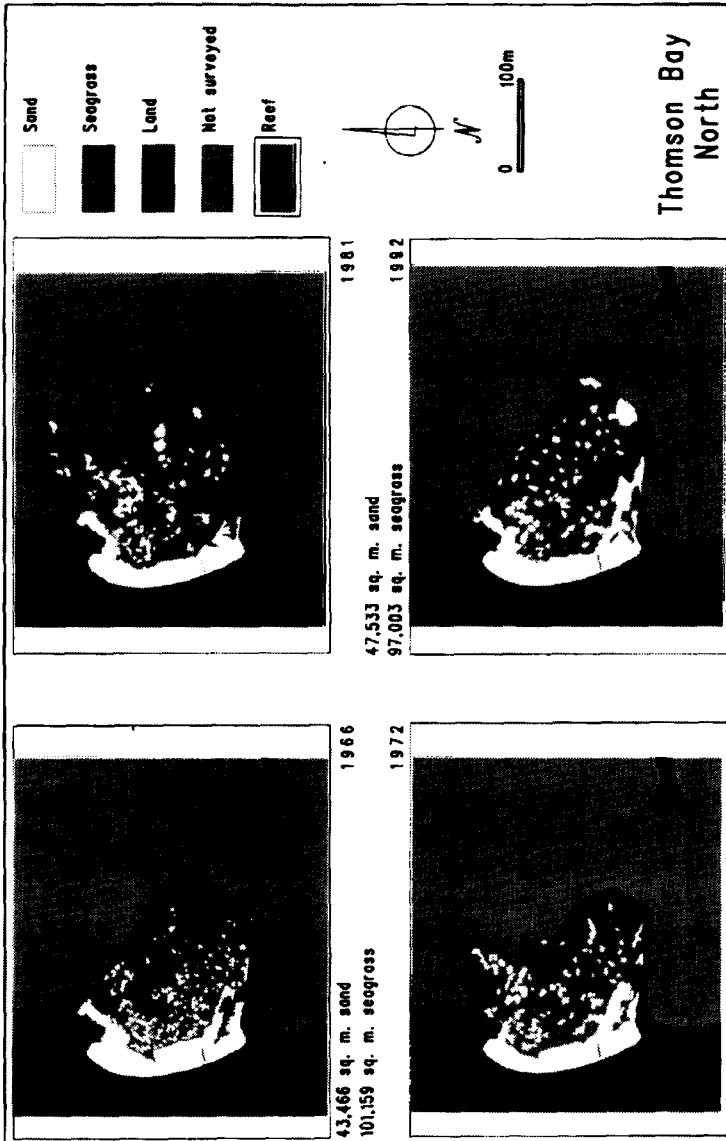


Fig. 7. ARC-INFO images of Thomson Bay North, Rottneet Island, for four photographic periods. The areal extent of sand (white areas) and seagrass (dark grey within the survey areas) is indicated for 1966 and 1992.

TABLE 5

Edge of seagrass exposed (m) within meadows around sand patches created by moorings from selected years between 1941 and 1992. Data determined from image analysis of scanned aerial photographs using NIH Image 1.44

<i>Year</i>	<i>Rocky Bay</i>	<i>Thomson Bay South</i>	<i>Thomson Bay North</i>
1941	1880	–	–
1966	–	11 311	2207
1972	2527	–	2333
1981	3540	11 332	4342
1992	12 874	20 391	4111

5. DISCUSSION

5.1. Seagrass changes and hydrodynamic processes

Between 1941 and 1992 in Rocky Bay and Thomson Bay, Rottneet Island, seagrass beds decreased in area, length of exposed edge of the seagrass beds increased, and area of sand patches associated with moorings increased. The magnitude of seagrass loss varied greatly between the two bays. Rocky Bay showed the largest areal loss of seagrasses (18%) and the greatest fragmentation of seagrass beds (260% increase in exposed edge of seagrasses). Areal changes in seagrasses and sand patches in Thomson Bay from 1966 were not significant and were within measurement error, although it should be noted that a significant reduction in seagrass area occurred prior to 1966 as a result of human activity. Seagrass beds in 1992 were more fragmented, as indicated by a 100% increase in the exposed edge of seagrasses associated with moorings between 1966 and 1992. At what level the length of exposed edge leads to loss of a large area of seagrasses is not known, but the amount lies between recorded losses observed from Thomson Bay and Rocky Bay.

Blowouts, or sand patches, naturally occur within seagrass beds^{1,2,11,12} and are known to migrate down current or wave direction.^{11–13} If seagrass rhizome extension rates are equal to, or greater than, the erosion of the down current exposed edge, then blowouts will migrate through the seagrass bed, or be grown over by seagrasses.¹¹ In situations

where the erosion rate is greater than rhizome extension rates, blowouts will grow and coalesce and seagrass area will decline.¹² Moorings do not 'migrate' (although they may be dragged off the original placement site by a large vessel), thus the sand patch produced by moorings is relatively stationary and seagrasses do not grow into it. The exposed edge down-current will still migrate and the blowout associated with the mooring will grow, and under extreme conditions, coalesce with neighbouring blowouts. The hydrodynamic conditions within Rocky Bay lead to this pattern of blowout growth and coalescence.

Seagrasses found at Rottneest Island have slow rhizome extension rates. *Posidonia* species grow 10–20 cm per annum and *Amphibolis* species 20–50 cm per annum.¹³ Slow rhizome extension rates result in poor recovery of seagrass meadows. Clarke¹² found *Posidonia* beds at Holdfast Bay, South Australia, were reworked by migrating blowouts every 95 years. Migration of blowouts and recovery of seagrasses in South Australia was an order of magnitude slower than the 8 years recorded for *Thalassia* in the West Indies.¹¹ Also, severely disturbed areas do not appear to recover at all. Experimental clearings in *Posidonia* beds in Botany Bay, New South Wales, were not recolonised after 35 years.¹⁴ Seagrass mining scars within *Posidonia* beds made in 1911 in Spencer Gulf, South Australia, are still visible 83 years later.¹³ Seismic detonation holes, between 20 and 120 m² in area, within *Posidonia* beds at Edithburg, Yorke Peninsular, South Australia, were also still visible after 17 years.¹³ Why man-made disturbances in seagrass meadows do not recover deserves further study. This study shows that seagrasses had recolonised small areas of sand patches in Thomson Bay and Rocky Bay. Larger disturbances, like the north-south trending Army barge mooring line in Thomson Bay South on 1941 aerial photographs, remain clearly visible in 1992. The size of the disturbed area may be critical in determining whether *Posidonia* can recolonise.

The process of blowout formation and revegetation in seagrass beds across current and wave exposure gradients is poorly understood. Rocky Bay is more exposed to westerly swells than Thomson Bay and had greater losses of seagrasses. Thomson Bay South has an erosional beach whereas the beach at Thomson Bay North is depositional. Effects of moorings on seagrass beds were least in the depositional environment of Thomson Bay North, suggesting that depositional bays on Rottneest Island are preferred as mooring areas, as seagrasses regrow relatively quickly. Further research is required to test this hypothesis.

6. IMPLICATIONS OF SEAGRASS LOSS AND REGROWTH

The loss of seagrasses in Rocky Bay and Thomson Bay has many implications. The seagrass meadows represent significant nursery habitats for a wide range of marine fauna.¹⁵ Seagrasses are highly productive¹⁶ and provide substrata for algae, small animals and microbes which are significant food sources for other organisms.¹⁷ The meadows also provide high levels of nutrients to the marine ecosystem.^{18,19} The canopy of a seagrass bed is capable of reducing current velocities, thus reducing erosion, enhancing sediment stability and promoting sedimentation.²⁰⁻²⁴ The fragmentation of seagrass beds on the scale observed in both bays represents a significant reduction in habitat, potentially important loss of species diversity and reduction in ecosystem functioning. Loss of seagrass may result in net erosion of the nearshore and potentially the beach.

Several authors state that it is difficult, if not impossible, for seagrasses to re-establish following removal (e.g. Kirkman¹). This study shows that seagrasses can regrow in formerly eroded areas, and at relatively fast rates (e.g. in around 10 years, with a range from 10 to 50 years maximum). This is an important finding and demonstrates that the natural seagrass ecosystem can recover from mooring damage, at least to a small degree. The scale of damage to the seagrass bed appears to affect the rates of recovery, with small mooring holes <20 m in diameter being recolonised although larger structures show little change over the 51 years of this study. The scaling of seagrass recovery deserves further attention.

7. MANAGEMENT POSSIBILITIES

There are a number of management scenarios which could be undertaken to reduce and potentially reverse the present situation. These are briefly outlined below.

A different management approach could be taken for each bay which allocates moorings based on their hydrodynamic conditions. This would mean that in the case of Rocky Bay far less moorings should be placed relative to Thomson Bay or other bays with lower wave energies and exposures.

Given the impacts in Rocky Bay, and the alarming, increasing trend of seagrass loss in recent years, there are too many moorings in the bay, and many should be removed. Otherwise, an irreversible, catastrophic

loss of the seagrass habitat may eventually result. Removal of moorings may still result in the gradual expansion of sand patches at the cost of seagrass, and it may therefore be necessary to embark on a stabilisation and blowout management programme in order to reverse the current trend. At the very least, part of the bay could be excluded from any mooring by utilising a system of ropes and floats to deter boat incursion. Monitoring of this exclusion zone could then be conducted to ascertain whether seagrasses will naturally recolonise the sand patches.

Diver observations and aerial photographic evidence in Rocky Bay indicate that the lower chains of some cyclone moorings are swinging across the bed and scouring the seagrass (Fig. 4), a process they were specifically designed *not* to do. This indicates that the moorings have not been constructed and placed correctly. It is critical that this trend does not continue, and it is imperative that the Rottnest Island Authority police and monitor the emplacement and performance of cyclone moorings in all locations. Obviously, it is vital that the present incorrectly constructed cyclone moorings are reconstructed to standard specifications immediately.

To reduce the damage to seagrass by moorings, a new, environmentally friendly mooring design is required. Presently, research is being undertaken to assess the utility and strength of a direct drilled, stainless steel rod which would be held below the seabed by a high pressure injected concrete plug or similar device. A mooring like this would impact very little of the seabed when first emplaced, and, if properly fitted, there would hopefully be much less likelihood of subsequent chain drag on the seabed.

8. CONCLUSIONS

Seagrass loss associated with moorings has been dramatic in Rocky Bay and Thomson Bay, Rottnest Island. The loss of seagrasses in Rocky Bay coincides with a doubling of moorings and an increase in boat traffic and boat size between 1981 and 1992. In Thomson Bay, where mooring and anchoring have occurred regularly and over a longer time, the impact of these activities on seagrasses since 1966 has been less dramatic. Still, the doubling of the length of exposed edge of seagrass meadow associated with moorings in Thomson Bay is cause for concern.

Several management possibilities exist for reducing the impacts of moorings in Rocky, Thomson and other bays, and these should be carefully and fully examined for future management.

ACKNOWLEDGEMENTS

The authors wish to thank the Rottnest Island Authority for the opportunity to carry out this research and for financial and logistic support. Peter Clash (formerly RIA Marine ranger; presently TAFE Maritime College, Perth), Luke Sibon and Paul Moll (Edith Cowan University) are especially thanked for their assistance in carrying out this project. Chang Chew Hung (National University of Singapore) is thanked for his assistance in creating Fig. 3. G.K. thanks the CSIRO, and K.H. and P.H. thank the Department of Geography, National University of Singapore for support.

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