Preliminary investigations of echinoid aggregations in the seagrass meadow at Garden Island, W.A.

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Table of Contents

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"The sea urchin is a most voracious and promiscuous feeder. always ready to eat...."[1].

1.0 Introduction

1.1 Purpose

This report has been prepared as an Independent Study Contract which is part of an undergraduate degree in Biology currently being undertaken at Murdoch University. It provides a preliminary investigation of a sea urchin aggregation intrusion into the seagrass meadow, off Garden Island in Cockburn Sound. Little is know about this type of behaviour and no similar event has been previously reported or investigated at Garden Island.

The aim of this report is to give the results of the preliminary investigation into this event which incorporates:

- **(a)** a review of historical data,
- **(b)** an account of personal observations,
- **(c)** identification of the three sea urchin species which are having the most impact on the seagrass meadow,
- **(d)** the observed population densities,
- **(e)** the rate of seagrass loss (predation),
- **(f)** feeding behaviour and
- **(g)** dietary preference through gut content analysis.

The report consists of a further six sections:
Section 1.2 is the review of background literature of both local and international source. The methodology and materials used in the investigations are outlined in section 2.0. In

[1]T.R.Jones, 1858 (*in* Lawrence, 1975)

section 3.0 the results are presented and then discussed in section 4.0. Finally in sections 5.0 & 6.0 respectively, the conclusions are drawn and recommendations for future research and monitoring are proposed.

1.2 Background

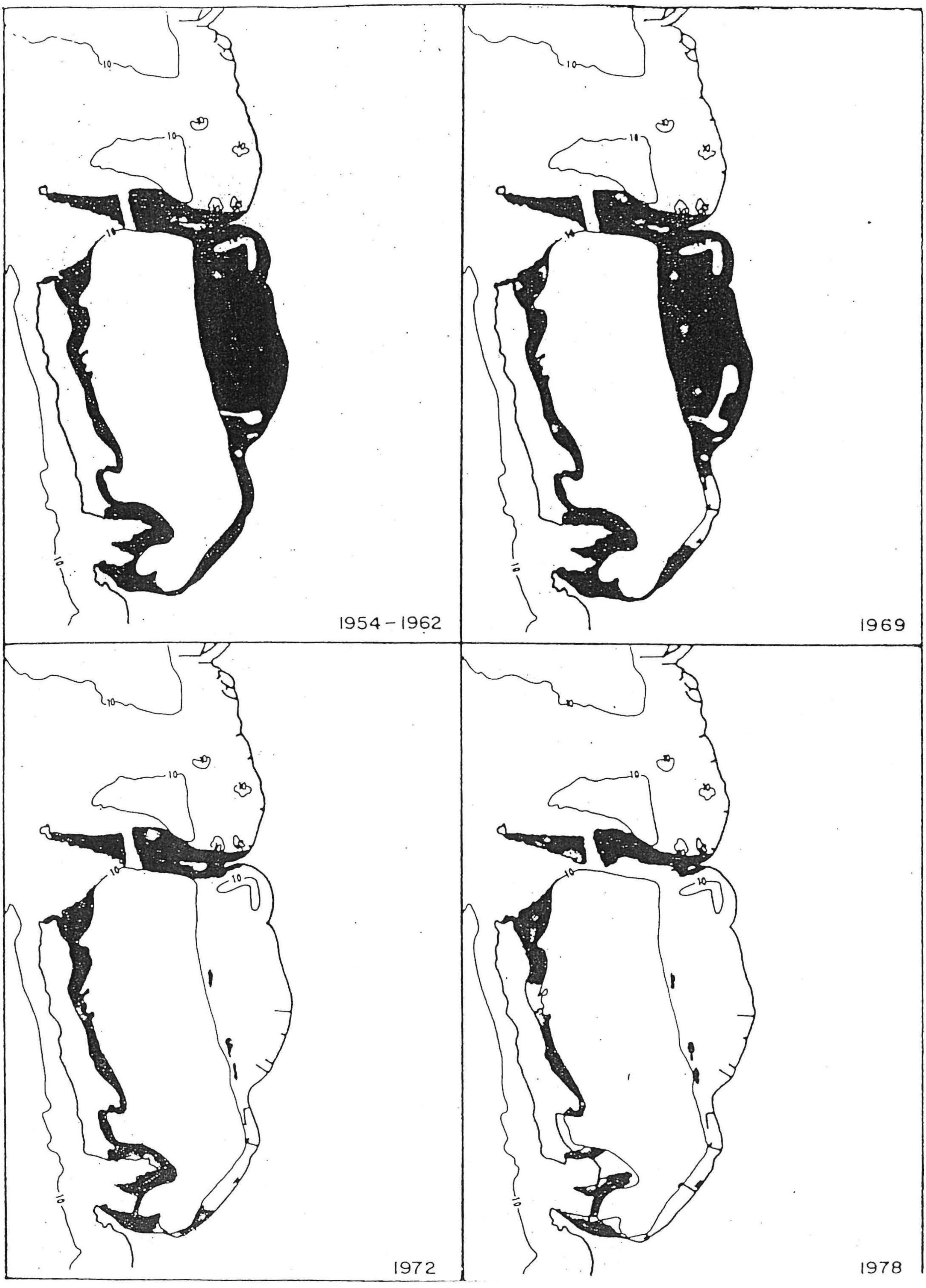
Seagrass meadows provide a distinctive habitat supporting a community of marine fauna as well as being an integral part in the life cycles of many others as their nursery grounds. The *Posidonia sinuosa* seagrass [2] meadows are a major biophysical agent in maintaining the stability of Cockburn Sound's foreshore and as the primary producer in the Cockburn Sound ecosystem. As there has been an extensive loss of seagrass meadow since 1962 , any amount of seagrass loss is significant and may have some consequence which may initiate a change in the management of the Cockburn Sound ecosystem (see Figure 1.0).

Ecologically, the loss of seagrass is instrumental in causing changes in the other main primary producers, from the benthic to the planktonic. This consequentially can result in a loss of leaf detritus production accompanied by changes in the food chain. There would also be a loss of the existing structural diversity, as compared to the limited habitat provided by the bare calcareous sands remaining after the destruction of the seagrass meadow (Cambridge & McComb, 1984). These productive and complex seagrass communities are susceptible to sea urchin grazing which, in this case has completely denuded the substratum of *Posidonia* seagrass forming barren grounds similar to the destruction of kelp beds in Northern America (Lawrence, 1975; Breen & Mann, 1976; Bernstein et al, 1981; Harrold & Reed, 1985 and others)

There seems to be no question that feeding by sea urchins can result in direct alteration of the environment as they feed continuously unless constrained by environmental or behavioural phenomenon (Lawrence, 1987). The Aristotle's lantern (ie. the mouth parts), are adapted for biting, tearing, rasping and also functions as a grab, therefore the regular echinoid can have the widest spectrum of food types. Sea urchins are mostly non-selective scavengers, browsing on whatever is readily available, including both animal and

[2] Identification by M. Borowitzka, Biology and Environmental Science, Murdoch University.

Figure 1.0: Seagrass loss in Cockburn Sound since 1954 (*after* Cambridge, 1979)



plant material (Baker, 1982). As a consequence, the food resources available to regular echinoids include soft bodied organisms (plants and animals), hard animals (corals, bivalves) (De Ridder & Lawrence, 1982) or hard surfaces (rock with boring or encrusting plants and animals). They have been observed feeding on the substratum whether soft (Lawrence, 1975; De Ridder & Lawrence, 1982) or hard (Lawrence & Sammarco, 1982).

The sea urchin primarily being investigated in this study is *Heliocidaris erythrogramma* [3] *H. erythrogramma* (Valenciennes, 1846) has a maximum size of test, 90 mm , flattened aborally and orally, with height of test about half of diameter. The spines moderately long, up to 25 mm and are usually tapered gently to a point, although sometimes they are spindle shaped. The primary spines are pale green or grey with purple tips, the secondaries are purple with a dark background test colour. The naked test may be green, light purple or whitish (Baker, 1982). This regular echinoid is common on Australian coasts, distributed from Coloundra, Queensland to Shark Bay in Western Australia (Dix, 1977), and probably not found anywhere else (Hyman, 1955). Its "usual" observed habitat has been that of a crypt dweller on the hard-bottomed intertidal zones contrary to the soft-bottomed, calcareous sand sills and banks typically found in Cockburn Sound (Marsh & Slack-Smith, undated; Baker, 1982).

H. erythrogramma was observed in large numbers on the peripheral edges of a denuded area in the *Posidonia* meadow at Luscombe Bay in mid 1991 (C. Simpson, *pers comm*). Echinoids are frequently found in large populations (Moore, 1966; Lawrence and Sammarco, 1982). These aggregations are by far the most common occurrence in nature, being mostly utilized for reproductive reasons, greater facility in feeding, to increase the chances of evasion from predation, and in response to clumped habitats (Russo, 1979). This phenomena is wide spread, having been seen and studied in Alaska (Duggins,1981), Bermuda (Moore *et al*, 1963), California (Tegner and Dayton, 1977; Russo, 1979; Harrold & Reed, 1985), Cockburn Sound (Cambridge, 1986), Florida (Moore *et al*, 1963; McPherson, 1965; McPherson, 1968), Great Britain (Kitching and Ebling, 1961), New

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[3]Identification by L. Marsh, W.A. Museum; Dartnell, 1980; Shepherd & Thomas [eds.], 1982.

England (Garnick, 1978), Maine, (Larson *et al*, 1980), New Zealand (Dix, 1970; Choat and Schiel, 1982), Nova Scotia (Breen & Mann, 1976), Southern California (North & Pearse, 1970), Virgin Islands (Odgen et al, 1973), Washington (Paine and Vadas, 1969). Aggregations of *H. erythrogramma* have been observed at Botany Bay, (Larkum & West, 1990), Cockburn Sound (Cambridge & McComb, 1984) New South Wales, (Shepherd, 1973) and Tasmania (Dix, 1977).

Rapid increases in population of any organism are of immense ecological importance, particularly when the animal migrates from its normal habitat and invades another. The rapid increase in a species population is often perceived as being diametric to the normal situation, where the number of animals in a mature (or stable) ecosystem do not fluctuate wildly. It is generally considered that the interactions of organisms on each other and their inanimate surroundings form a complex set of feedback controls which prevent wild fluctuations in numbers. Fluctuation in species populations are indicative of the unstable ecological situation and instability may be the product of unusual or unnatural events in the ecosystem. Thus abnormal increase in population may be reflected throughout the whole ecosystem. The initial part of the ecosystem affected is the major food source of the prolific species (E.R.A., 1973).

The phenomenon of sea urchin aggregation and consequential ecological damage has been the centre of widespread interest and has been the cause of several arguments (North and Pearse, 1970; Mann, 1977; Choat and Schiel, 1982). The dominant views include the lack of or the increase of predator pressure and food availability and / or abundance.

The presumption was made that sea urchin density increased with the lack of predator pressure and eventually became so abundant that predators were able to locate them. These aggregations remain in the open even in the presence of predators. Bernstein *et al* (1981) argued that this behavioural mechanism, a defensive aggregation response due to the presence of predators, is the trigger that precipitates widespread destructive urchin grazing and the transformation of extensive faunal beds to barrens. The predator in this case has shown that it has two opposite roles. At low urchin densities, predators keep urchins in hiding (crevice dwelling) and thereby contribute to kelp bed persistence. At higher urchin densities, predators trigger the formation of large, exposed urchin aggregations that graze destructively on kelp (aggressive herbivores) (Bernstein *et al*, 1981; Mann,1985). It also has been postulated that the presence of predators in the kelp beds and in the barrens, triggered the formation of even larger aggregations. This argument of defensive aggregation has been the subject of research by Garnick, 1978; Bernstein *et al*, 1981; Duggins,1981; Mann, 1985 and others.

Although the fundamental mechanism for triggering sea urchins to aggregate and graze destructively has largely not been determined, some studies suggest that predators, specifically crabs and lobsters do not control sea urchin abundance. These observations suggest that crabs and lobsters should not be considered, either as important predators regulating sea urchin abundance or as a precursor to destructive grazing. It was proposed that the mechanism for the transformation of macro algal beds to barren grounds need not involve predator mediated responses on the part of sea urchins and through observation and manipulation, through tank and field experiments, Vadas *et al*, (1986) clearly shows that the only requirement for sea urchins to form aggregations is the presence of sufficient food to focus as an attractant. It has also been showed that in the population with abundant food, sea urchins are highly aggregated; in the other population where food is limited and the spatial pattern of the urchins is random. Urchins aggregate in laboratory aquaria when well supplied with food, when those without food tend to be positioned more random (Russo, 1979). This paradigm of food availability inducing aggregations in sea urchins, seems to be more consistent and is verified by numerous independent observations (Vadas, 1977; Russo, 1979; Vadas *et al*, 1986).

2.0 Methods and Materials

2.1 Overview

This section describes the methods and materials by providing an outline of the study site, the sampling strategies and techniques used in the laboratory research .

The study site description is a general introduction therefore a supplementary site survey was carried out to obtain a more extensive picture of this event which is presented in the results. Comparative sampling sites were selected and a night dive organized to reflect dietary preference similarities or differences and to observe feeding behaviour.

Various sampling strategies were utilized to try to establish a reasonable representation of the population densities, rate of seagrass predation and sea urchin harvesting for laboratory examinations. Density counts along, as well as across the front were performed to achieve a picture of the concentration of sea urchins at the interface. Population density of the smaller echinoids was investigated, even though they were not the primary cause of seagrass loss, they certainly maintain the barrens left behind the front. A preliminary look at the rate of predation was required to provide some comprehension of the potential of such an aggregation.

A significant part of this study incorporated a literature search , personal communications and examination of historical data (past research and aerial photographs [+]), which provided background material, invertebrate identification, sampling strategies and relevant information for discussing the results.

2.2 Site

2.2.1 *General Study Site Description.*

The site of the extensively damaged sea grass meadow is within the Navy restricted area at Luscombe Bay, on the east coast of Garden Island (32° 10' 6" S, 115° 40' 24" E), shown in Figure 2.0. The "blowout" is approximately 400 metres south of Second Head and the western front about 150 metres offshore. It is roughly rhomboid in shape, approximately 250 metres across and about three quarters to one hectare in area.

The study site is typical of the soft bottomed areas of Cockburn Sound, with a peripheral intertidal sill and shallow bank (2-6 metres deep) of calcareous sands. In Luscombe Bay, the banks and subtidal zone are covered with lush *P. sinuosa* meadow (Marsh & Slack-

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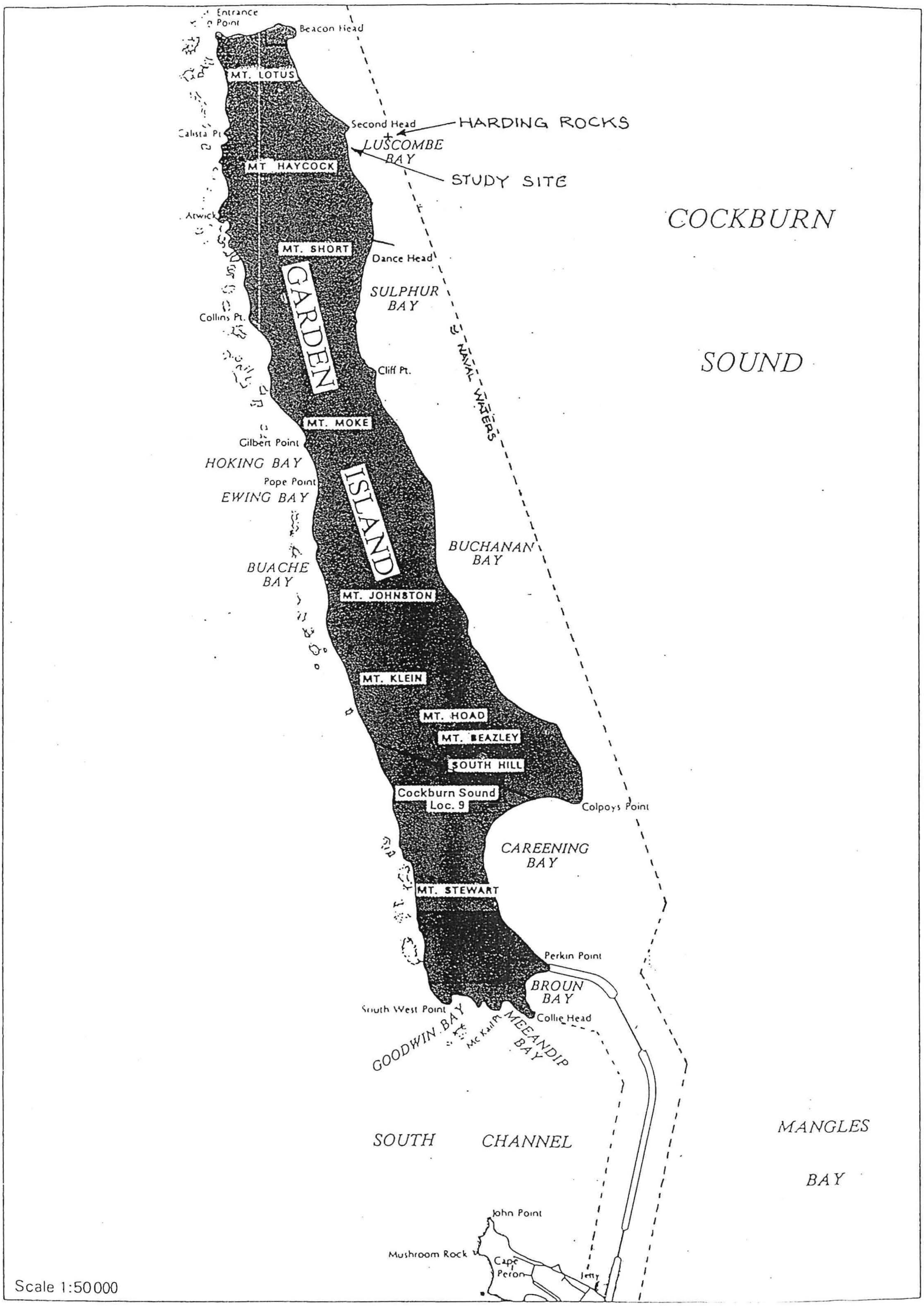
[+]By courtesy C. Simpson, Environmental Protection Authority, W.A.

Figure 2.0: Garden Island (*after* F.P.C.,1978)



Smith, undated) except where the urchins have destructively grazed the seagrass. The site is situated on the Garden Island bank and supports the remnants of the once extensive *P. sinuosa* meadows which once covered the western and eastern shores of Cockburn Sound (Cambridge & McComb, 1984).

2.2.2 *Comparative Sampling Sites.*

Comparative sampling sites for *H. erythrogramma* were selected for comparative gut content analysis and are as follows:

- **(a)** on a submerged cable on the northern front of the "blowout".
- **(b)** off the reef at Harding Rock. Harding Rock is located in 4-10 metres of water about 300-400 metres south-east off the site (32° 10' 3" S, 115° 40' 46"E). Harding rock is an outcrop of calcareous rocks covered with *Sargassa*, sponges and corals with the seagrass meadow growing right up to the rock's shallow edge.
- **(c)** and a night sampling at the study site.

2.3 Sampling Strategies

2.3.1 *Interface Population Density.*

For the density counts of *H. erythrogramma* along the seagrass / barrens interface, a 1 m^2 (1.0 x 1.0 m) quadrat was laid with its centre on the interface, that is half in the seagrass and the other half in the barrens. The line of the interface was defined as where the short browsed *Posidonia* blades gave way to the long untouched seagrass blades. This was quite distinct and easy to determine.

2.3.2 *Transect Density.*

For the *H. erythrogramma* density across the interface, a six metre transect line with marked 1 metre increments was laid in a north - south direction (at 90°) across the front, with its mid mark corresponding with the interface. A 0.25 m^2 (500 x 500 mm) quadrat was laid centrally on each mark and counts recorded. The transect locations were not randomly selected, but were approximately 10 metres apart at the interface, within the defined study site at the southern front (see results).

2.3.3 *Sea Urchin Density in the Barrens.*

In determining the densities of *T. michaelseni* and *N. scotiopremnus*, the 0.25 m^2 quadrat was utilized again. The sites were chosen at random in the barrens up to 150 metres from the defined study site. Both species were counted within each quadrat. All urchins lying within the quadrats including those that touched the edge as well as being 50% or more included within the quadrat, were recorded as the count for that quadrat (Russo, 1979).

2.3.4 *Rate of Seagrass Predation.*

The predation rate was determined by driving a stake in, at the interface and periodically measuring the distance which the interface progressed. There were only two locations along the southern front, with in the defined study site.

2.3.5 *Harvesting of Sea Urchins.*

The sampling strategy for collecting the *H. erythrogramma* tests required for laboratory examination was:

- (a) at the study site, to collect thirty (30) specimens at random along the interface per field trip,
- (b) at the "cable", to collect specimens at random along the cable and
- (c) at Harding Rock, to collect at random specimens from their cryptic habitat.

2.4 Laboratory Techniques:

2.4.1 *Fixing of Samples.*

Tests were fixed within a couple of hours after they were collected. The technique used was as follows:

- (a) A small hole was made in the centre of the aboral surface, in the vicinity of its anus (Figure 2.1).
- (b) Tests were injected through the peristomal membrane with buffered 4% formalin. The amount injected varied from 1-4 mL depending on test size.
- (c) They were then placed in buffered 4% formalin in 20 L tubs, for a minimum of 96 hours, until they were required for dissection.

Figure 2.1: Anatomy of a regular echinoid: *Echinus* spp. (*after* Kershaw,1983)

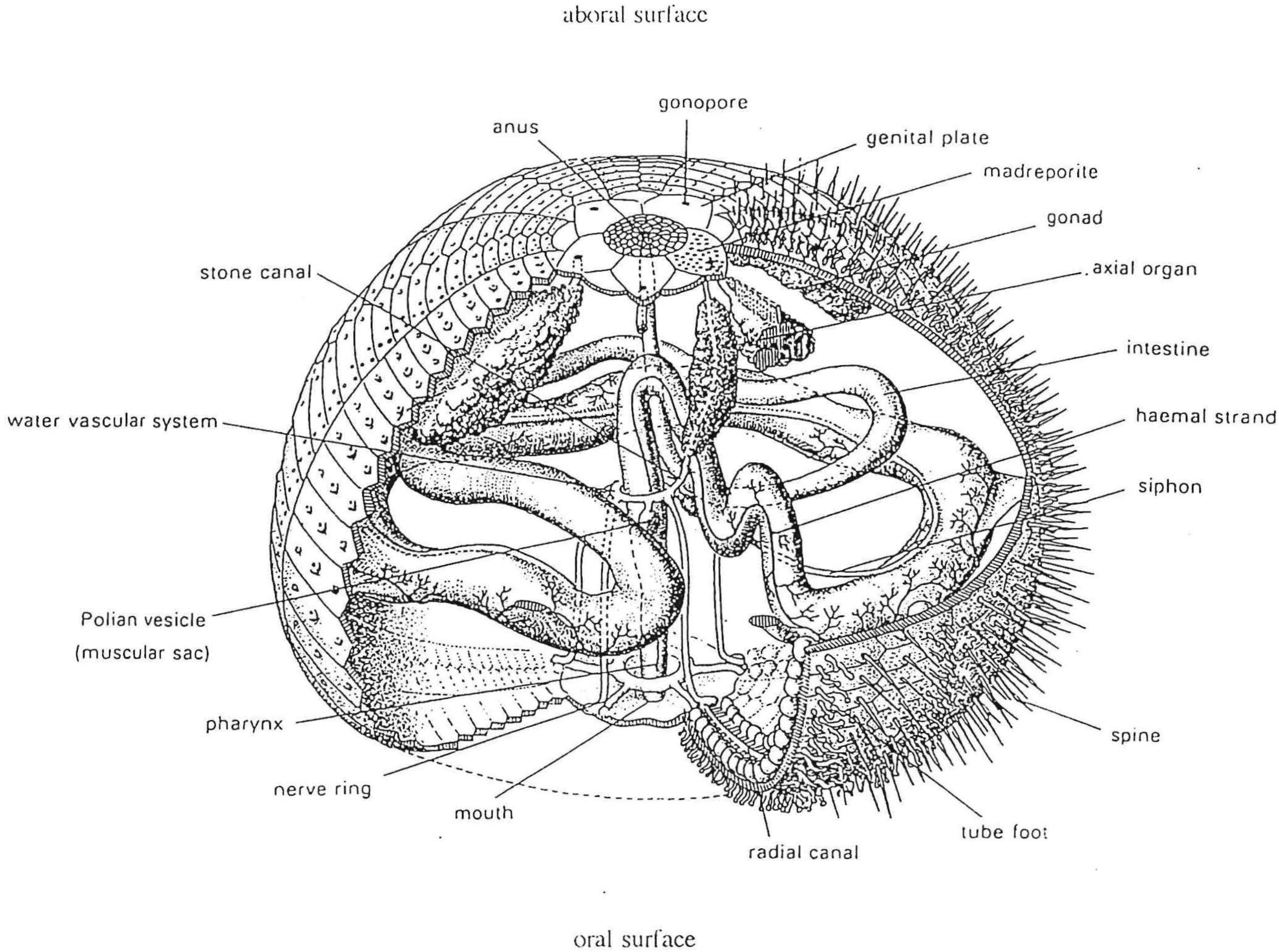
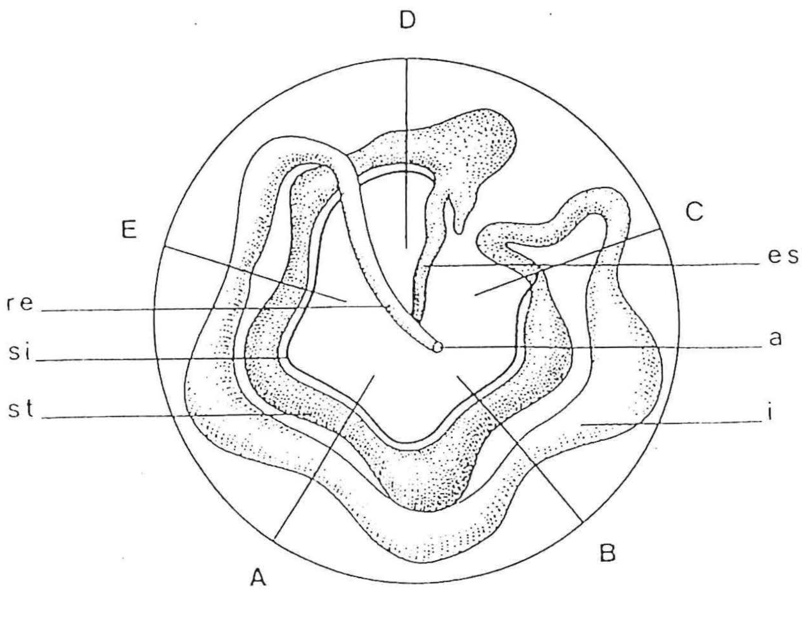


Figure 2.2: Regularia (*Echinus* spp.): aboral view of the digestive tract (*after* De Ridder & Jangoux, 1982)
a anus, es esophagus, i intestine, re rectum, si siphon, st stomach.



The 4% buffered formalin formula:

added to 1 Litre of sea water 4 mL Formalin

4 g Sodium dihydrogen phosphate monohydrate

6.5 g Disodium hydrogen phosphate anhydrase

(Mueller, *pers comm*).

2.4.2 *Dissection.*

All dissection work was done in fume cabinets with the appropriate protective clothing, gloves and respirator. Dissection procedure was:

(a) Chose randomly 12 sea urchins (if 12 were available), per field trip.

(b) Wash and drain preserved specimens initially on mesh, and finally on blotting paper. The diameter was measured by placing test on rule. N.B. spines were not included in diameter. Each test was also weighed.

(c) Gut and gonads (Figure 2.1 & 2.2) were removed. Gonads then placed in 4% buffered formalin for future study.

(d) Gut weighed. Visual assessment of gut fullness on a scale of 0-5. Gut then placed into sample jars with 70% ethanol.

2.4.3 *Determination of Gut Contents.*

Trials on two initial sea urchin gut contents, using either a portion of gut or a portion of macerated gut content, did not result in giving a representative picture. It was determined through further repetitious trials that the following procedure did give a reasonable representation:

(a) Remove a 20 mm portion of the gut (similar to the section A-B of the stomach in Figure 2.2) and place into a petri dish pre-marked with 1 cm x 1 cm grid on the bottom (*as* Harrold & Reed, 1985).

(b) Add approximately an equal quantity of macerated remaining gut contents to petri dish. Contents thoroughly mixed with 70 % ethanol to give even distribution of contents.

(c) Eight subsample counts of adjacent 1 cm^2 squares were made with the petri dish on top of graph paper under a binocular dissecting microscope. The following categories were considered: seagrass, epiphyte or algae, calcareous or siliceous materials, obvious animal and indeterminable matter.

(d) The results were then related as relative percent of contents, ie. if 60 out of 100 of 1 mm^2 squares were counted, then this represented 100% and each individual category became a percentage of this (see raw data in Appendix I).

3.0 Results

3.1 Site Survey

Photographs of the study site are presented in Appendix 2, and will illustrate the extent of this aggregation event. A more detailed site survey is described in the following:

3.1.1 *The Western Front*

Observations on the western front showed grazing up to the naturally bare wave impact and intertidal zone with the exception of one reasonable patch of seagrass supporting a small population of sea urchins (*H. erythrogramma*) at fairly thick density. The depth ranged from 0.5 - 2.0 metres. Rolls of drift material, consisting mainly of seagrass blades were present lying parallel to the coast.

3.1.2 *The Northern Front*

The seagrass here is dense but not as dense as the Southern front. There seems to be more of a epiphyte load especially towards the deeper water (five metres) in the East. There is a thin presence of macroalgal growth on the substrata behind the front and also observed was a 50 - 60 mm multistrand twist cable that runs approximately parallel to this front. In the NE corner, where this cable is on the surface of the substrata and running deeper into the seagrass, it is supporting a small population of about 40 -50 *H. erythrogramma*. The seagrass seems to be grazed 300 - 400 mm on either side of the cable. There is another community of about 20 individuals further towards the centre, otherwise the rest of the front seems to be void of sea urchins.

3.1.3 *The Eastern Front*

The seagrass here has a heavy epiphyte load and it is quite sparse. The depth is on average five metres and goes deeper towards the east. The southern portion of this front has a reasonable *H. erythrogramma* presence whereas the NE corner has only very small groups, being three groups of approximately 20-30 individuals. No sea urchin presence was observed in the middle of this front .

3.1.4 *The Southern Front*

The seagrass here is quite lush and thick. It is mainly made up of *P. sinuosa* with a few tiny patches of *P. australis* [5] and only has a very light epiphyte load compared to the other fronts. This front showed the largest aggregation of *H. erythrogramma* over a portion of 150 metres. The sea urchins aggregated along the seagrass / barrens interface at a width of only 0.9 - 1.2 metres wide. Initially the front was not as wide and the sea urchins were sitting on top of each other. It is along this southern front where the investigation was restricted (Figure 3.0), as the sea urchins here seemed to have the highest potential impact on the seagrass meadow.

Also present in large numbers are the sea star, *Patriella brevispina* and the crinoid, *Comatula pectinata* (Shepherd & Thomas, 1982; Marsh & Slack-Smith, undated). Also observed in the SE corner was a school of approximately 30, juvenile Port Jackson sharks. *Heterodontus portusjacksoni* (Whitley,1940; Grant, 1975; Hutchins and Thompson, 1983). Large rolls of drift material, mainly *Posidonia* blades, were present in the SW corner .

3.1.5 *The Barrens*

The "barrens" is so named because the area is totally void of seagrass and not showing any significant sign of seagrass regeneration. The only plant life here is some macroalgal growth. Large quantities of drift material, mainly seagrass blades was observed gathered in sinks throughout the barrens. Attached to the underside of these blades by their aboral

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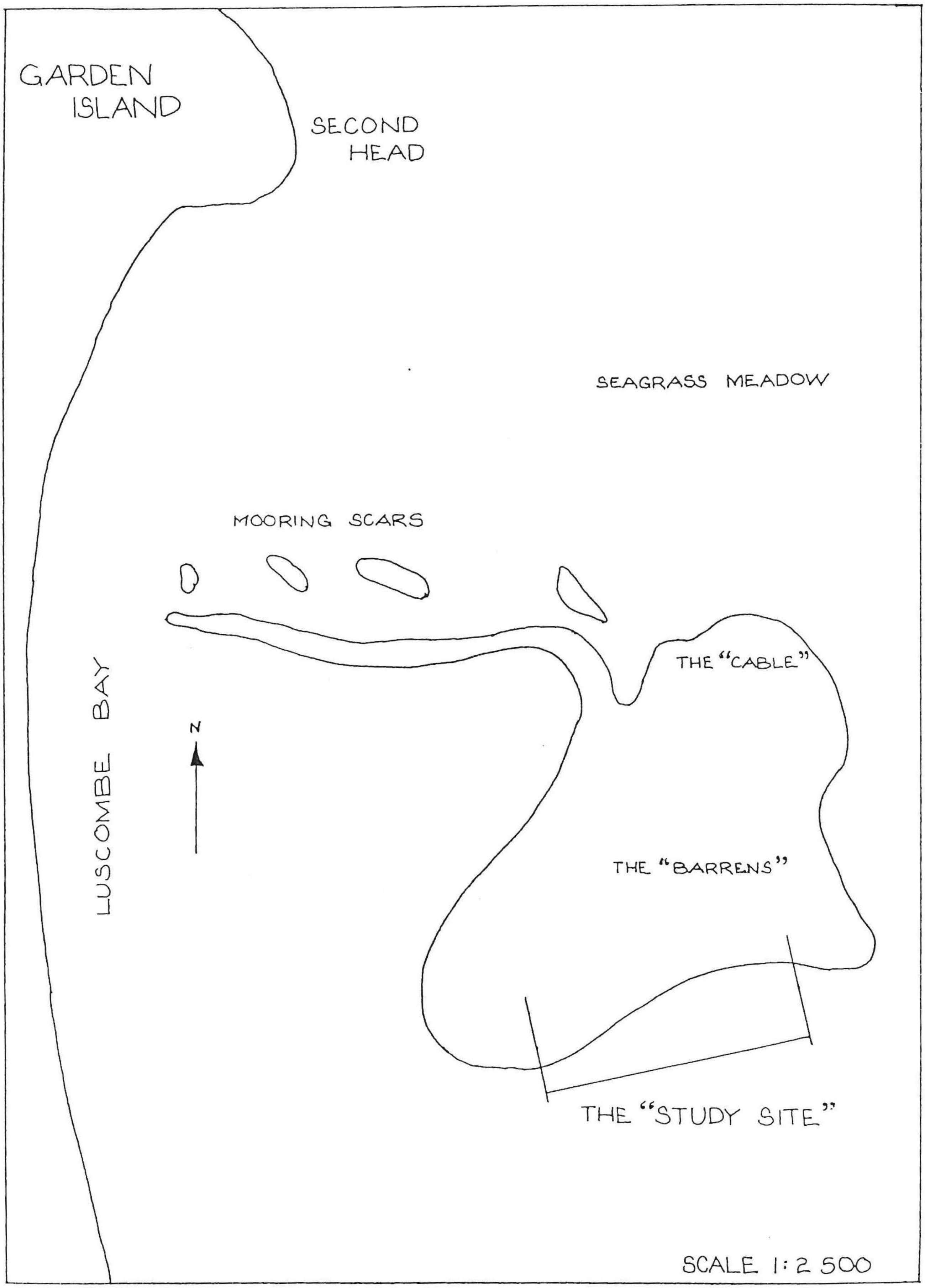
[5]Identification by G. Bastyan, Water Research Centre, Murdoch University.

Figure 3.0: Defined study site at Luscombe Bay, Garden Island



tube feet, were large numbers of small sea urchins, *Temnopleurus michaelseni*[6], no larger than 30 mm in diameter. Another species of sea urchin, *Nudechinus scotiopremnus*[7] were also observed here and were half buried in the substrate, with shells as "parasols" over their aboral surface. These sea urchins were also small, no larger than 40 mm and at moderate density. On excavating in the centre of the barrens, the *Posidonia* rhizome was found to be dead and decomposing, obviously incapable of regeneration.

3.2 Interface Population Density

The accumulative means of *H. erythrogramma* density counts for 17/12/92 (Figure 3.1), resulted with quadrat counts of five and six to have constant variance, therefore it could be assumed that the sampling strategy incorporating only six quadrats counts, was sufficient to give a representative picture of the population density.

The density counts (Table 3.1) show that the mean population density of *H. erythrogramma* drops from 67.00 on 17/12/92 to 45.33 individuals per square metre on the 13/3/92. Figure 3.2 indicates that there seems to be a trend of a steady decline, over the study period, in sea urchin population density at the seagrass / barrens interface.

Table 3.1: H. erythrogramma population density at Luscombe Bay

Quadrat N°	Number of Individuals per metre^2					
/Date	17-Dec-91	14-Jan-92	6-Feb-92	24-Feb-92	9-Mar-92	30-Mar-92
#1	77	47	61	65	69	36
#2	74	59	62	49	38	56
#3	60	64	74	74	42	48
#4	65	69	71	58	50	40
#5	59	64	68	50	78	40
#6	67	70	59	45	76	52
Mean	**67.00**	**62.17**	**65.83**	**56.83**	**58.83**	**45.33**
SE	2.98	3.44	2.47	4.51	7.21	3.21

[6]Identification by L. Marsh, W.A. Museum.
[7]Identification by L. Marsh, W.A. Museum.

Figure 3.1: Acccumulative means for H. erythrogramma population density along the interface (17/12/92)

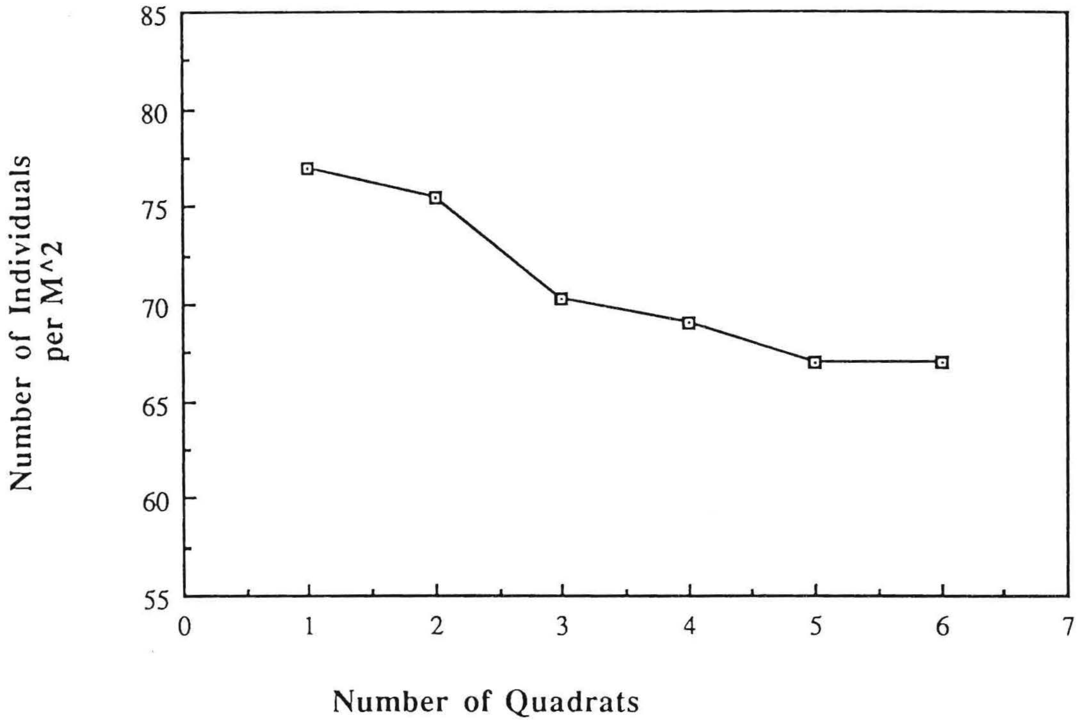
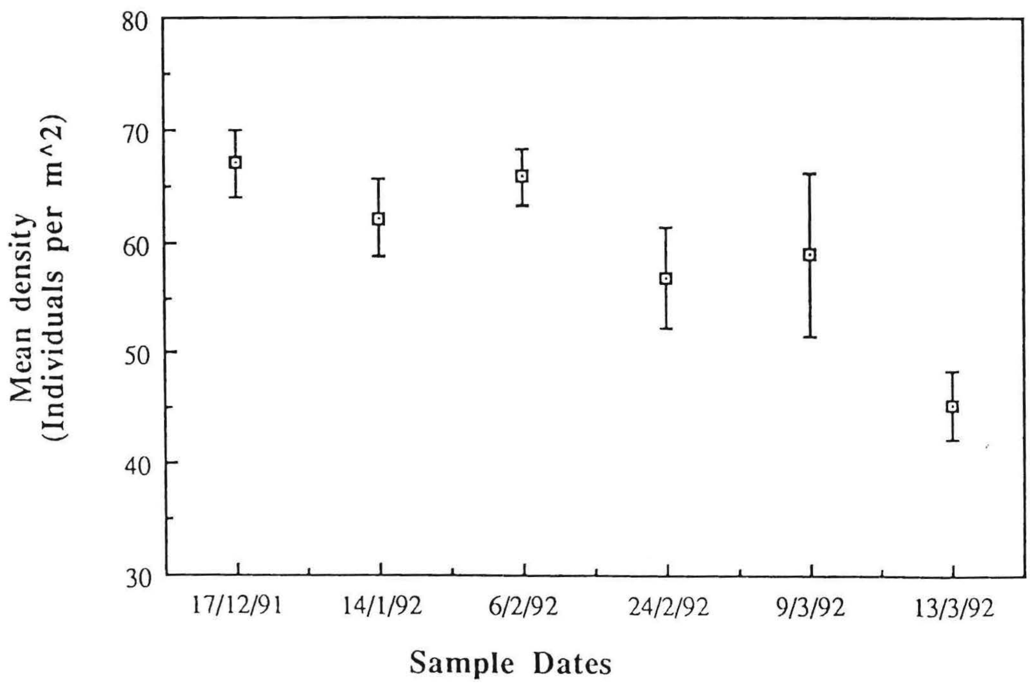


Figure 3.2: Mean H. erythrogramma density at study site



3.3 Transect Density

The assumption made here is that a ten transect sampling strategy would be enough to give a representative picture of *H. erythrogramma* population density across the front. The mean counts (Table 3.2) show a low density three metres into the barrens from the interface with a moderately sudden increase to over four times that density at the interface. This almost immediately gives way to no sea urchins present at two to three metres into the seagrass from the interface. This is graphically presented in Figure 3.3, illustrating that the greatest density is at the interface.

Table 3.2: H. erythrogramma population density transects across aggregation front (Individuals per m^2)

Distance (m) Quadrat N°	Barrens 3	Barrens 2	Barrens 1	Interface 0	Seagrass 1	Seagrass 2	Seagrass 3
#1	8	16	36	28	4	0	0
#2	12	20	40	24	0	0	0
#3	4	4	52	52	0	0	0
#4	4	0	16	32	4	0	0
#5	12	8	16	40	4	0	0
#6	8	16	56	56	8	4	0
#7	4	16	44	48	4	0	0
#8	12	20	24	16	4	0	0
#9	8	20	24	52	4	0	0
#10	12	0	24	32	4	4	0
Mean	**8.40**	**12.00**	**33.20**	**38.00**	**3.60**	**0.80**	**0.00**
SE	1.11	2.60	4.58	4.31	0.72	0.53	0.00

3.4 Sea Urchin Density in the Barrens

To test that the sampling strategy was appropriate, the accumulative means of sea urchin densities in the barrens were plotted (Figure 3.4). This indicated that the variation in both species became constant around 15 quadrats implying that 18 quadrat counts was sufficient for reasonable representation of sea urchin population densities in the barrens. Table 3.3 which represents the density counts, produced a mean density for *N. scotiopremnus* of 59 individuals @ m^2 with a standard error of 5.98 and for *T. michaelseni* a mean density of 130 individuals @ m^2 with a standard error of 15.46. Since these

Figure 3.3: mean densities of H. erythrogramma on transect across the aggregation front (13/4/92)

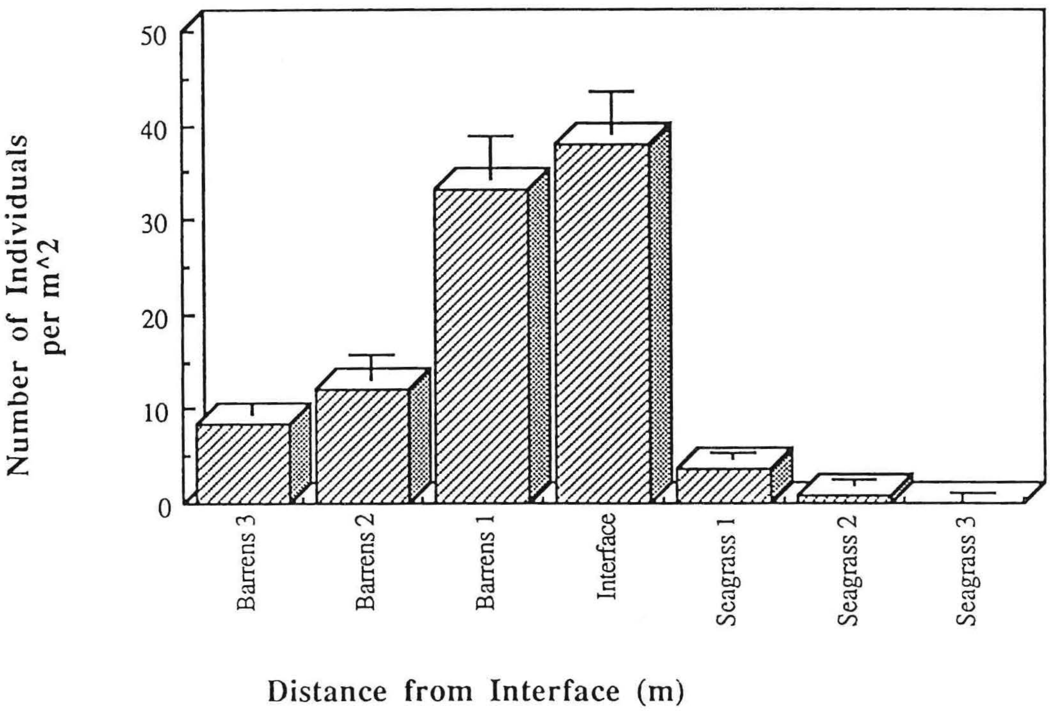
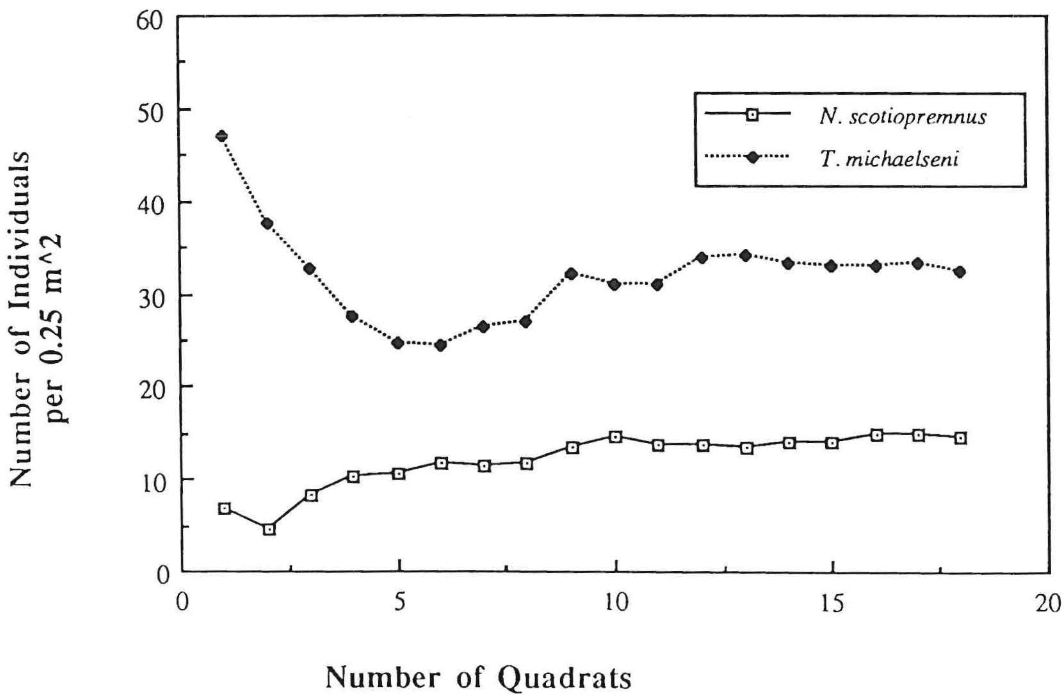


Figure 3.4: Accumulative density means of sea urchins in the barrens



populations are dependant (counted in the same quadrat), the small sea urchin population has a mean density of 189.

Table 3.3: Urchin population density in the barrens

Quadrat N° /Quadrat size	Nudechinus 0.25 m^2	Nudechinus m^2	Temnopleurus 0.25 m^2	Temnopleurus m^2
#1	7	28	47	188
#2	2	8	28	112
#3	16	64	23	92
#4	16	64	12	48
#5	12	48	14	56
#6	18	72	22	88
#7	10	40	39	156
#8	13	52	31	124
#9	27	108	74	296
#10	24	96	20	80
#11	8	32	32	128
#12	14	56	66	264
#13	10	40	37	148
#14	19	76	23	92
#15	17	68	26	104
#16	24	96	33	132
#17	15	60	37	148
#18	14	56	20	80
Mean	**16.25**	**59.11**	**32.44**	**129.78**
SE	1.49	5.98	3.86	15.46

3.5 Rate of Seagrass Predation

The rate of predation of *Posidonia* by *H. erythrogramma* (Table 3.4) varied from 42.86 mm per day to a maximum rate of 83.33 mm day^{-1}. The mean predation rate was 51.11 mm day^{-1} with a Standard Error of 9.54. As the data indicates, the rate of predation increased to peak in February and slowed down as towards the end of the study period.

Table 3.4: Rate of predation of Posidonia by sea urchins on the southern front at the study site

Date Recorded	Mean Dist. Travelled (m) Location 1	2	Mean Distance Travelled (m)	Rate of Predation mm @ Day
17/12/91	0.00	0.00	0.00	0.00
14/1/92	1.30	1.10	1.20	42.86
6/2/92	1.60	1.65	1.63	70.87
24/2/92	1.40	1.60	1.50	83.33
9/3/92	1.00	0.90	0.95	67.86
30/3/92	1.20	0.90	1.05	50.00
13/4/92	0.80	0.40	0.60	42.86
Total	**7.30**	**6.55**	**6.93**	
			Mean Rate	**51.11**
			SE	9.54

3.6 Gut Contents of Study Site Sampling

The mean test diameters during the majority of the study period was reasonably constant in the low 60 mm's except in first (17/12/91) and the last (13/4/92) samplings were the means were 58.17 mm and 57.25 mm respectively, as shown in the data in Table 3.5. The mean gut weights were also relatively static, resulting with a mean of means of 13.70 g. The mean gut fullness was constant as well and in the majority of cases, the gut was full (5 on the scale). The mean test weight again shows hardly any variance besides in the last sampling on 13/4/92 it drops from an average of ≈62.00 g to 53.04 g.

As shown in also in Figure 3.5, the the mean seagrass content of the gut, exhibited a general trend of increased percentage whereas the macroalgae and algal epiphyte, and the indeterminable content generally decreased over the study period. The animal and the calcareous or siliceous matter content remained reasonably constant over the study period.

Figure 3.5 : Mean gut contents of H. erythrogramma at study site

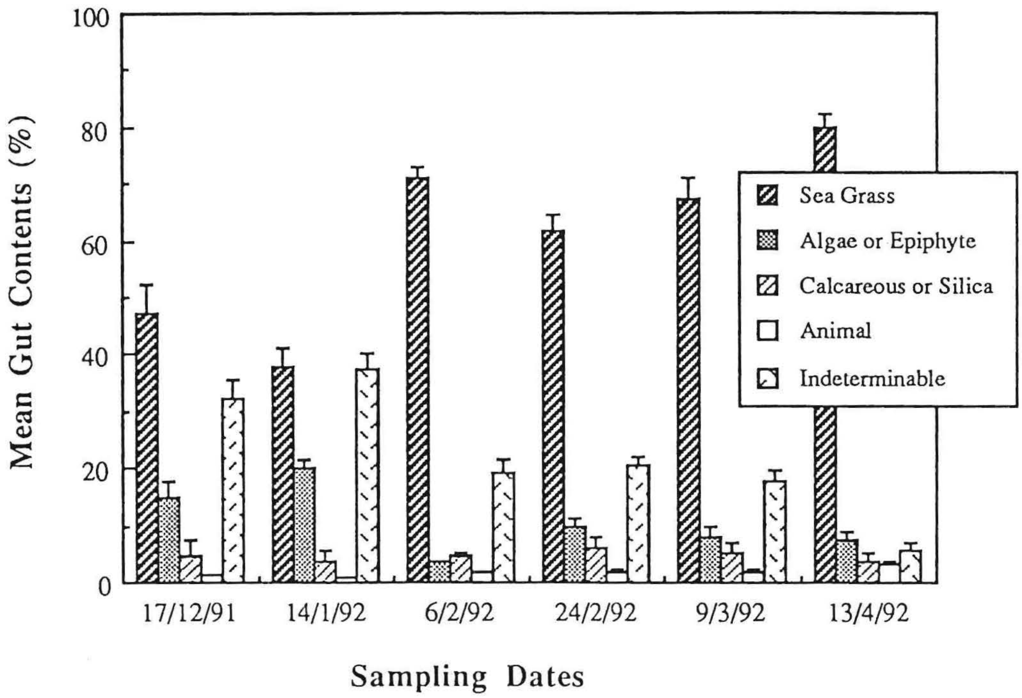


Figure 3.6: Comparison of mean gut contents between sites

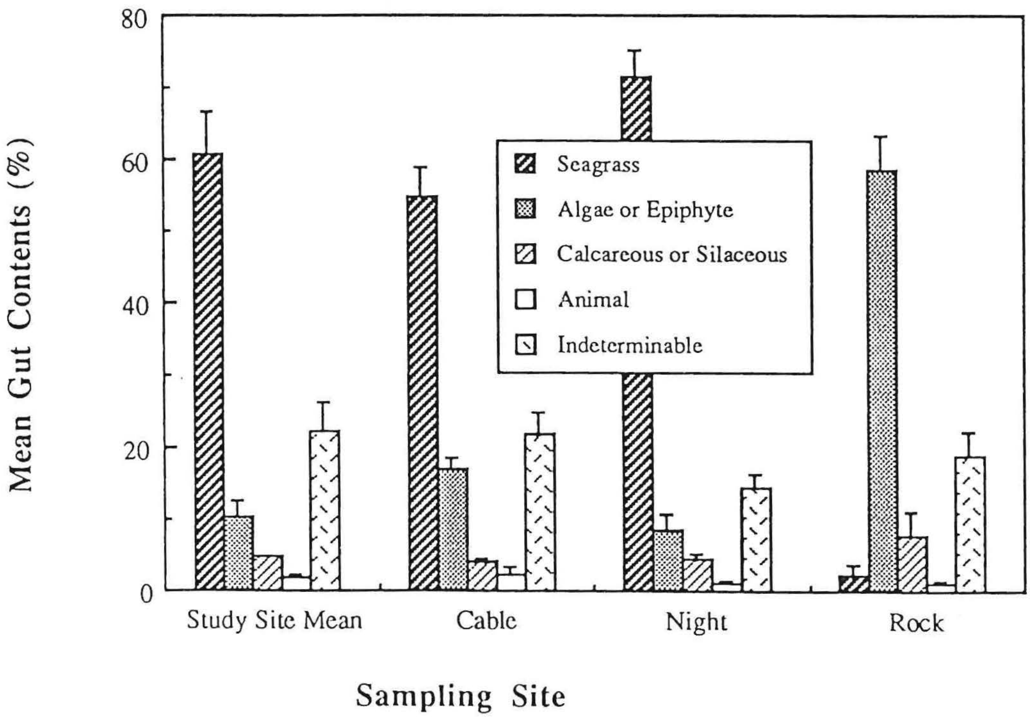


Table 3.5: Means of H. erythrogramma gut content from study site

Sample Date & Number	Mean Test Dia (mm)	Mean Test Weight (g)	Mean Gut Fullness (0-5)	Mean Gut Weight (g)	Mean Gut Contents (%) Sea grass	Algae or Epiphyte	Calcareous or Silica	Animal	Indeterminable
17/12/91	58.17	62.50	4.58	13.98	47.21	14.87	4.53	1.20	32.19
14/1/92	63.25	61.74	4.33	14.29	37.93	20.07	3.93	0.84	37.23
6/2/92	62.00	64.30	4.42	12.80	70.84	3.51	4.56	1.94	19.16
24/2/92	63.58	62.78	4.83	15.00	61.79	9.58	6.26	1.96	20.41
9/3/92	64.67	60.33	4.83	13.94	67.41	7.82	4.93	2.10	17.73
13/4/92	57.25	53.04	4.50	12.19	80.02	7.44	3.63	3.20	5.72
Mean	**61.49**	**60.78**	**4.58**	**13.70**	**60.87**	**10.55**	**4.64**	**1.87**	**22.07**
SE	1.14	1.49	0.08	0.38	5.83	2.22	0.34	0.30	4.18

Table 3.6: Means of H. erythrogramma gut contents from comparative sampling sites

Sample Date & Number	Mean Test Dia (mm)	Mean Test Weight (g)	Mean Gut Fullness (0-5)	Mean Gut Weight (g)	Mean Gut Contents (%) Sea grass	Algae or Epiphyte	Calcareous or Silica	Animal	Indeterminable
"Cable" 24/2/92	53.73	43.47	4.45	8.62	54.78	17.06	4.09	2.26	21.81
"Night" 27/2/92	60.83	61.69	4.58	13.35	71.33	8.59	4.57	1.18	14.34
"Rock" 30/3/92	57.66	69.46	3.53	10.01	2.37	58.49	7.76	0.94	19.03

3.7 Gut contents of Comparative Sampling

With the sampling from the cable, the diameter, test weight and gut weight were less than the study site means. They also had less seagrass and more algae represented in the gut content. According to the data (Table 3.6), the other three classes remained approximately the same as the study site.

The night dive at the study site (27/2/92) corresponds with the study site means, with the seagrass content percentage up by approximately 10% on the overall mean and the sampling on 24/2/92 (three days prior).

The specimens from Harding Rock were larger in diameter and heavier in weight whereas the gut fullness and weight were lower than the study site means. Figure 3.6 plainly shows that at Harding Rock, the seagrass proportion of sea urchin gut contents, to be dramatically lower than the study site sampling and also shows a corresponding dramatic increase in algal content. The other categories of gut content seem to be constant, that is equally represented between the sites.

4.0 Discussion

4.1 Densities

The densities of all three species present at the study site were reasonably high. The maximum mean density of *H. erythrogramma* at the study site of 67.00 per square metre, could be similar to those densities of the same species observed by Larkum & West (1990) in Botany Bay where they did considerable damage to the seagrass meadows (approximately 45 hectares lost). To help alleviate this destruction, a government sponsored project in 1985-1986, removed by hand, in excess of 500 000 sea urchins from a 1 km front. The situation at Luscombe Bay is different to that at Botany Bay, as there is secondary grazing in the barrens by the two smaller sea urchin species, *T. michaelseni* and *N. scotiopremnus*.

The population densities of the smallest sea urchin, *T. michaelseni* was similar to the densities recorded at various sites on the Kwinana foreshore (E.R.A., 1973). *T. michaelseni* has been observed in large numbers on the soft bottom calcareous substratum of the Cockburn Sound basin as far back as 1958-60, well before the start of seagrass decline (Cambridge *et al*, 1986). The implications here are, that *T. michaelseni* was not a major predator of seagrass, but in 1987, an outbreak of this sea urchin was observed grazing on seagrass at the lower edges of Warnbro Sound (Shepherd *et al*, 1989). *T. michaelseni* was also observed damaging transplanted shoots in the shallow waters north of Garden Island (Hancock, *pers comm*).

N. scotiopremnus is indigenous to seagrass meadows but has never been observed in densities similiar to those experienced at Luscombe Bay. They also have not been observed causing serious denuding of seagrass meadow (E.R.A., 1973; Marsh & Cambridge, undated).

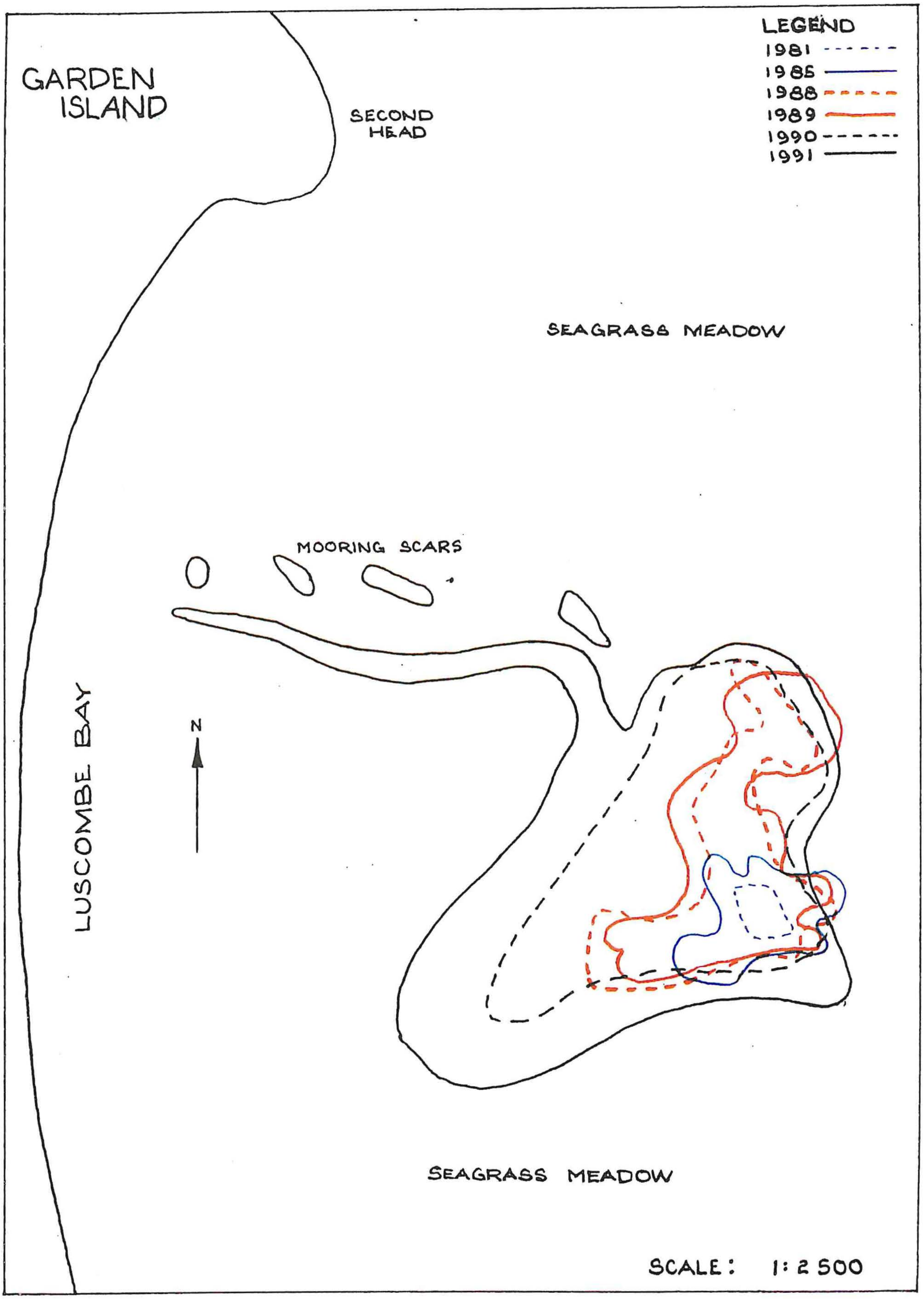
The presence of both small sea urchins species observed within the barrens, is contrary to the previous reports as they are not the primary contributors of seagrass loss, but are the principal organisms responsible for maintaining the nakedness of the barrens. They were observed grazing not only on drift material but on new shoots and on any shoots overlooked by the migrating front.

4.2 Rate of Predation.

The rate of predation (approximately 19 metres year^{-1}) was surprisingly slow when one considers the overall size of the blowout and the number of urchins involved. Due to this slow pace, a backwards extrapolation was attempted to determine when this event originated, assuming that the rate of predation and the population density remained constant, over all distance travelled (250 metres).

The mean age determined was 13.40 years, therefore this suggests that the year of origin was approximately 1978-79. This estimated time of origin was close to the period determined through the aerial photographs of between 1978 and 1981. To extrapolate for future seagrass loss at this blowout, it would be erroneous as there are many limiting

Figure 4.0: Progression of seagrass loss since 1981taken from aerial photographs (*by courtesy* Environmental Protection Authority,W.A.)



variables, for example the amount of seagrass meadow available for grazing. However, looking at Figure 4.0 which shows the relative area of the blowout from the aerial photographs (no adjustments for error in altitude have been made), it is obvious that if conditions are left unchanged, there would be rather considerable loss of seagrass in future years.

Figure 4.0 also reveals that sometime during 1990 to 1991, a major scarring occurred in the NW corner. This seems to be quite unlikely and for the sea urchins to cause this tentacle - like intrusion into the seagrass. Their population density would have had to been extremely concentrated for this infringement to occur to such an extent, in such a short period of time. It seems unlikely that it was actually caused by sea urchins therefore the cause must lie with other unknown reasons.

4.3 Feeding Behaviour and Dietary Preferences.

It has been long recognised that patterns and processes in marine biological systems are surrounded by much noise, that is large levels of variability in time and space. (Choat and Schiel, 1982). Therefore, caution is required when interpreting the diet of a species by quantative analysis of stomach contents because of the limitations of this method. Although the relative frequency of each item can be estimated, the method gives no indication of the respective total biomass of individual components (Ritz *et al*, 1990).

The major dietary component of the study site *H. erythrogramma* was seagrass which confirms site observations of what they are consuming. The algal content seems to decrease comparatively with the seasonal change of algal epiphyte loads (Lethbridge, *pers comm.*). This seems to imply that the algal epiphyte presence in the stomach is a function of seagrass grazing, implying that the seagrass was eaten as a result of being attached to the seagrass blades.

The graph in Figure 3.3 illustrates, the grazing behaviour of *H. erythrogramma* observed at the study site well. It shows an aggregation front similar to the feeding mode of aggressive herbivore as described by Mann (1985). This is in contrast with the "crypt dwelling" behaviour displayed by the same species at Harding rock.

As already indicated, the stomach content analysis has shown what the sea urchins are eating but not what they prefer to eat. The latter can only be determined when there is a choice of food available. The fact that through the gut content analysis, it has been clearly shown that the Harding Rock *H. erythrogramma* are not consuming any seagrass and are preferring macroalgae even though the seagrass is readily available as it is present right up to the rocky outcrop.

This macroalgae preference seems to conform with the gut content examination of Mortensen in 1943 where *H. erythrogramma* was found to have a diet of small bits of algae (mainly large brown algae), *Corallina* and encrusting encrusting organisms (De Ridder & Lawrence, 1982).

Analysis of stomach contents was easiest way to obtain data on the proportion of different food items composing the diet, but there were problems with this method. such as identifying materials undergoing digestion (indeterminables) and possible errors resulting from differences in the rates of digestion of different foods and the moment of sacrifice. The amount of indeterminables varied between 5 - 40%. This could be due to the moment of sacrifice which occurred at various stages of their feeding cycle. This is shown by an increase in seagrass content in the night dive sampling (see Figure 3.6).

Even so, researchers have considered it possible to determine the species and their abundance in the diet. Caution must be used when drawing conclusions from the gut content as variations in diet with time, locality and age of the urchins have been noted, and must be considered in any thorough analysis (Lawrence, 1975).

4.4 Other Field Observations

There were numerous other field observations of this preliminary investigation which will not been discussed in detail in this report.

(a) All species of sea urchins seem to be dormant during day light hours.

(b) *H. erythrogramma* was observed feeding at night by pulling seagrass blades down with the tube feet and cutting blade close to sheath. This behaviour gave the visual effect of knotted clumps in the seagrass.

(c) There was seemingly excessive amounts of human litter within the blowout.

The following was observed on the last field trip on 18/5/92:

(d) There was evidence of a large death event of unknown reasons (see photographs in Appendix 2).

(e) The Port Jackson shark juveniles were still present. They could possibly be feeding on exposed molluscs or the small sea urchin species.

(f) Front seems to be spreading out over a larger width at less densities.

(g) New *H. erythrogramma* activity on the northern front. This is not a new recruitment.

4.5 Summary and Possible Causes

A possible trigger to this event may be related to the construction of the causeway which joins the naval base, HMAS Stirling to the mainland in 1973. Studies of Cockburn Sound since its completion have shown that it has caused less flushing of the embayment, increased turbidity and assisted in the accumulation of nutrient pollutants. All of these factors together, resulted in the consequential, 80% loss of seagrass meadow in Cockburn Sound (Cambridge, 1979).

The relationship between seagrass and sea urchins can be straight forward and abrupt. This is illustrated by the large areas of seagrass that have been rapidly removed (Larkum & West, 1990) and when compared to the extensive grazing of the kelp beds (Larson *et al*, 1980; Lawrence & Summarco, 1982; Harrold & Reed, 1985; Mann, 1985), it can be postulated that if left unchecked, this event at Garden Island will result in considerable changes in species composition, community organisation, and productivity.

As research experiments have shown (Breen and Mann, 1976), the removal of the sea urchins from the destructive feeding front will allow the regeneration of marine flora. Revegetation of this bare patch is unlikely as *P. sinuosa* is very slow to recolonize through rhizome proliferation (Clarke & Kirkman, 1989), low seedling survival (Larkum & West, 1990) and due to the absence of viable rhizome in the barrens. The removal of sea urchins may stop the loss of seagrass for the present but won't help future management to understand or predict possible future destructive aggregations.

The origins of the cable on the northern boundary are unknown. One theory could be that it is a remnant of an anti - submarine boom net that stretched across Cockburn Sound during World War 2 (Kirkman, *pers comm.*). Another is that it is an obsolete communication cable, but then it should be bound in rubber and be marked on the marine charts. It seems unlikely to be the point of origin and this is confirmed by the aerial photographs (see overlay in Figure 4.0) but it may be a corridor for sea urchin migration.

The aerial photographs seem to indicate the origin being in the south western corner. Maybe it was a mooring as the shape of the initial outbreak is similar to the that of the other mooring scars (present prior to 1981). This would be ample for the sea urchins to gain a foot hold in the seagrass.

Heliocidaris erythrogramma seem to be present in two distinct recruitments. Test sizes being of around 65 mm and 55 mm, the latter being the smallest recruitment. Why aren't there more size variation with juveniles present ? From where did they migrate or did their pelagic larvae settle here ? If the latter is the case, what were the environmental conditions that facilitated this event ?

What were the precursors to this event ? This is a question that warrants future research.

5.0 Conclusions:

1/. Diet confirms observations of sea urchins eating sea grass.

2/. In the process of eating the seagrass they pick up a broad range of epiphytes (algae, diatoms and protozoan).

3/. Proportion of algae in diet varies with algal seasonal drop off.

4/. It is not possible to determine from data, whether the sea urchins are eating consistently over the research period (five months).

5/. At above mentioned densities and rate of predation, this aggregation has, is and will cause substantial damage to affirm the need for concern in the environmental management of the remnant *Posidonia* meadows in Cockburn Sound.

6/. It is unlikely that Posidonia sinuosa will regenerate at the blowout before the establishment of other marine flora.

6.0 Recommendations:

The cause for this event has still to be defined, therefore it is suggested that further research should include:

1. Constant monitoring of site will help to avoid the same extensive damage that occurred in Botany Bay. This event may be a long term phenomenon.
2. Determination of the cause of this event, ie. whether this was man- made or if it is a natural event (cyclic or otherwise). Knowledge of a precursor to this phenomenon would help in anticipating a similar outbreak.
3. The managers of this area (E.P.A., The Navy, C.A.L.M and W.A.W.A.), need to evaluate the significance of this event in the context of wider Cockburn Sound management strategies. The choice to destroy this event would mitigate possibilities for on going monitoring and further research. Alternately the loss of any further seagrass in this system may be unacceptable.

7.0 Acknowledgements:

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Appendix 1

Table A1 [cont.]: Test measurements and mean contents of H. erythrogramma at study site

Sample Date & Number	Test Dia (mm)	Test Weight (g)	Gut Fullness (0-5)	Gut Weight (g)	Gut Contents (%) Sea grass	Algae or Epiphyte	Calcar-eous or Silica	Animal	Indeter-minable
9/3/92									
1	58	53.96	5	11.13	83.42	1.94	5.07	1.40	8.17
2	64	64.42	5	14.20	64.94	10.18	4.61	2.74	17.53
3	60	47.93	3	9.02	70.31	2.81	3.42	1.17	22.29
4	65	58.62	5	13.35	60.88	10.70	6.56	1.66	20.21
5	65	59.08	5	12.03	75.11	3.79	5.42	2.41	13.27
6	68	60.05	5	16.07	54.22	8.24	6.86	2.60	28.08
7	65	59.23	5	15.09	74.18	6.58	3.25	2.23	13.76
8	62	57.00	5	15.68	71.56	6.38	5.01	2.41	14.63
9	66	66.36	5	14.48	37.91	28.60	4.30	2.63	26.56
10	68	68.31	5	14.88	80.06	4.67	3.86	2.17	9.23
11	70	65.87	5	15.64	59.46	6.12	7.57	2.54	24.30
12	65	63.16	5	15.72	76.88	3.86	3.25	1.24	14.77
Means	**64.67**	**60.33**	**4.83**	**13.94**	**67.41**	**7.82**	**4.93**	**2.10**	**17.73**
SE	0.98	1.67	0.17	0.63	3.69	2.05	0.42	0.17	1.89
13/4/92									
1	47	44.00	5	10.76	65.53	19.02	3.69	2.51	9.26
2	61	53.76	5	14.68	77.70	9.56	3.79	8.95	0.00
3	62	53.44	3	7.73	82.85	6.04	4.07	1.59	5.45
4	58	53.58	5	12.32	81.50	4.73	4.13	2.42	7.21
5	54	45.55	4	8.89	79.98	9.31	3.55	2.99	4.17
6	63	67.80	5	17.17	83.42	7.12	2.72	2.13	4.60
7	55	43.29	5	10.48	88.74	1.99	2.93	1.76	4.58
8	56	53.99	5	15.18	71.50	12.55	4.47	2.67	8.81
9	55	46.19	5	10.98	81.25	4.60	3.72	2.33	8.10
10	63	63.04	5	15.62	91.29	2.43	3.78	2.50	0.00
11	63	62.79	5	15.48	86.37	5.14	2.90	5.59	0.00
12	50	49.01	2	7.04	70.15	6.74	3.78	2.91	16.41
Means	**57.25**	**53.04**	**4.50**	**12.19**	**80.02**	**7.44**	**3.63**	**3.20**	**5.72**
SE	1.55	2.32	0.29	0.98	2.22	1.37	0.15	0.60	1.37

Table A1 [cont.]: Test measurements and mean contents of H. erythrogramma at study site

Date & Number	Dia (mm)	Weight (g)	Fullness (0-5)	Weight (g)	Sea grass	Algae or Epiphyte	Calcar-eous or Silica	Animal	Indeter-minable
6/2/92									
1	60	65.72	3	10.00	71.59	1.68	5.35	1.50	19.88
2	59	67.72	5	12.27	81.30	2.37	3.20	2.31	10.82
3	70	71.51	5	13.90	71.26	4.75	6.50	2.21	15.29
4	58	50.22	4	9.39	74.85	7.20	3.99	1.74	12.22
5	66	73.22	5	18.65	70.66	3.02	4.95	1.85	19.52
6	62	52.40	5	12.29	63.76	2.96	4.07	1.46	27.75
7	63	79.31	5	18.08	53.08	4.20	4.57	2.20	35.94
8	60	66.42	4	11.52	73.85	2.93	6.44	3.10	13.68
9	63	68.79	3	9.76	77.38	4.29	4.01	1.59	12.73
10	69	67.22	5	14.63	69.48	2.73	3.27	1.50	23.03
11	60	57.47	4	11.10	64.57	4.14	5.75	2.20	23.35
12	54	51.64	5	12.01	78.28	1.81	2.60	1.60	15.70
Means	**62.00**	**64.30**	**4.42**	**12.80**	**70.84**	**3.51**	**4.56**	**1.94**	**19.16**
SE	1.33	2.68	0.23	0.88	2.20	0.44	0.37	0.14	2.14
24/2/92									
1	62	69.28	5	16.10	70.19	5.81	3.95	1.37	18.68
2	65	61.27	5	14.54	71.33	3.81	5.66	3.59	15.60
3	68	75.88	5	15.84	46.24	21.94	4.29	2.33	25.21
4	60	61.43	5	14.13	66.90	12.25	3.43	0.79	16.63
5	73	86.58	5	22.23	67.11	8.82	5.24	1.67	17.15
6	65	56.74	5	14.58	47.49	3.06	16.58	3.90	28.96
7	58	50.60	4	9.33	59.79	10.17	6.04	1.89	22.12
8	64	52.79	5	10.75	53.26	6.48	7.06	1.83	31.36
9	66	65.52	5	17.88	62.36	18.36	4.94	1.25	13.09
10	63	52.39	4	12.52	67.94	6.41	4.78	1.64	19.23
11	58	64.43	5	16.02	59.47	11.08	7.84	2.15	19.47
12	61	56.45	5	16.12	69.40	6.73	5.36	1.09	17.42
Means	**63.58**	**62.78**	**4.83**	**15.00**	**61.79**	**9.58**	**6.26**	**1.96**	**20.41**
SE	1.24	3.05	0.11	0.96	2.52	1.65	1.00	0.27	1.59

Table A1: Test measurements and mean contents of H. erythrogramma at study site

Sample Date & Number	Test Dia (mm)	Test Weight (g)	Gut Fullness (0-5)	Gut Weight (g)	Gut Contents (%) Sea grass	Algae or Epiphyte	Calcar-eous or Silica	Animal	Indeter-minable
17/12/91									
1	55	70.89	5	12.48	44.87	13.84	10.65	2.43	28.21
2	62	86.14	5	12.56	46.47	12.47	5.37	1.26	34.42
3	59	67.78	5	16.02	51.94	18.09	3.64	1.19	25.14
4	62	81.68	4	14.65	48.89	6.95	4.38	0.68	39.10
5	59	67.51	4	12.07	34.29	12.00	4.35	1.79	47.58
6	60	54.35	5	16.42	80.21	4.60	2.96	0.75	11.48
7	53	49.89	5	13.93	74.63	4.36	5.88	1.27	13.85
8	66	73.30	5	14.42	12.09	43.49	2.30	0.96	41.16
9	58	61.59	5	15.87	41.70	13.18	6.30	1.11	37.71
10	49	43.39	4	10.25	57.61	10.77	2.88	0.52	28.22
11	58	55.62	5	15.62	33.24	19.89	3.03	1.24	42.60
12	57	37.83	3	13.45	40.58	18.77	2.69	1.20	36.76
Means	**58.17**	**62.50**	**4.58**	**13.98**	**47.21**	**14.87**	**4.53**	**1.20**	**32.19**
SE	1.28	4.28	0.19	0.54	5.26	2.99	0.67	0.15	3.23
14/1/92									
1	58	49.77	2	9.48	36.63	13.98	2.87	0.70	45.83
2	65	64.56	3	11.63	29.42	14.16	4.22	1.20	51.00
3	62	55.07	5	15.54	23.68	24.55	5.30	0.58	45.89
4	66	64.39	5	17.30	43.92	17.72	5.16	0.67	32.52
5	75	84.33	5	18.24	40.67	32.15	1.74	0.83	24.62
6	62	54.72	5	14.18	16.27	24.43	8.40	0.25	50.66
7	64	70.74	4	14.24	44.68	20.90	3.15	0.71	30.56
8	62	61.59	4	13.15	51.17	15.97	6.65	1.81	24.40
9	59	59.31	4	13.06	45.58	15.19	2.32	0.94	35.97
10	65	67.58	5	14.09	39.45	23.51	2.48	0.76	33.81
11	63	54.79	5	15.18	54.22	21.13	2.20	0.26	22.20
12	58	53.97	5	15.33	29.47	17.17	2.62	1.41	49.32
Means	**63.25**	**61.74**	**4.33**	**14.29**	**37.93**	**20.07**	**3.93**	**0.84**	**37.23**
SE	1.32	2.74	0.28	0.68	3.27	1.57	0.60	0.13	3.13

Table A2: Test measurements and mean contents of H. eryhtrogramma at comparative sites

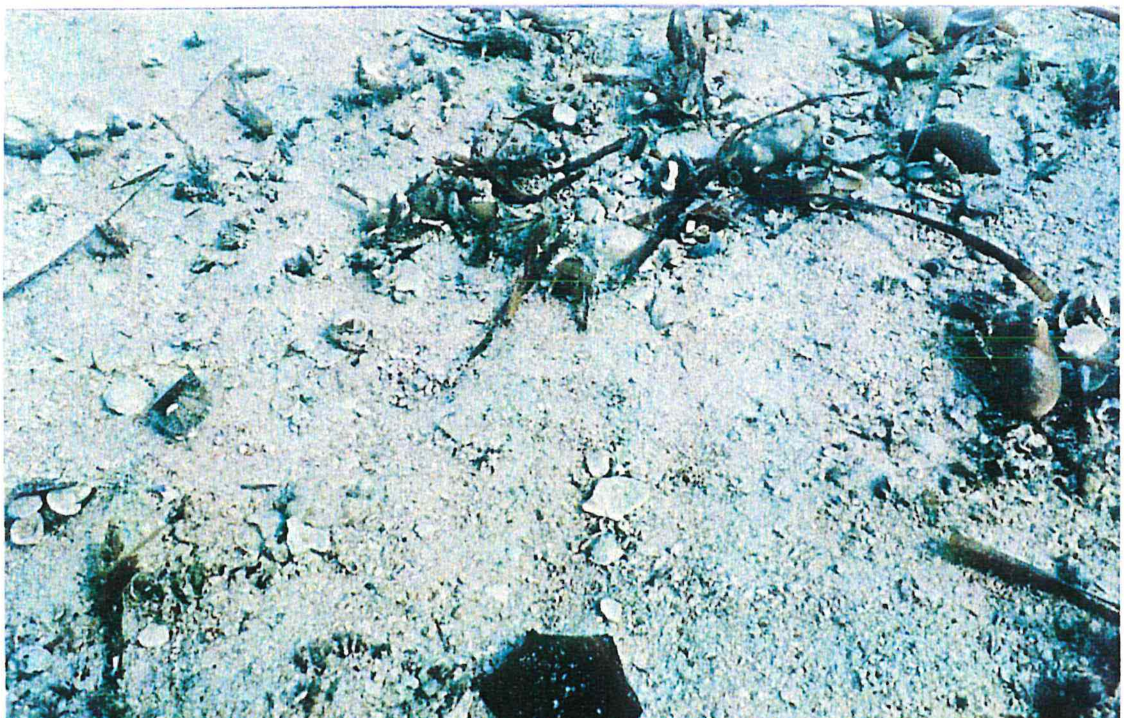
Sample Date & Number	Test Dia (mm)	Test Weight (g)	Gut Fullness (0-5)	Gut Weight (g)	Gut Contents (%)				
					Sea grass	Algae or Epiphyte	Calcar-eous or Silica	Animal	Indeter-minable
Cable 24/2/92									
1	66	53.77	4	11	63.45	14.27	2.35	1.04	18.89
2	45	26.89	3	5.35	71.05	11.88	2.74	1.20	13.14
3	55	39.05	4	9.68	63.96	16.55	4.08	0.86	14.54
4	68	68.83	5	11.94	69.29	12.15	2.92	0.51	15.14
5	54	52.29	5	10.48	55.00	15.99	2.99	13.61	12.40
6	55	51.51	5	9.84	37.13	21.71	4.11	0.19	36.86
7	52	36.25	4	7.5	30.34	23.49	4.04	0.19	41.94
8	55	44.43	5	10	62.75	12.75	3.16	0.51	20.84
9	46	35.46	5	6.17	62.12	17.47	6.39	1.75	12.28
10	50	39.57	4	5.51	38.30	27.01	6.34	2.09	26.25
11	45	30.13	5	7.32	49.16	14.38	5.89	2.87	27.69
Means	**53.73**	**43.47**	**4.45**	**8.62**	**54.78**	**17.06**	**4.09**	**2.26**	**21.81**
SE	**2.31**	**3.69**	**0.21**	**0.70**	**4.23**	**1.50**	**0.45**	**1.16**	**3.09**
Night 27/2/92									
1	66	77	4	15.13	71.10	8.49	3.65	1.56	15.20
2	65	69.11	5	12.7	74.37	6.53	3.29	1.43	14.38
3	59	48.78	5	12.44	79.50	4.60	2.17	1.65	12.08
4	56	63.74	5	13.08	52.49	20.52	5.82	1.15	20.02
5	59	53.94	5	12.03	83.11	2.12	3.33	0.84	10.61
6	53	52.21	5	13.98	72.91	2.20	4.94	0.65	19.30
7	65	55.85	2	6.98	41.85	27.66	3.95	0.77	25.77
8	55	46.03	4	10.68	75.43	7.90	3.20	0.49	12.98
9	64	69.61	5	16.03	82.39	3.73	3.09	1.58	9.21
10	63	59.97	5	14.06	67.15	7.95	9.41	0.68	14.81
11	62	70.64	5	16.26	66.91	5.13	7.60	2.61	17.74
12	63	73.42	5	16.77	88.75	6.20	4.35	0.69	0.00
Means	**60.83**	**61.69**	**4.58**	**13.35**	**71.33**	**8.59**	**4.57**	**1.18**	**14.34**
SE	1.25	**2.98**	**0.26**	**0.79**	**3.81**	**2.22**	**0.61**	**0.18**	**1.85**

Table A2 [cont.]: Test measurements and mean contents of H. eryhtrogramma at comparative sites

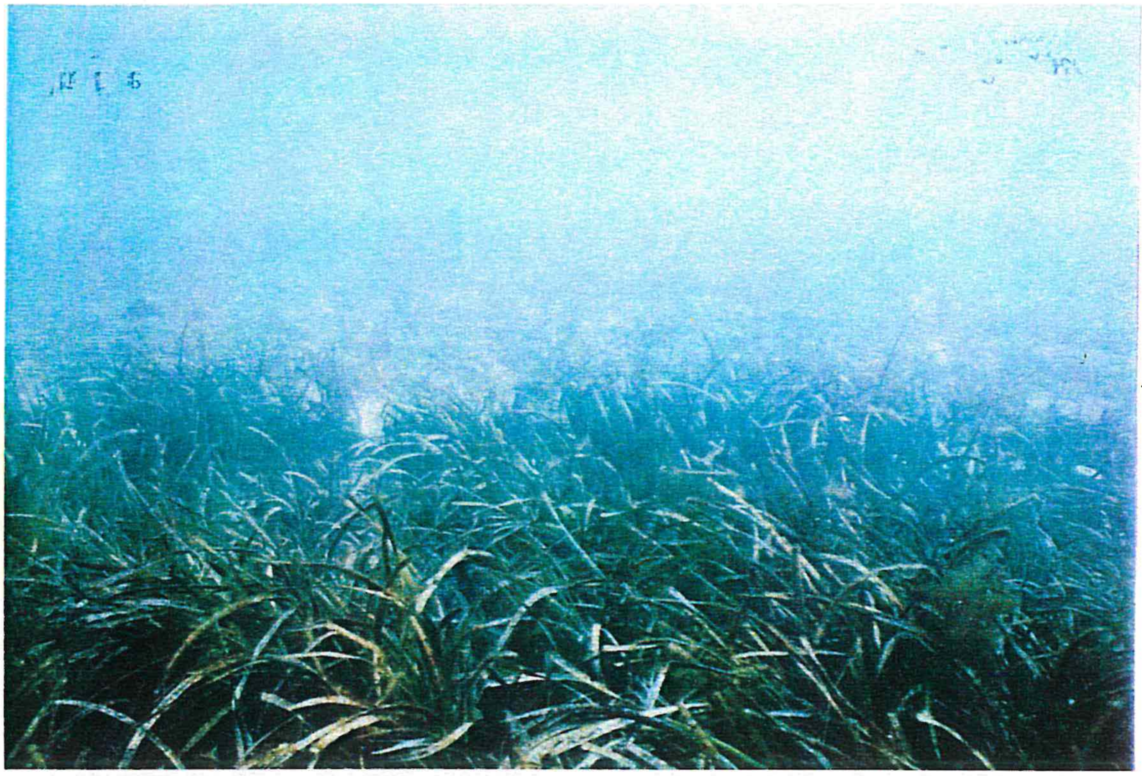
Sample Date & Number	Test Dia (mm)	Test Weight (g)	Gut Fullness (0-5)	Gut Weight (g)	Gut Contents (%) Sea grass	Algae or Epiphyte	Calcar-eous or Silica	Animal	Indeter-minable
Rock 30/3/92									
1	80	122.87	2	16.48	0.00	82.22	2.45	3.25	12.08
2	66	101.79	5	8.1	0.27	53.77	7.61	0.00	38.35
3	69	72.64	5	9.33	10.39	60.21	3.55	0.97	24.89
4	64	66.6	3	12.31	0.00	63.78	13.92	0.79	21.51
5	63	78.82	4	13.05	0.88	79.15	2.83	0.49	16.65
6	63	56.64	4	12.88	0.00	75.29	5.30	1.56	17.85
7	55	53.35	5	7.11	3.58	51.25	25.84	0.28	19.06
Means	**57.66**	**69.46**	**3.53**	**10.01**	**2.37**	**58.49**	**7.76**	**0.94**	**19.03**
SE	2.88	9.51	0.44	1.24	1.45	4.70	3.21	0.41	3.19

Appendix 2

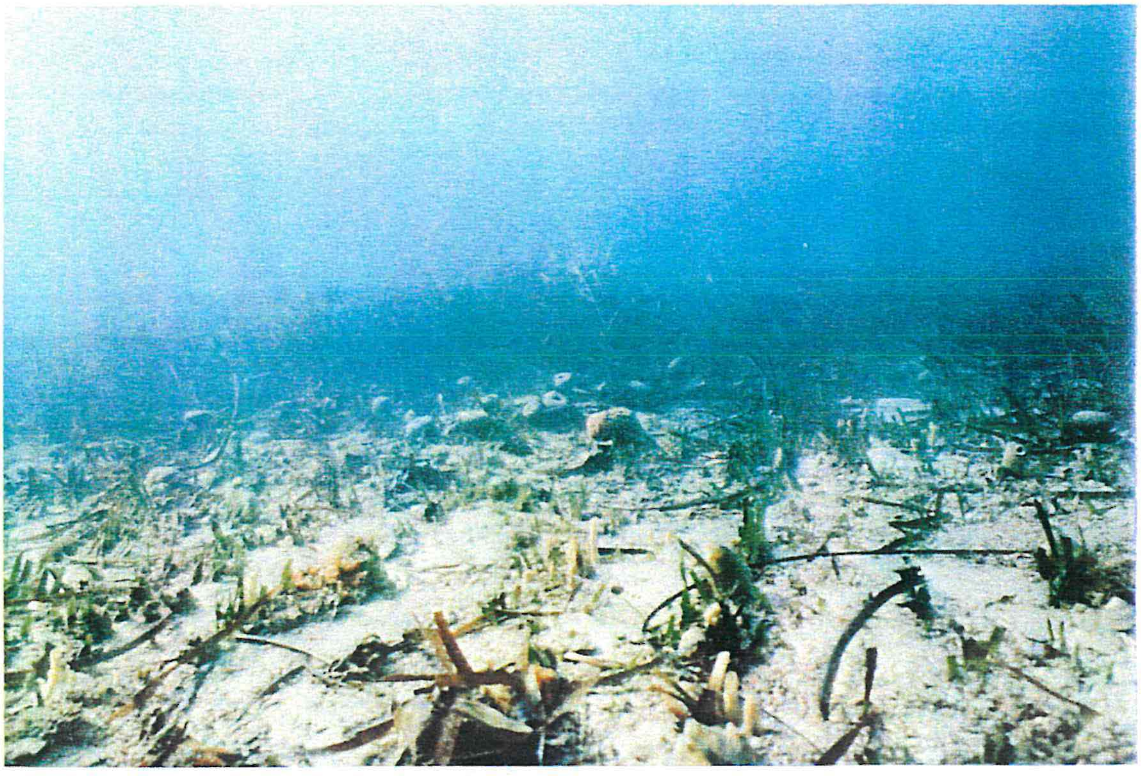
Heliocidaris erythrogramma; the echinoderm responsible for the initial and the major loss of seagrass.



In the barrens: no sign of *Posidonia* regeneration; *T. michaelseni* and *N. scotiopremnus* present in large numbers (18/5/92).

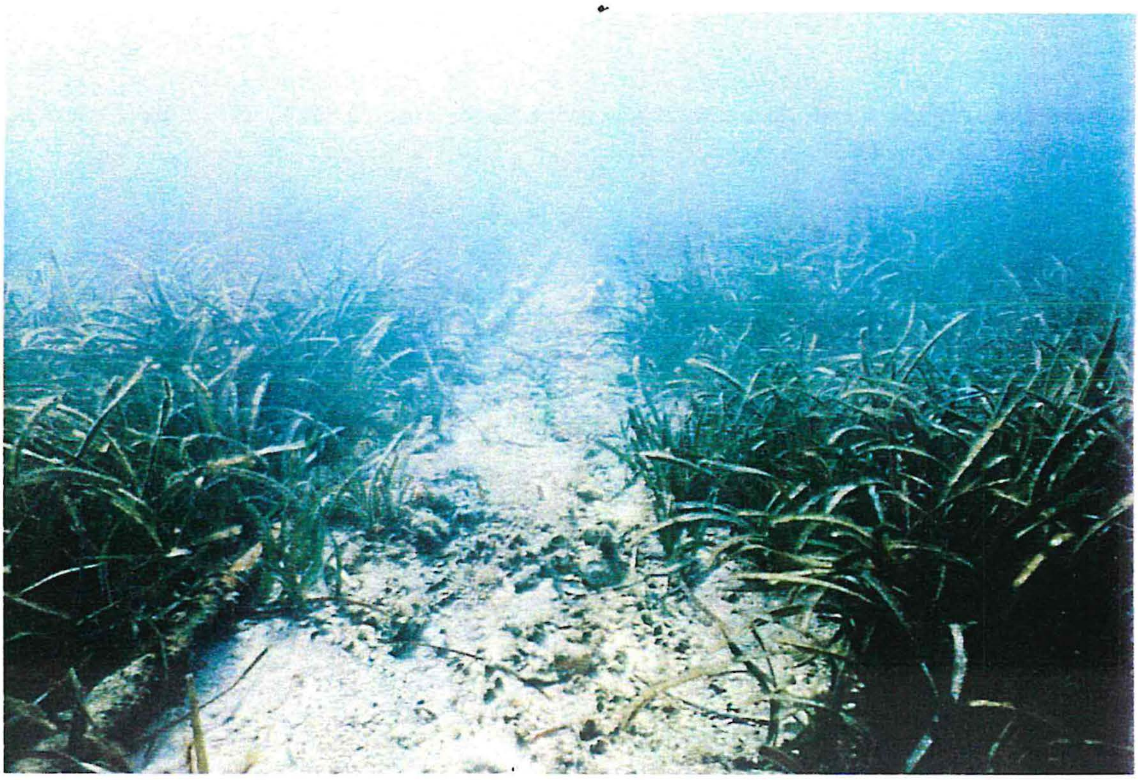


Looking north over the interface at the defined study site. Note the epiphyte load on the seagrass in the foreground (18/5/92).



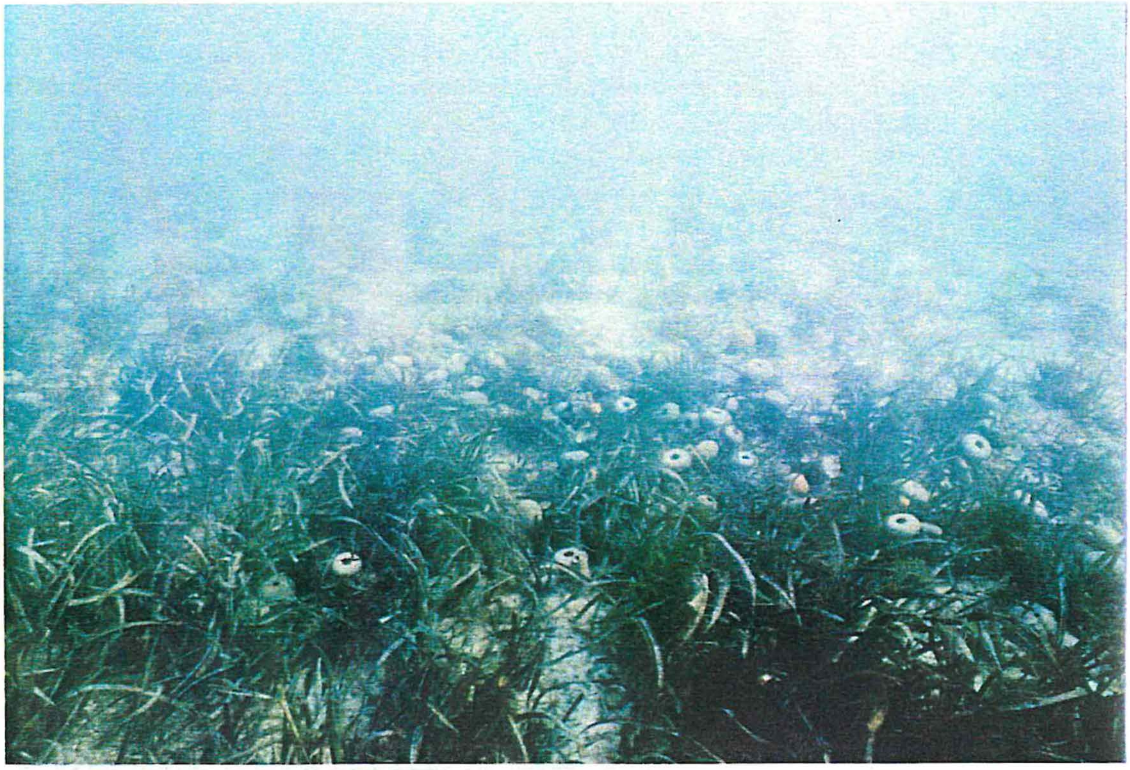
In the barrens: looking south over the interface. "It was quite distinct and easy to determine" (18/5/92).

Heliocidaris erythrogramma; at the comparative sampling site, "the cable" (18/5/92). The origin of the cable is still unknown.



The small population of *H.erythrogamma* possibly had used the cable as a corridor through the seagrass from the east (18/5/92).

Port Jackson sharks are present in the SW corner of the "blowout". Any remaining Posidonia shoots were ultimately grazed by the smaller sea urchin species.



Observed at the interface on the last field trip (18/5/92), were the dead naked tests of a recent death event of unknown cause.