

Kelp grazing by the common sea urchin *Parechinus angulosus* Leske in False Bay, Cape

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The effect of grazing by the common sea urchin on a local kelp bed was studied. The need for this investigation was felt in view of the importance of kelp beds to the near-shore ecosystem and reports describing the extent of damage to some Californian and eastern Canadian kelp beds by the grazing activity of certain urchin species. Experimental sites typical of the area were permanently marked. A study site was protected from urchins, while the control was not. Urchins were regularly removed from the study site. Kelps growing on the experimental plots were harvested seasonally, counted and their biomass calculated. Results over one year suggest that although the grazing potential of sea urchins is considerable, little impact was made on kelp beds in the study area. The grazing potential of *Parechinus* seems to be directed principally at the early sporophytes of *Ecklonia maxima* rather than at adult plants.

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Die gevolg van beweiding op 'n plaaslike seewierbedding bestaande uit *Ecklonia maxima* deur die gewone seekastaiing is ondersoek. Daar was 'n behoefte vir 'n soortgelyke studie, in die lig van die belangrikheid van seewierbeddings vir die nabye kus ekosisteem. Daar bestaan menige berigte in die literatuur met betrekking tot die omvang van skade aangerig in sommige Kaliforniese en Kanadese ooskus kelpbeddings deur beweiding van sekere soorte seekastaiings. Ons het proefpersele wat tipies vir die gebied is, gekies en blywend gemerk. Die proefperseel is herhaalde kere gedurende die studie-tydperk van seekastaiings bevry, maar nie die kontroleperseel nie. Kelp wat op die persele gegroei het, is elke seisoen ge-oes, getel, en die droë massa bepaal. Resultate gedurende een jaar dui aan dat, ofskoon die beweidingspotensiaal van *Parechinus* aansienlik is, daar nietemin uitwerking op die kelpbeddings van die area blyk te wees. Beweidingsdruk van *Parechinus* blyk tot 'n hoë mate teen die spoorkiemplantte van *Ecklonia maxima* gerig te wees, in plaas van 'n uitdunningseffek op volwasse plante te hê.

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Parechinus angulosus Leske is the most widespread of South African echinoids, forming very dense, sometimes continuous, populations of up to 90 animals per m² in some inshore localities around the Cape Peninsula. Their high population density and voracious feeding pattern (Greenwood 1975; Buxton 1977) imply that these echinoderms play a major role in the kelp ecosystem. Kelp beds have recently been shown to have considerable importance not only as nursery grounds for numerous invertebrates and fish species (Mann 1972a, b; Miller & Mann 1973; Field *et al.* 1977), but also to be of great potential commercial importance as a source of valuable extracts (Simons 1977).

The destructive effect of intense grazing by Californian urchins *Strongylocentrotus* spp. on beds of *Macrocystis pyrifera* has been described by North (1965), North and Pearse (1970), Leighton *et al.* (1966), Mattison *et al.* (1977), Breen and Mann (1976) and Lang and Mann (1976). Along the eastern coast of Canada evidence for advancing destruction of beds of *Laminaria longicuris* and *L. digitata* by *Strongylocentrotus* spp. has been the subject of detailed study by workers in Nova Scotia. Interest in our study was stimulated by similarities between the situation in the vicinity of the Cape Peninsula and parts of the Californian and Canadian coast. In all these areas kelp productivity is high because environmental conditions are favourable, while over-exploitation of the controlling predators of the herbivorous urchins appears to have affected the balance of the kelp ecosystem. The destruction wrought by increased numbers of urchins in Californian and Canadian kelp beds does not seem apparent in the vicinity of the Cape Peninsula. A map of the area is shown in Fig. 1.

The pronounced upwelling conditions along the Cape west coast, with their high productivity (Field *et al.* 1977) and generally turbulent sea conditions, may prevent urchins from grazing on attached kelps, while generating an abundant supply of organic matter as food for the echinoids. Observations on a plot near the study area at Millers Point, False Bay suggested however, that protection from sea urchins for a matter of months resulted in a dramatic increase in the density of a stand of *Ecklonia maxima* within little more than a year. Following upon these preliminary findings, an experiment was started which

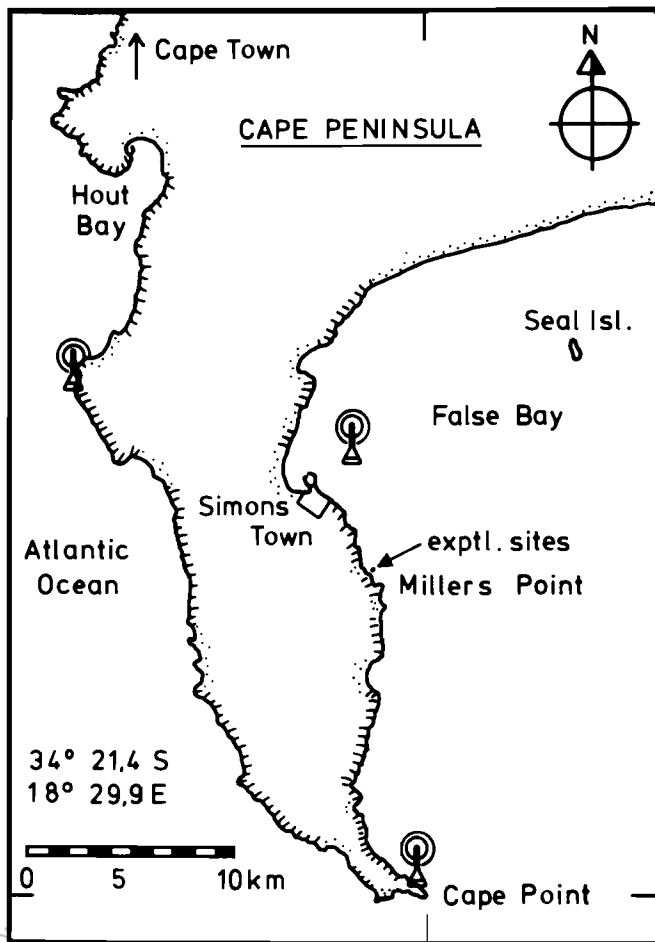


Fig. 1 Map of Cape Peninsula showing the location of experimental stations.

consisted of a series of seasonal kelp harvests over a study site and control.

Methods

Permanent stations

These were established at Miller's Point, False Bay, by placing circular concrete anchors of low relief, weighing 70 kg in air, on level positions on the sea-bed (Fig. 2). The anchors were fitted with small sub-surface buoys to facilitate relocation. It was essential that the arrangement should withstand turbulent sea conditions and possible tampering. Under no account was the anchor to move or else the study would be affected. For the sake of clarity, the terms *cropping* and *harvesting* will be used for plant material, while urchins are *cleared* or *removed*.

Two experimental stations in a kelp bed (the study site and the control) were selected so that they were as similar as possible with respect to substrate topography and aspect. The stations consisted of circular areas of 10 m². Such an area was swept by a radial line 1,78 m in length. For purposes of harvesting, the stations were divided into four quadrants by means of weighted lines laid out in the compass directions.

The experiment was started by clearing all urchins from the study site and also from a ring-shaped outer zone 1,22 m wide. The entire cleared area thus had a radius of 3 m (area = 20 m²). Experience suggested that the buffer zone was wide enough to effectively protect the study site, provided urchins were cleared away at roughly monthly intervals. Both sites were initially cropped free of all but

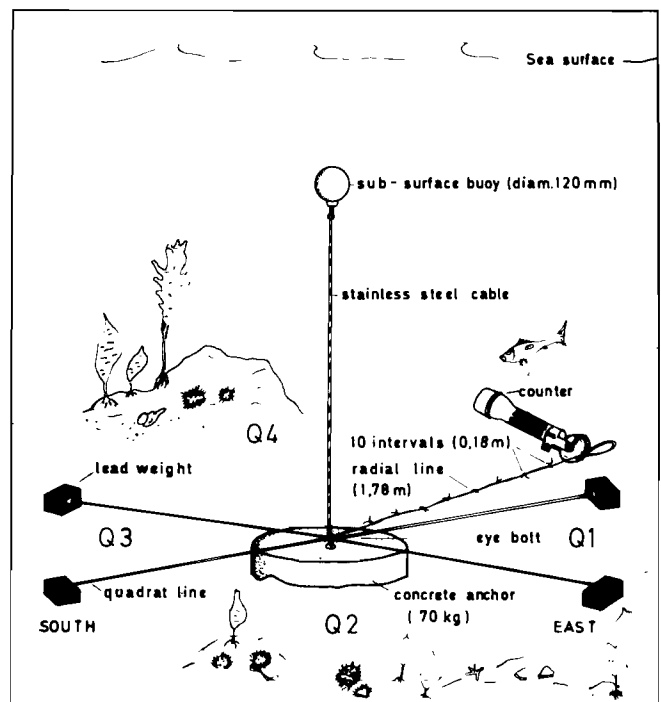


Fig. 2 Layout of quadrant lines on experimental stations.

adult kelps, which were left *in situ* to provide canopy cover. Holdfasts of harvested *Ecklonia* were removed since recolonization is favoured by the protective shelter offered by the meshwork of the haptera.

The kelps harvested were counted and their dry mass (at 105 °C) determined from a wet/dry mass regression given by Buxton (1977) ($dm = -0,11 + 0,15 wm$; $N = 20$; $r^2 = 0,84$). Adult canopy plants were counted to check on losses in the course of time.

After this initial preparation, a three-month period was allowed to elapse before the first quadrants (Fig. 2) on the study site (Qs) and control (Qc) were cropped of newly grown kelps. After successive three-month periods of quadrants 2, 3 and 4 on both stations were similarly harvested. Finally, the entire algal cover on both stations was cropped. This was done in order to determine the total amount of kelp produced during the period of study.

Correction for substrate surface irregularities

Available solid substrate surface seems to be of importance in the density distribution of sea urchins at high population densities (Dahl 1973; Laxton & Stablum 1974; Greenwood 1975; Fricke 1976) since the echinoids avoid unconsolidated sediment. Measurement of substrate surface within the 10 m² of both experimental plots was done after the last kelp harvest had left the two plots barren. A counting wheel, described in an earlier paper (Fricke 1976) was employed for this task.

Four weighted quadrant lines, 1,78 m long were laid out as equally-spaced radii from the central anchor. Each quadrant was treated individually. A moving radial line of the same length and marked in ten equal intervals, each representing a step in the measurement, was used in conjunction with the counting wheel (Fig. 2). The device was carefully pushed over the irregularities encountered in the arc delimiting a quadrant at each of the ten marks. Sand patches were ignored. Initial and final readings were noted on each arc, giving the number of revolutions of the wheel and hence linear distance travelled.

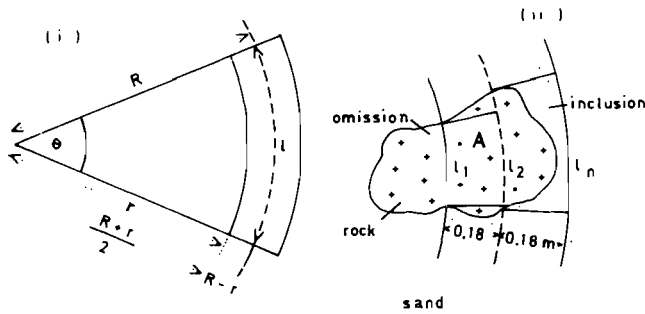


Fig. 3 Geometrical construction to determine area of partial annulus A.

Calculation of surface area

Each block of solid substrate was considered to approximate a parallel-sided slab (strictly speaking a segment of a partial annulus, as in Fig. 3(i)). This assumption results in omissions of area, but these are cancelled out on the average by compensating over-estimates (Fig. 3(ii)).

For the sector in Fig. 3(i)

$$\text{Area of sector} = \frac{1}{2}L^2 \times \theta \text{ radians}$$

$$\text{Therefore area A required} = \frac{1}{2}(R^2 - r^2) \times \theta$$

$$\sin l = (R + r)/2\theta$$

Eliminating the area term:

$$\frac{\text{area}}{\text{length}} = \frac{R^2 - r^2}{R + r} = R - r;$$

$$\text{Thus required area} = (R - r) \times \text{length of medial l} \\ = \text{spacing of block} \times l$$

$$\text{Therefore } \Sigma \text{ area of blocks} = \text{spacing} \times \Sigma \text{ length of blocks}$$

The precision of the above approximation was tested by three replicate measurements of a circle of 10 m² on firm terrain. The replicates fell within 4% of the theoretical value.

Results and Discussion

Urchin density, immigration and removal

When initially cleared, the study site had a *Parechinus* density of 61 individuals m⁻² (76 m⁻² when corrected to actual surface area). At the conclusion of the experiment, the urchins living on the control site were also counted and their numbers corrected (Table 1). There was no significant difference between the two sites. This supports the well-known fact that substrate surface availability is of importance to many sessile and slow-moving marine organisms (Marsh 1970; Dahl 1973; Laxton & Stablum 1974).

Table 1 Number of *Parechinus* cleared from experimental stations, corrected for actual benthic area

	Study Site	Control
Project area (m ²)	10	10
Actual area (m ²)	8,0	11,5
Percentage difference	-20	+15
Number of urchins	609 ^a	831 ^b
Urchins m ⁻²	61	83
Urchins m ⁻² (corrected)	76	72

^a Urchins cleared from the study site at the beginning of the experiment.

^b Urchins cleared from the control at the end of the experiment.

The total number of *Parechinus* removed during the study (excepting the control) was 785 animals.

The schedule of maintenance clearings of urchins is summarized in Fig. 4. Data from a pilot study are also shown and support the evidence for a fluctuating seasonal immigration rate. The two studies were performed on different scales, hence the difference in urchin numbers. Immigration of *Parechinus* shows highest values between September and November, while those for the period from November to April are low. This appears to be related to the reproductive cycle of the urchin (Fricke 1974). Near spawning, *Parechinus* appears to remain relatively stationary (*pers. obs.*), while the feeding rate of gravid urchins is much reduced (Greenwood 1975; A.H. Fricke *unpubl.*).

Kelp harvests

Table 2 summarizes the harvesting data for the entire study. Although the actual surface area between the sites differs by 35%, the adult population of *Ecklonia* found initially was similar (14 kelps were found on the study site and 11 on the control). Surface area appears to be of no importance to kelp density (K.H. Mann *pers. comm.* 1976, A. Chapman *pers. comm.* 1977) unless the water column is under-utilized. This would be the case if sand patches larger than a mature kelp plant intervened between solid substrate.

Initial cropping

This operation served the purpose of determining standing stock at the start of the experiment. The number of individuals harvested on the study site was almost twice that obtained from the control, while the ratio of biomass was 1,8:1 (Table 3). Adult canopy kelps were counted during successive field trips to follow their fate (Table 4). Such information is valuable because sudden breaks in the canopy (e.g. as a result of a storm) may significantly change light

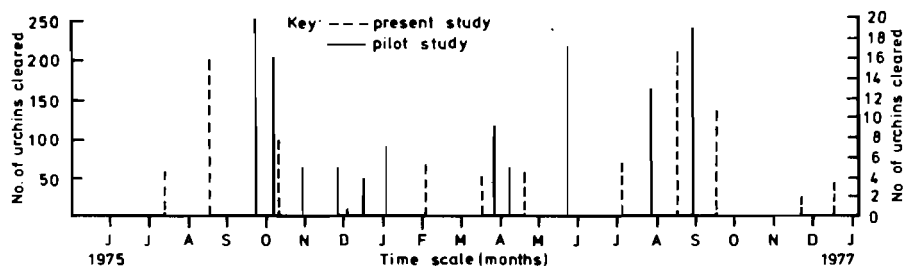


Fig. 4 Immigration of *Parechinus angulosus* into cleared sites. The solid line denotes data of the present study (scale on left). Dashed lines refer to data of a pilot study (scale on right).

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Table 2 Initial, seasonal and final harvests of *Ecklonia maxima* on experimental stations at Millers Point, False Bay

	Quadrants of study site			
	Qs1	Qs2	Qs3	Qs4
Initial harvest				
Date	7.9.76	7.9.76	7.9.76	7.9.76
Numbers	57	74	80	13
Mass (g)	1575	2217	1792	645
Seasonal harvest				
Date	3.12.76	10.3.77	7.6.77	10.9.77
Numbers	68	175	60	29
Mass (g)	5	58	102	110
Final harvest				
Date	25.12.77	25.12.77	25.12.77	25.12.77
Numbers	24	24	45	2
Mass (g)	27	16	43	3

	Quadrants of control			
	Qc1	Qc2	Qc3	Qc4
Initial harvest				
Numbers	34	38	27	17
Mass (g)	1912	742	422	485
Seasonal harvest				
Date	3.12.76	10.3.77	7.6.77	10.9.77
Numbers	45	11	55	1
Mass (g)	28	4,5	121	0,1
Final harvest				
Numbers	13	8	—	—
Mass (g)	16	26	—	—

availability to sub-canopy kelps, resulting in an unexpected growth response (Kain 1977). In the shallow-water environment of this locality (4–6 m) this consideration was particularly relevant.

The two sites being relatively small (10 m²), individual comparisons of plants could not be made. Therefore the crop for a site was considered as a whole. The cropping of sub-canopy kelps served the purpose firstly of determining the standing stock of immature *Ecklonia* and secondly of revealing any seasonality in recruitment. Differences between the two sites would suggest an effect of urchins grazing on young sporophytes.

Table 3 Comparison of kelp yield between study site and control (excluding adult kelps)

	Study site (Qs1 — 4)	Ratio (Qs/Qc)	Control (Qc1 — 4)
Initial harvest			
No. of individuals	224	1,9:1	116
Biomass (g dry mass)	6228	1,8:1	3562
Final harvest			
No. of individuals	95	4,5:1	21
Biomass (g dry mass)	88	2,1:1	42
Combined seasonal harvest			
No. of individuals	332	3,0:1	112
Biomass (g dry mass)	274	1,8:1	154

Table 4 Fate of canopy kelps on experimental stations (numbers of plants)

Date of count	Study site	Control
2 December 1976	14	11
1 February 1977	12	10
7 March 1977	8	10
26 April 1977	7	9
3 November 1977	6	6

Seasonal cropping

Three months after initial cropping of sub-canopy kelps on both sites the respective first quadrants (Qs1 and Qc1) were harvested. A response to protection from urchin grazing emerged clearly (Table 2), in that 34% more plants survived on the study site. The figures obtained for the biomass were however, puzzling. The plants which grew on the study site, although much higher, had a combined biomass of roughly one-sixth of those obtained on the control. A depth difference found between the two plots was probably the cause.

Kain (1977) came to the tentative conclusion that protection due to depth may be the cause of thinness of small (young) fronds. *Ecklonia* which grew on the shallower site (control) possessed thicker fronds, also being larger on the average (50% of plants from the control exceeded 90 mm in length, but only 13% from the study site reached that value).

The second harvest (Qs2 and Qc2) showed the response to protection even more clearly (Table 2). Once again the juvenile kelps are both smaller and filmier on the study site.

The third harvest (Qs3 and Qc3), which took place in winter, showed a drop in numbers by two-thirds relative to the previous crop, while the control showed an increase. In the course of the nine months which had elapsed since the original cropping, a number of *Ecklonia* had developed secondary fronds. The low winter yields were unlikely to result from storm damage, since young kelps were never found washed up on the shore. Observations during winter showed few juveniles, while adult kelps had much front-tip erosion and appeared flaccid and blanched. A few canopy kelps were seen to be dying off.

The fourth harvest (Qs4 and Qc4) was small, in fact the control was almost devoid of *Ecklonia*.

The variations of these seasonal harvests tie in well with results obtained in the pilot study carried out in a similar manner (Fig. 5). The peak number of kelps harvested was found between January and March, while the lowest values were recorded during the period from June to September. It therefore appears that young sporophytes of *Ecklonia* commence active growth in early summer and continue on into autumn. In other words, the southern winter represents a period of dormancy for *E. maxima*. This agrees with the findings of G.S. Dieckmann & N.G. Jarman (*pers. comm.* 1978).

Final site-cropping

At the end of the one-year study, both plots were cropped clear of all kelps in order to assess the overall change in numbers of plants and biomass ratios (Tables 2 and 3).

Since harvest intervals could for unavoidable reasons not be kept exactly to three months, it was considered more meaningful to compare respectively the yields of the initial, the combined seasonal and the final site harvest.

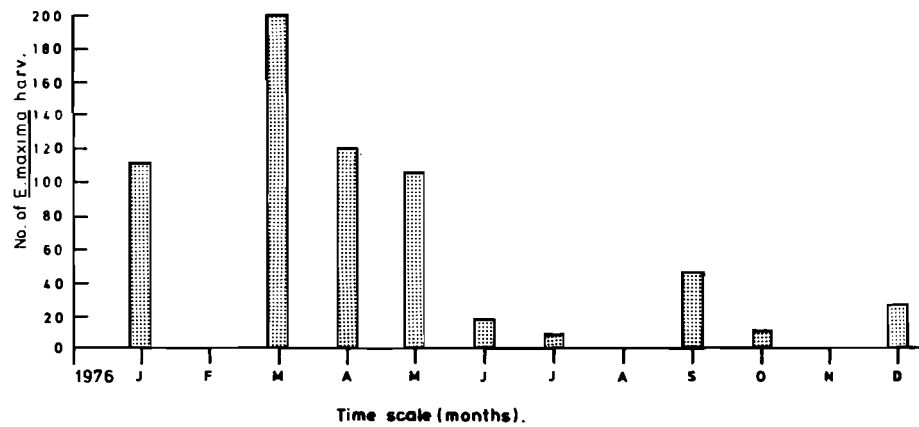


Fig. 5 Number of juvenile *Ecklonia maxima* harvested on urchin-free plots during a previous study (projected surface area 20 m²).

Protection from urchin grazing during the period of observation clearly permitted a larger survival of *E. maxima* as well as an increase in total biomass, despite the depth difference between the two sites, which favoured the control with regard to frond thickness and length. The effect of the urchins was, however, not nearly as marked as might be expected considering the results of Mann (1977) and others.

If we compare the standing stock of juvenile *Ecklonia* on the study site and control at the start of the experiment with the respective overall changes during the period of study (final plus harvests), it can be seen that kelps became 91% more numerous on the protected (study) site, but only 15% more numerous on the control.

The final harvest schedule unavoidably resulted in opening up the experimental sites. As a result (light penetration?) successional changes occurred. The vigorous seaweed *Pterosiphonia cloiophylla* became especially abundant and overgrew the understory species *Bifurcariopsis capensis*. The low survival on the control and considerable drop in the numbers of plants on the study site suggest that *E. maxima* is slow in re-establishing itself on substrate when it has been eliminated, particularly when exposed to grazing pressure by urchins.

Impact of urchin grazing on the kelp bed

The term grazing will be applied to urchins feeding on attached kelps, which includes the tender microscopic sporophytes as well as detached pieces of stipes and fronds. Field *et al.* (1977) consider *Parechinus* to be a debris feeder, not a herbivore. For immature stages (up to 20 mm diameter) this may be correct, since these urchins depend on fine debris, being unable to trap frond tips. Mature *Parechinus* are, however, well able to accomplish this and climb up the stipes under calm conditions. This is a relatively rare event, which may be the key to the low impact of the echinoderm on False Bay kelp beds.

In contrast to observations by North (1965) and Leighton *et al.* (1966) on the Californian coast, *Parechinus* fails to sever kelp stipes, which makes the urchin much less destructive than its American counterpart (*Strongylocentrotus* spp.). *Parechinus* exerts an impact on local kelp beds in a more subtle manner by grazing on the early sporophytes, thereby regulating the density of False Bay kelp stands. (Personal observations showed a dramatic increase in plant density on a site protected from sea urchins for some months.) It appears then that once *Ecklonia* has passed the vulnerable early stage, grazing by the urchin

does not much affect the survival of the kelp, but merely limits the kelp climax.

The study indicated that there was a 10% increase in the kelp biomass ratio of study site to control site between the initial harvest and the combined seasonal plus final harvests on the study site (Table 3). This means that 622 g more dry mass had been produced above the figure obtained before clearing the site of urchins.

How do the figures for urchin consumption and kelp production relate? Assuming Greenwood's (1975) kelp consumption figure of 32 mg dry mass day⁻¹ urchin⁻¹ to be about twice the amount realized in the field (sea conditions frequently prevent *Parechinus* from feeding), the population consumption for this study will have amounted to 9.7 g dry mass day⁻¹ [3.6 kg dry mass year⁻¹, which is equal to 3.97 × 10⁴ kJ year⁻¹, using a calorific value for *E. maxima* obtained by Buxton (1977)]. The P/B ratio for *E. maxima* in False Bay is estimated very conservatively as 1 (N.G. Jarman *pers. comm.*). The total production at the study site in one year is represented by the standing stock on the site at the end of the experiment. This amounted to 8.7 kg dry biomass, but was more likely at least twice that figure (17 kg), since no allowance was made for losses not due to predation nor for dissolved matter. Consumption therefore amounts to about 20% of production. For comparison, Field *et al.* (1977) reported 12% for the same urchin feeding on another kelp with a similar calorific value (*Laminaria pallida*) in a cold-water locality on the west coast of South Africa.

Conclusions

Parechinus angulosus Leske feeds exclusively on algae, mainly *Ecklonia maxima*, while occurring in very dense (90) animals m⁻² and more) continuous populations inshore in many parts of False Bay, Cape.

Kelp productivity on the experimental stations at present more than compensates for the losses to this echinoderm, probably by virtue of favourable conditions of water movement (nutrient supply), irradiation and substrate availability.

The feeding activity of *Parechinus* appears to regulate the climax density of kelp stands by grazing on the young sporophytes and delays recovery of areas from which *Ecklonia* has been removed. Destruction of the top canopy of *E. maxima* produces successional changes in the under-

storey algal community, especially *Pterosiphonia cloiophylla* which then covers much of the available solid substrate.

Most active visible growth of *E. maxima* appears to take place from December to April. The highest invasion rates of *Parechinus* into cleared plots were observed during spring, possibly in anticipation of an increased food supply. Protection from urchin grazing results in an increased survival of young *E. maxima* in False Bay kelp beds.

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