

Changes in Sea Urchin Populations after the Destruction of Kelp Beds

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Abstract

In St. Margaret's Bay, Nova Scotia, Canada, there are large areas in which sea urchins (*Strongylocentrotus droebachiensis*) have eliminated beds of kelp (*Laminaria* spp.). Sites were identified where destruction of kelp beds had taken place 1, 2, 3, 3.5 and 4 years ago. With increase of time since kelp disappearance, the sea urchins showed decreased growth rate, reduced gonad size, but an increase in numbers resulting from high recruitment rates in the first two years after kelp bed destruction. These sea urchin populations, by their browsing, effectively prevent the regeneration of kelp. There is, as yet, no evidence of the sea urchin populations being starved out to allow the kelp to return.

Introduction

A study of trophic relations between lobsters (*Homarus americanus*), sea urchins (*Strongylocentrotus droebachiensis*) and kelp (*Laminaria* spp.) in St. Margaret's Bay, Nova Scotia, has shown that sea urchin populations have been increasing explosively and destroying the kelp beds by overgrazing (Mann and Breen, 1972; Breen, 1974; Breen and Mann, 1976). The explanation offered is that lobsters are key predators on sea urchins and that the population density of lobsters in the area is now so low that they cannot control sea urchin numbers. As a result, the kelp bed ecosystem which has a high productivity of both plant material and lobsters has been destroyed over large areas, and has been replaced by another system characterized by dense populations of sea urchins attached to almost bare rock. While these sea urchin populations persist, they graze off any young sporophytes which settle, and inhibit recolonization by kelp. Similar interactions between sea urchins and kelp have been reported for *Strongylocentrotus purpuratus*, *S. franciscanus*, (Paine and Vadas, 1969) *Paracentrotus lividus* (Kitching and Ebling, 1961), and *Echinus esculentus* (Jones and Kain, 1967). Leighton (1971) documented cyclic interactions between the giant kelp *Macrocystis pyrifera* and *Strongylocentrotus* spp.

In deciding what strategy to adopt for management of this system, it is important to find out whether the sea urchin populations are likely to persist indefinitely, or whether the system is in oscillation, with destruction of kelp leading to sea urchin populations dying or dispersing, so that kelp beds can regenerate. As a contribution to the solution of this problem, sites were identified where kelp beds had been destroyed at varying times in the past 4 years. The population dynamics of the sea urchin populations at these sites were then studied through the summer of 1975.

Materials and Methods

Five sampling stations in Northwest Cove, St. Margaret's Bay, Nova Scotia, were selected to represent sites at which kelp beds had been destroyed 1, 2, 3, 3.5 and 4 years previously, according to the observations of the second author and his students. They were designated as Sites 1, 2, 3A, 3B and 4. All were at a depth of 5 to 7 m, except Station 2, which was at 2 to 4 m. The bottom types were as follows: Station 1, boulders on sand; Stations 2 and 3A, bed rock; Stations 3B and 4, stones. All stations were within a radius of 300 m, except Station 1 which was 1600 m away. Data from these stations were compared with

the averages for the whole of St. Margaret's Bay before the destruction of kelp beds (Miller and Mann, 1973).

Twenty samples of *Strongylocentrotus droebachiensis* were collected each month from May to September, 1975 at each site by means of randomly located quadrats of area 0.1 m². Age Classes 0 could not be sampled quantitatively because many were in small crevices and could not be extracted. For all sea urchins, their diameter was determined to the nearest millimeter. From each of the 5 sites each month a subsample of 40, representative of all size classes, was aged by growth rings on the plates according to the procedure given in Jensen (1969), and the fresh weight of the gonads was determined to the nearest milligram.

Tests for significance of differences between sample means were carried out using several *a posteriori* contrast tests from the Statistical Package for the Social Sciences (Nie *et al.*, 1975).

Results

Growth Rate

Data from all sampling dates were pooled and then sorted according to age of the urchins. In Fig. 1 mean diameters of *Strongylocentrotus droebachiensis* of ages 2 to 7 years are plotted against sampling sites, which are arranged according to time since kelp disappearance. With very few exceptions, it is clear that the growth rate of the urchins declines drastically after kelp in their area has been destroyed. This is particularly true of urchins recruited since kelp disappeared. The 2- and 3-year olds have mean diameters which decline in a linear manner with increasing time since kelp disappeared. On the other hand, the 7-year-olds at the site from which kelp disappeared 4 years ago are large for their age, and this may be explained by their having had 3 years of growth while kelp was still present. Also, the sample size for the Age 7 group was very small at Site 4.

It was noted that the slow-growing urchins also had thinner tests. For example, among 5-year-olds, those at Station 1 averaging 38 mm diameter had a mean test thickness of 0.97 mm while those at Station 4 averaging 29.5 mm diameter had a mean test thickness of 0.85 mm. (Wilcoxon's signed-rank test, $P = 0.03$).

Gonad Size

Again, data from different dates of sampling were pooled and then sorted ac-

ording to age of urchins. Fig. 2 shows that urchin gonad size tended to decline with increasing time since kelp destruction. The exception is that urchins at Site 1 tended to have smaller gonads than those at Site 2. Note that the results were not influenced by spawning, since the samples were taken between the spring and autumn spawning periods (Miller and Mann, 1973). For urchins aged 6 and 7 years, gonad size was very variable and was not significantly different at the various sites. This may be the first indication of reproductive failure in part of the population, for the samples included urchins with no measurable gonad tissue, and none had gonads of average size for the control populations.

Gonor (1972) showed that gonad weight is well correlated with test diameter, so in this situation it is useful to see whether there is an effect on gonad weight independent of test diameter. The results of an analysis of variance (Table 1) show that for Age Classes 3, 4, and 5 there is a significant effect of time since kelp disappearance, independent of decreasing test diameter.

Population Density and Age Structure

In general, sites which had been longer without kelp tended to have more sea urchins (Fig. 3), and this pattern was stable through the summer. The exception was Site 2, which tended to have fewer urchins than Site 1. (It was also noted above that the urchins at Site 2 had larger gonads than those at Site 1, and Site 2 is in shallower water than the others.) The question then arises: is the increase in numbers due to large numbers of newly settled recruits, which radically change the age composition of the population?

A plot of the age-frequency distribution at the 5 sites (Fig. 4) suggests that at Sites 3A, 3B and 4, a particularly large year class settled 1 year after kelp disappearance, but after that recruitment was less. The significance of these changes is discussed below. It is interesting to note that although 3A and 3B differ in type of bottom substrate, the general population structure and density are very similar.

Discussion

The present work was designed to answer the questions: do *Strongylocentrotus droebachiensis* populations starve and die, or migrate away, after destroying kelp beds? The answer is: they do not, at least

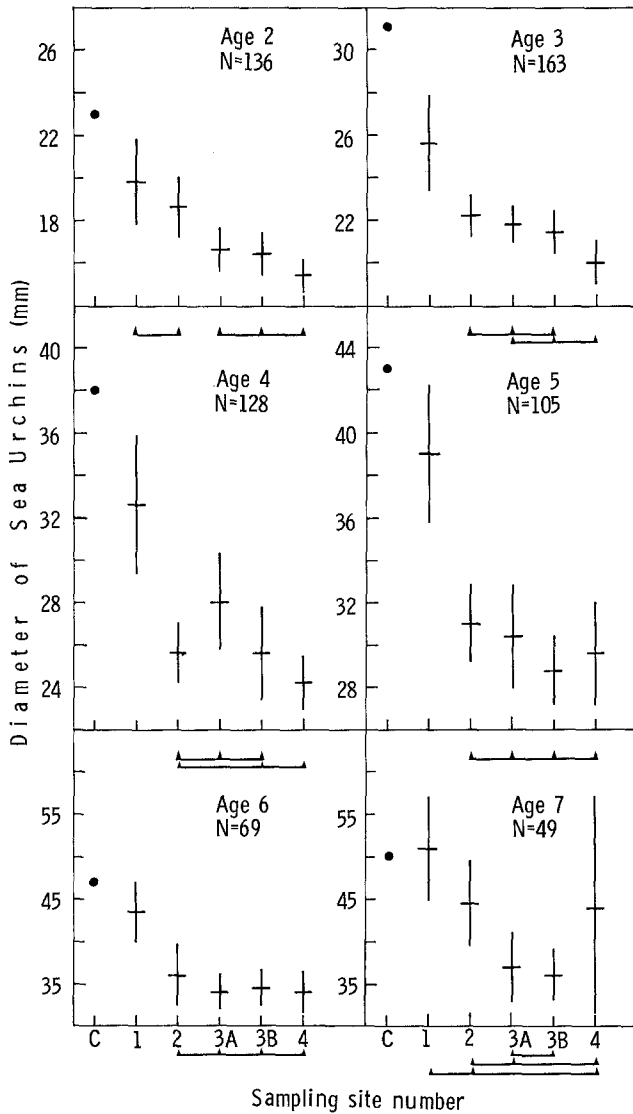


Fig. 1. *Strongylocentrotus droebachiensis*. Mean diameter of sea urchins in each age class, at 6 sampling locations. C: control, average data for St. Margaret's Bay for sea urchins from inside kelp beds (Miller and Mann, 1973); 1-4: sampling stations of this study, each number indicating number of years since kelp disappeared. Small arrow-heads joined by horizontal lines indicate stations between which differences are not significant. Vertical lines indicate 95% confidence intervals

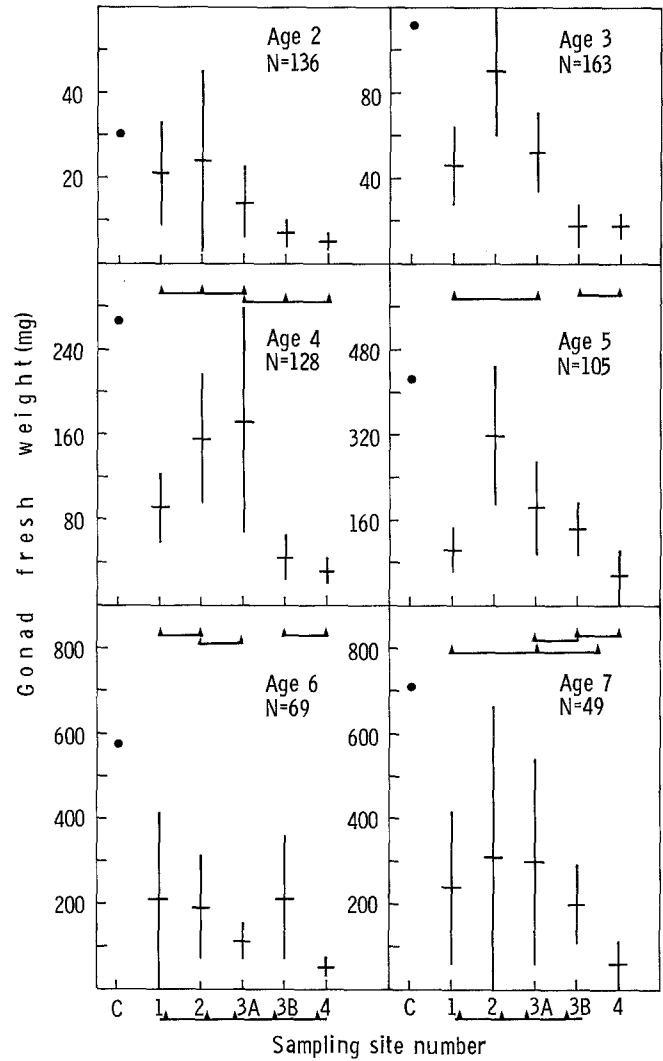


Fig. 2. *Strongylocentrotus droebachiensis*. Gonad live weight for sea urchins in each age class. Symbols as in Fig. 1. Control data for sea urchins inside kelp beds are means of June and August data in Miller and Mann (1973)

Table 1. *Strongylocentrotus droebachiensis*. Analysis of variance of gonad weight, to distinguish between effect of test diameter and effect of time since kelp disappearance. NS: Not significant

Age class (years)	Source of variation					
	Test diameter			Time since kelp disappearance		
	DF	F	Significance	DF	F	Significance
2	130	58.805	0.001	130	0.831	NS
3	157	43.300	0.001	157	11.118	0.001
4	122	16.517	0.001	122	5.967	0.001
5	99	3.876	0.049	99	10.271	0.001
6	63	5.230	0.024	63	0.788	NS
7	43	6.774	0.012	43	2.406	NS

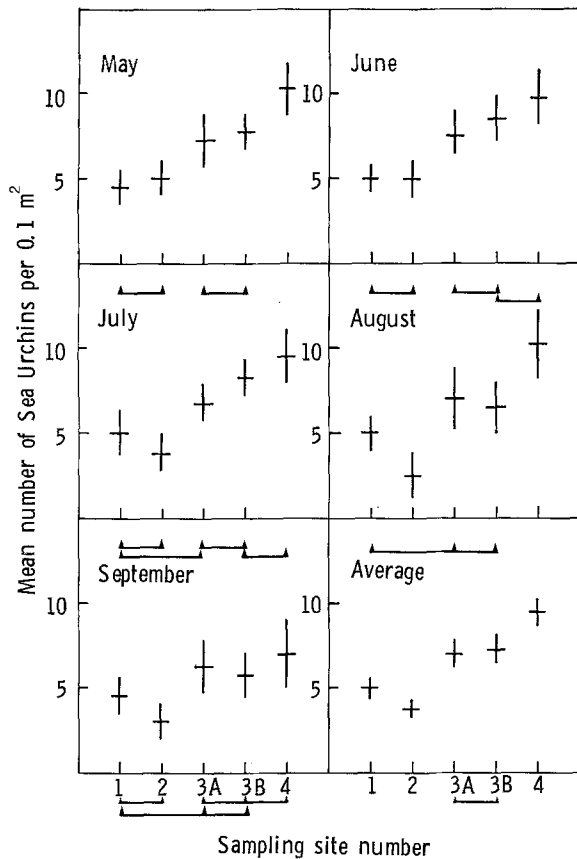


Fig. 3. *Strongylocentrotus droebachiensis*. Mean numbers of sea urchins on 5 sampling locations from May to September, 1975. Symbols as in Fig. 1

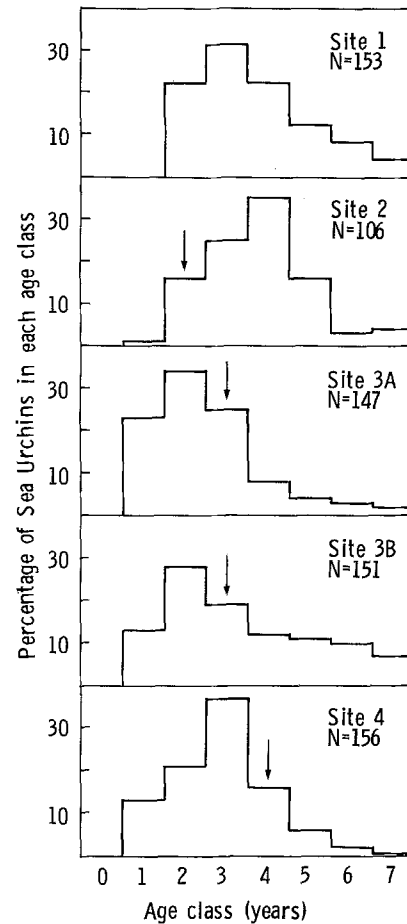


Fig. 4. *Strongylocentrotus droebachiensis*. Age structure of sea urchin populations at 5 sites differing in time since kelp disappearance, averaged over 4 collections. Arrow indicates year class recruited at time of kelp destruction. Sea urchins less than 1 year old were not collected

within 4 years. The sea urchin populations tend to increase in abundance, while decreasing their growth rate and individual gonad production. The sequence of events that takes place during and after the destruction of a kelp bed can be described as follows: The age structure of a stable sea urchin population within a kelp bed is as shown in Fig. 5a (from Miller and Mann, 1973). There is steady recruitment and mortality, so that the younger age classes are most abundant. The population density averages $36.8/m^2$. The urchins live among the kelp, on the rock or on the holdfasts. When they attempt to climb on the plants they are thrown off by wave action, so they feed mainly on the kelp detritus which settles on the rock surface (Breen and Mann, 1976).

When a sea urchin population begins to destroy a kelp bed, it does so by assembling a critical biomass capable of

holding the *Laminaria* plants down on the rock surface and eating them completely (Breen and Mann, 1976). At the edge of a receding kelp bed there is a "wave-front" of large individuals at a high population density. Fig. 5b shows that such a population may consist of predominantly 5- and 6-year-old urchins. Apparently the older, heavier individuals congregate at the advancing wave-front, and tend to exclude the younger, smaller specimens. Only 3 m from the edge of the kelp the population may be dominated by 3- and 4-year-old animals (Fig. 5c).

At the sites where kelp had been destroyed 1 or 2 years previously the population was also dominated by 3- and 4-year-old urchins (Fig. 4), but at the sites which had been devoid of kelp for 3 and 4 years there was evidence of a strong recruitment of young urchins in the year after kelp destruction, leading to higher population density, after

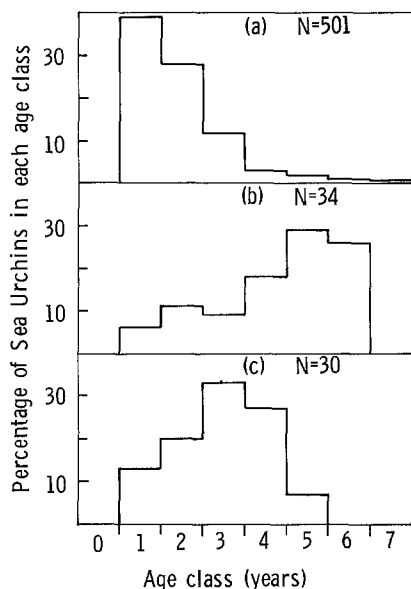


Fig. 5. *Strongylocentrotus droebachiensis*. Age-frequency distribution of sea urchins (a) within kelp bed; (b) at edge of kelp bed where large urchins are destroying the *Laminaria*; (c) 3 m distant from edge of a kelp bed. Data in (a) are from Miller and Mann (1973). Sea urchins less than 1 year old were not collected

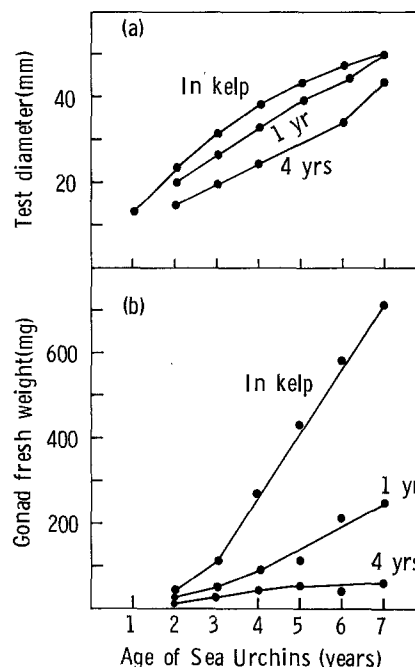


Fig. 6. *Strongylocentrotus droebachiensis*. (a) Comparison of growth curves, and (b) comparison of individual gonad size, in populations before and after destruction of kelp beds. "In kelp" signifies data from sea urchins in kelp beds from Miller and Mann (1973); "1 year" and "4 years" signify time since destruction of kelp beds

which recruitment was less good. These populations presumably feed on encrusting algae, and on detritus from the nearest seaweed beds. Breen and Mann (1976) have recorded that sites exist which have been kept free of kelp for 6 years. Unfortunately, these sites were too inaccessible to form part of this study. Fig. 6 summarizes the evidence that the populations on "bare rock" have a slower rate of growth and reduced gonad size, but there is, as yet, no evidence that they are not viable. Until an area is found in which an urchin population on bare rock declines to extinction, permitting the re-establishment of kelp, the prospects are poor indeed for increasing the productivity of these rocky, subtidal areas and the shellfish populations which depend on them (Miller et al., 1971).

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Literature Cited

- Breen, P.A.: Relations among lobsters, sea urchins and kelp in Nova Scotia, 190 pp, Ph.D. thesis, Halifax, Nova Scotia. Dalhousie University 1974
- and K.H. Mann: Changing lobster abundance and the destruction of kelp beds by sea urchins. *Mar. Biol.* 34, 137-142 (1976)
- Gonor, J.J.: Gonad growth in the sea urchin *Strongylocentrotus purpuratus* (Stimpson) (Echinodermata: Echinoidea) and the assumptions of gonad index methods. *J. exp. mar. Biol. Ecol.* 10, 89-103 (1972)
- Jensen, M.L.: Age determination of echinoids, *Sarsia* 37, 41-44 (1969)

- Jones, N.S. and J.M. Kain: Subtidal algal colonization following the removal of *Echinus*. Helgoländer wiss. Meeresunters. 15, 460-466 (1967)
- Kitching, J.A. and F.J. Ebling: The ecology of Lough Ine. XI. The control of algae by *Paracentrotus lividus* (Echinoidea). J. Anim. Ecol. 30, 373-383 (1961)
- Leighton, D.L.: Grazing activities of benthic invertebrates in Southern California kelp beds. Nova Hedwigia (Suppl.) 32, 421-453 (1971)
- Mann, K.H. and P.A. Breen: The relation between lobster abundance, sea urchins, and kelp beds. J. Fish. Res. Bd Can. 29, 603-609 (1972)
- Miller, R.J. and K.H. Mann: Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. III. Energy transformations by sea urchins. Mar. Biol. 18, 99-114 (1973)
- and D.J. Scarratt: Production potential of a seaweed-lobster community in eastern Canada. J. Fish. Res. Bd Can. 28, 1733-1738 (1971)
- Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner and D.H. Bent: Statistical package for the social sciences, 675 pp. New York: McGraw-Hill Book Company 1975
- Paine, R.T. and R.L. Vadas: The effects of grazing by sea urchins, *Strongylocentrotus* spp., on benthic algal populations. Limnol. Oceanogr. 14, 710-719 (1969)
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