THE JOLLY RANCHERS

VARIATIONS IN GROWTH DUE TO WAVE EXPOSURE AND DIET IN THE GREEN SEA URCHIN *STRONGYLOCENTROTUS DROEBACHIENSIS*

TECH 797
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ABSTRACT

Growth of the green sea urchin, *Strongylocentrotus droebachiensis* has become an area of increased interest in the Gulf of Maine with the explosion of the sea urchin fishery. Growth studies in this paper include a comparison of varying diets of herbivory, omnivory and carnivory; a comparison of low and high wave exposure habitats; and a mark recapture field study. The diet study supports the conclusions of previous researchers (Briscoe and Sebens, 1988, Nestler and Harris, 1994) that an omnivorous diet of the kelp *Laminaria saccharina* with the encrusting bryozoan *Membranipora membranacea* stimulates optimal growth. Experimental urchins from the field study indicate that growth in lab-fed urchins is superior to growth in natural habitats. The first attempt at studying exposure effects on growth of juvenile *S.droebachiensis* suggests a preference for high wave action. Collectively, these experiments should serve as an impetus for future investigations into the growth of *S. droebachiensis*.

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INTRODUCTION

The green sea urchin, *Strongylocentrotus droebachiensis*, has been harvested and shipped from the Gulf of Maine as early as 1933. The industry began expanding rapidly in 1987, reaching 26,502,068 pounds valued at $15,426,363 in 1992, making this the second largest fishery in Maine (Creaser,1993). Increased fishing combined with poor regulation and management has raised great concern about the sustainability of the resource.

The lack of published information on the green sea urchin has added to the problem. Specific relationships between size, age, reproductive maturity, and habitat are not known. The biology and ecology of urchins must be fully understood if sustainability is to be achieved. The need exists to study the urchins thoroughly before history is repeated and the Gulf of Maine experiences the impending decline characteristic of fisheries on the west coast and Japan.

Breen and Mann (1976a) revealed that increased populations of the green sea urchin resulted in depleted *Laminaria spp*. beds along the eastern coast of Nova Scotia. Lobsters avoided these urchin-dominated barrens and thus, a decrease in lobster fisheries was observed (Breen and Mann, 1976b). Similar urchin barrens exist in the Gulf of Maine, however, the mass mortalities seen off the coast of Nova Scotia (Miller and Colodey, 1983), have not occurred in Maine. Commercial harvesting, not predation or disease, is the controlling factor over sea urchin populations in the Gulf of Maine. It has been predicted that a fishery utilizing divers could be profitable if the urchins could be marketed at $.20 a pound (Nieder et al.

1985) The current price far exceeds this and if sound management is not underway soon, the demise of the fishery is inevitable.

There is significant evidence that herbivory is a major component in the feeding habits of the green sea urchin *Strongylocentrotus droebachiensis* (Arnold 1976, Foreman, 1977) but little is known of the extent of omnivory in the sea urchin diet and its effects on growth rate. Arnold (1976) observed that areas of the sublittoral algal population of New Brunswick, Canada were decimated when urchin populations increased.. The results of lab experiments show the main algal food choice of *Strongylocentrotus droebachiensis* to be the kelp *Laminaria saccharina* over other possible algal species (Larson, et al, 1980, Mann, et al, 1984). The most common non-algal food choice of the green sea urchin may be the blue mussel *Mytilus edulis*, suggested by analysis of gut contents of field collected urchins (Himmelman and Steele, 1971). Field observations have shown sessile invertebrates such as hydrozoans, bryozoans, some bivalves, and tunicates to be common prey items also.

Studies show that urchin growth rate is effected by diet : comparative growth experiments show that kelp-fed urchins grow faster than than mussel-fed urchins, indicated by growth in test diameter and biomass (Briscoe and Sebens, 1988). This may be due to increased energy expediture during feeding on *Mytilus* due to more time spent ingesting mussel shell and tissue.

Short term experiments show faster growth in urchins fed an omnivorous diet of kelp covered with the bryozoan *Membranipora membranacea* than urchins fed a diet of kelp alone (Nestler and Harris, 1994). Perhaps an omnivorous diet is the best for achieving maximum growth. **A purpose of our studies is to provide an examination of**

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differential growth of urchins fed hebivorous, carnivorous, and omnivorous diets, including combinations of kelp, bryozoans, and mussels.

There have been no previous studies comparing the differential growth of urchins living in exposed and protected habitats. If differential growth does indeed exist, it is unknown whether adaptability to the environment is genetically determined or environmentally induced by differential mortality or settlement. **Another goal in this project is to examine variable growth of young of the year urchins collected from exposed habitats and placed in simulated exposed and protected habitats in the laboratory.**

In the field, urchins often occur in high numbers in both kelp bed areas and "barren" areas that they have completely denuded of algae. The food source for urchins existing in barren areas is often drift algae and coralline algae. Lang and Mann (1976) and Wharton (1980) found that urchin growth rates significantly decreased after denudation of a kelp bed. Truchon (1988) found no difference in growth rate between barren area urchins and kelp bed urchins, but found that there was more variability in growth rates among the barren area urchins. It was postulated that availability of the main food source for barren urchins (drift algae) was dependent on the frequency and intensity of storms that brought in drift algae, and was therefore a less temporally stable food source than that of kelp bed urchins. **A third goal of our research is to conduct a mark-recapture field study and to compare growth of laboratory urchins to those growing in the field.** Differences in growth rate between areas with variable amounts of drift algae were examined.

As a whole, the purpose of the present study is to quantify some of the variables that produce optimum growth. Do urchins grow faster on an herbivorous, carnivorous, or omnivorous diet? Is growth rate affected by increased or decreased water movement (exposure)? And finally, is there a significant difference in growth rate between urchins studied in the lab and those existing in the wild? If these questions can be answered, they will help in the process of creating a successful urchin fishery.

MATERIALS AND METHODS

Diet Experiments

At the University of New Hampshire's Coastal Marine Lab in Newcastle, NH, a varying diet study was performed in an eight foot by four foot sea table. Sea urchins ranging in size from 11 mm to 29 mm were collected from the Isles of Shoals and Nubble Light in October 1993. A solution of 6.25 g Calcein to 50 L water was employed to dye the urchins for a 24 hour period. Twenty wire mesh cages were constructed using quarter inch hardware cloth. The cages were divided into four treatments with five replicates in each treatment. Twelve urchins were selected and their test diameters recorded for each cage. To avoid fouling problems, the cages were set on submerged bricks.

The five cages of treatment one were fed a diet of the kelp, *Laminaria saccharina* only. Treatment two received *Laminaria* with the ectoproct, *Membranipora membranacea*, growing on it. The diet of treatment three consisted of *Laminaria* and *Mytilus edulis* while treatment four was fed *Mytilus* alone. The size of the mussels ranged from approximately 5mm to 15mm depending on their availability. Unlimited food was supplied to the urchins on a weekly basis. When necessary, the sea table was cleaned out entirely as wastes accumulated.

In April 1994, five months after the start of the experiments, the urchins were removed and frozen. A solution of 50% bleach and 50% water was used to remove the spines from the animals. After soaking for a period of two to three hours, the urchins were removed and their test diameters were measured with calipers. The initial and final data were compared for each cage. Average changes in diameter were determined for the varying diets.

Wave Exposure Experiments: Protected vs Exposed

Young of the year urchins were collected in November, 1993 from Nubble Light; York, Maine (Truchon, 1988) and off the Isles of Shoals, NH (Martin et al. 1988). The Isles of Shoals urchins were collected from astroturf substrate recruitment panels. The test diameter of all urchins were measured, and then the animals were separated into two treatments for each collection site. The treatments simulate high wave action or exposed conditions and low wave action or protected conditions. The ten gallon aquaria used for each treatment utilized an intake siphon (1cm diameter tubing) from a seawater flow source at the UNH Coastal Marine Laboratory in Newcastle, NH. The protected treatment aquaria had no other flow disturbance, but exposed treatment aquaria had an additional high-flow water jet as well as a turbulent air stone.

The four aquaria, each with 100 or more sea urchins in them began phase 1 of this experiment. For three months the urchins were monitored and fed the kelp *Laminaria* with the encrusting bryozoan *Membranipora*..

In February, 1994, the urchins were recollected from their respective aquaria and measured again to monitor growth. Sixteen urchins of smallest and largest size classes were chosen in each of the four treatments to begin a second phase of the experiment. The rest of the uchins were returned to continue in their original aquaria.

Phase two of the exposure experiments consisted of a site-specific alternation between exposure treatments to determine if the slowest growing urchins would experience an increase in growth, or if the fastest growing urchins would be growth inhibited once their wave exposure had changed. For each site, eight uchins (four large, four small) were separated as control organisms and eight urchins were placed in their alternate treatment. The experimental and control organisms for phase two were held in plastic containers with mesh sides to provide adequate water movement. At the end of the experiments, all urchins were again measured for test diameter.

Mark-Recapture Field Experiment

In October 1993, several hundred urchins were collected from two study sites at Nubble Light, ME. The study sites were about 15 meters in diameter and 50 meters apart. Both sites are relatively protected urchin barrens. Site B was located in a "corner" where a substantial amount of drift algae collected regularly. Less drift algae appeared to collect in Site A.

The urchins were brought to the Coastal Marine Lab and soaked overnight in a 6.25g/50 L sea water Calcein solution. Calcein stains the bony parts of the urchin test and jaw bone (Aristotle's lantern) similarly to the way tetracycline injections mark bony parts (see Truchon, 1988). Half of the urchins were returned to each study site.

A linear regression of jaw length to test diameter (Figure 2) was created for use later to determine final test diameter, using a representative sample of 145 urchins (R^2=0.947). Test diameter and jaw length (keel to abboral edge) were measured with calipers (see Figure 1).

In April 1994, six months from the start, the urchins found at both study sites were collected and de-spined in a 1:1 solution of bleach and water. Urchins were then analyzed in the lab to determine 1) percent urchins recaptured 2) percent increase in growth over the 6 month period.

UV light was used to identify calcein-marked urchins. A marked urchin "glows" under UV light. The jaws were dissected out of marked recaptured urchins and analyzed under UV light for growth. The distance from the Calcein mark to the aboral growing edge was measured with calipers to determine initial and final jaw length. Using the linear regression equation (see Figure 2) original and final test diameters were calculated to determine percent increase in growth over the six month period.

RESULTS

Diet Experiments

The urchins were incubated in a Calcein dye solution for 24 hours at the start of the experiment. The residual marks on the test and jaw bone were intended for use in calculating the amount of growth (Truchon, 1988). However, the Calcein dye did not mark the urchins successfully.

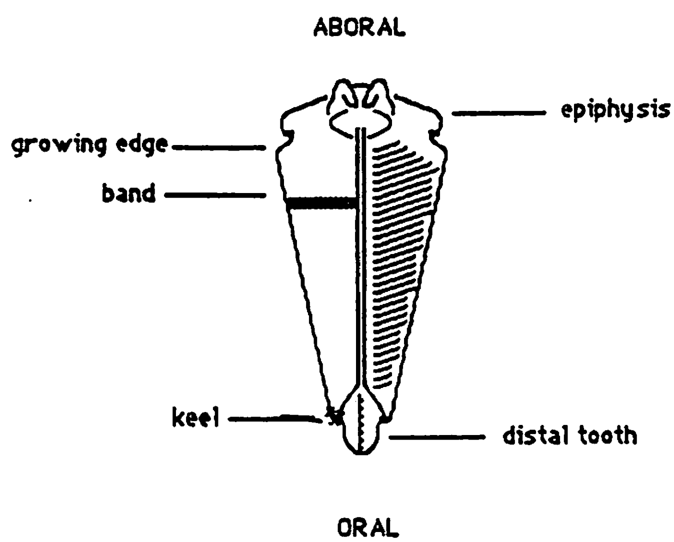


Figure 1: Shows a lateral view of one of the five jaw bones in *Strongylocentrotus droebachiensis*, noting the growing edge, Calcein band, and keel (Truchon, 1988).

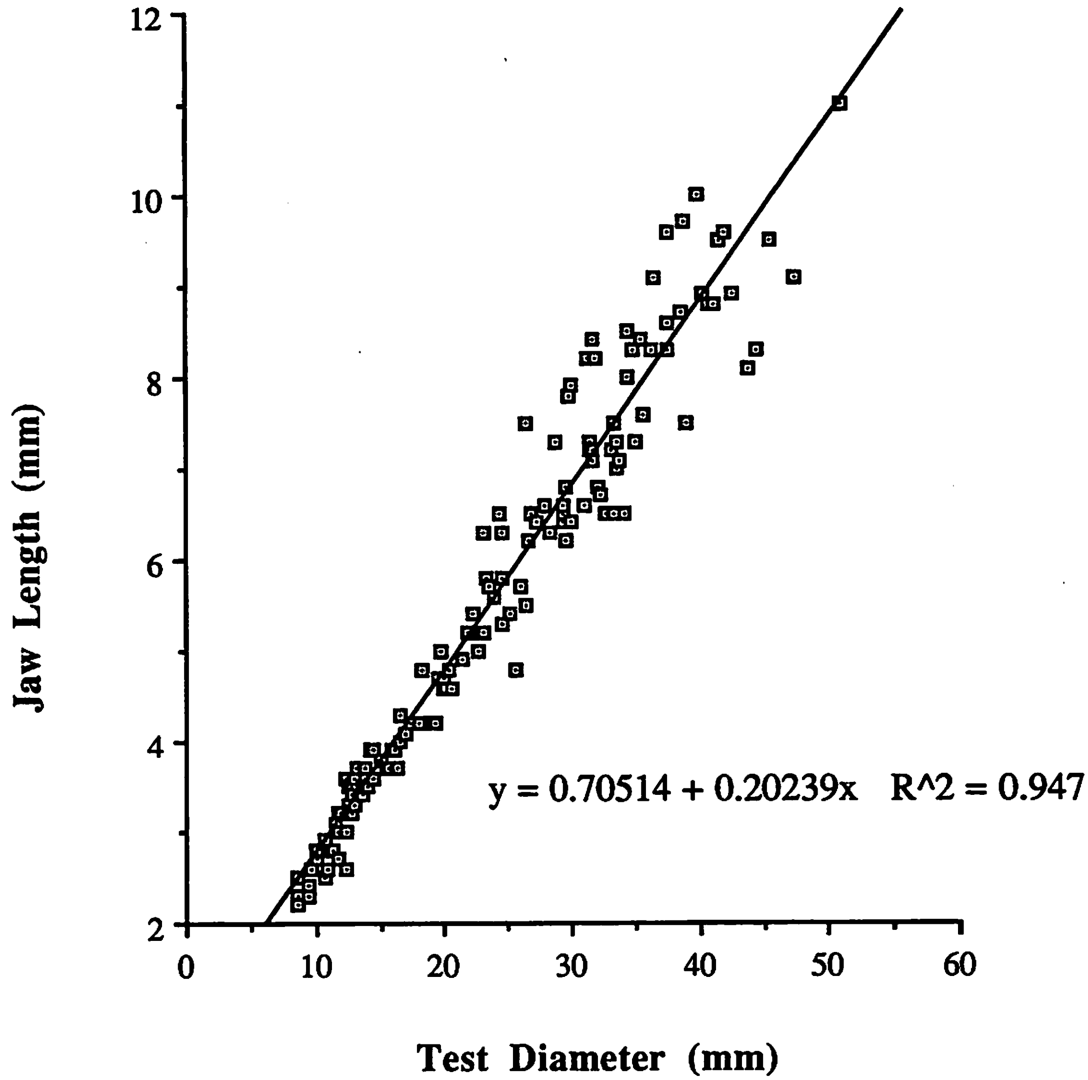


Figure 2: Linear Regression of Jaw Length (mm) to Test Diameter (mm) in *Strongylocentrotus droebachiensis*

Therefore determination of overall growth could only be determined by change in test diameter.

Table 1 shows the average change (mm) and percent increase in test diameter for the four treatments. Figure 3 is a graph of average change in test diameter between treatments. The highest change in average test diameter occurred in treatment two urchins which were fed the *Laminaria saccharina* with *Membranipora membranacea* diet. The initial mean test diameter was 18.97 mm (S.E. 0.55). The urchin test diameter grew 40.75% with an final mean test diameter of 26.7 mm (S.E. 0.64).

In treatment one, which was fed exclusively *Laminaria* , an average increase in test diameter of 26.1% occurred. The initial mean of these sixty urchins was 20.0 mm (S.E. 0.47). Tests of treatment one urchins grew to a final average diameter of 25.22 mm (SE. 0.61).

The *Laminaria* and *Mytilus edulis* diet, treatment three, showed a similar growth rate to treatment one with a 25.08% increase in mean test diameter. The urchins had an average initial test diameter of 18.86 mm (S.E. 0.61) and an average final diameter of 23.59 mm (S.E. 0.72).

The lowest average increase in test diameter was seen in treatment four which was fed a diet of *Mytilus* alone. The average final test diameter was 23.77 (S.E. 0.66), an increase of 23.29% from the initial average test diameter of 19.28 mm (S.E. 0.36).

Exposure Experiments

At the start of the experiment, the urchins from the Nubble site were a somewhat uniformly sized group, the smallest urchin measuring 1mm in diameter and the largest 6mm. In contrast, the range of sizes for the Shoals site was 1mm to 10mm. Figures 4 and 5 show the test diameters of

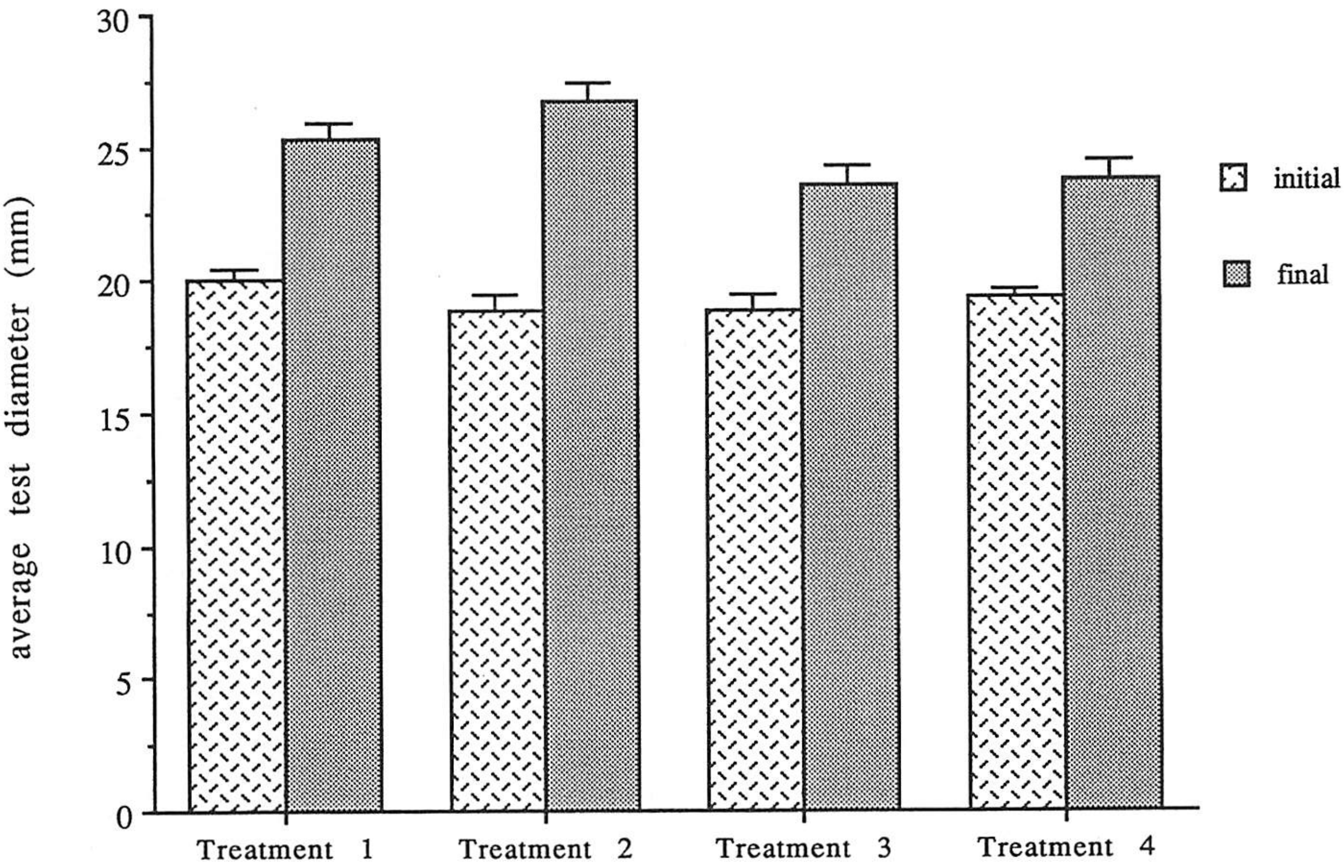
Data for Diet Experiments

Diet	*Laminaria saccharina*	*L. saccharina* and *Membranipora membranacea*	*L. saccharina* and *Mytilus edulis*	*Mytilus edulis*
Average Initial Test Diameter-mm (S.E.)	20.00 (0.47)	18.97 (0.55)	18.86 (0.61)	19.28 (0.36)
Average Final Test Diameter-mm (S.E.)	25.22 (0.61)	26.70 (0.64)	23.59 (0.72)	23.77 (0.66)
Change in Diameter-mm	5.22	7.73	4.73	4.49
Percent Increase	26.10%	40.75%	25.08%	23.29%

Table 1: Summary of change in average test diameter and percent increase in *Strongylocentrotus droebachiensis* for the four diet treatments

Figure 3: Shows the average initial and average final test diameter for the four diet treatments in *Strongylocentrotus droebachiensis* .

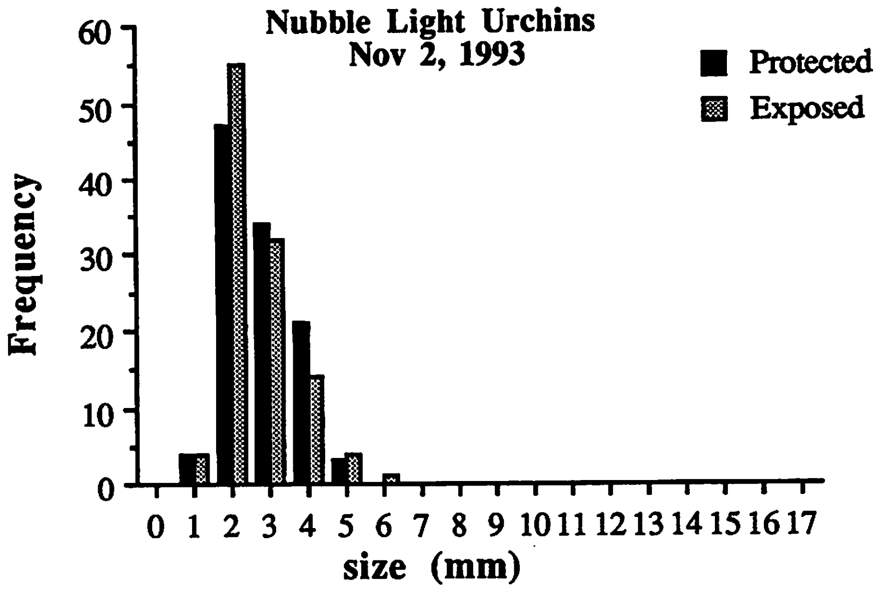
Average Change in Test Diameter between Diets



Treatment 1	Treatment 2	Treatment 3	Treatment 4
Laminaria saccharina	*L. saccharina* with *Membranipora membranacea*	*L. saccharina* with *Mytilus edulis*	*Mytilus edulis*

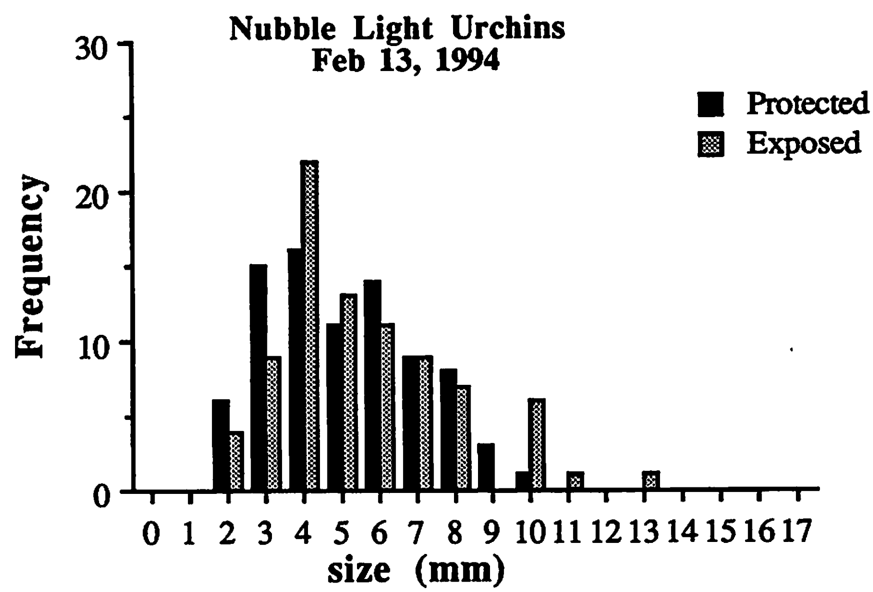
y-error bars represent standard error

Figure 4: Shows the changes in test diameter over time between the protected and exposed treatments in the sea urchins taken from Nubble Light, Maine.



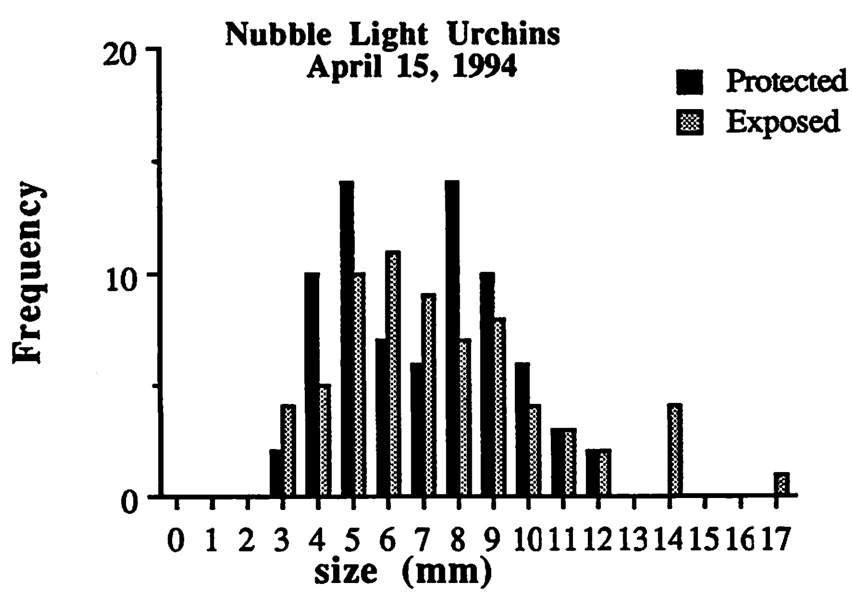
Nubble Light Urchins
Nov 2, 1993
Protected
Exposed
Frequency
0
10
20
30
40
50
60
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
size (mm)

a.



Nubble Light Urchins
Feb 13, 1994
Protected
Exposed
Frequency
0
10
20
30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
size (mm)

b.

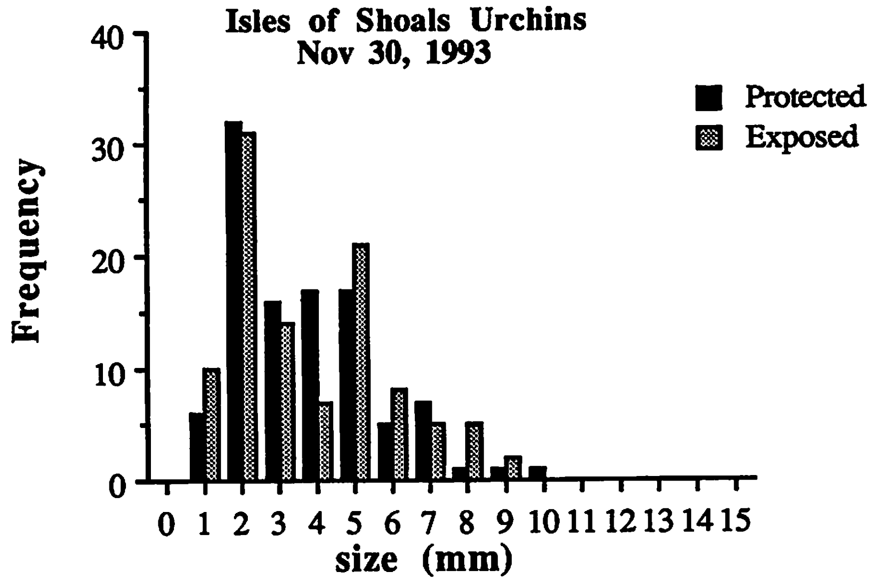


Nubble Light Urchins
April 15, 1994
Protected
Exposed
Frequency
0
10
20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
size (mm)

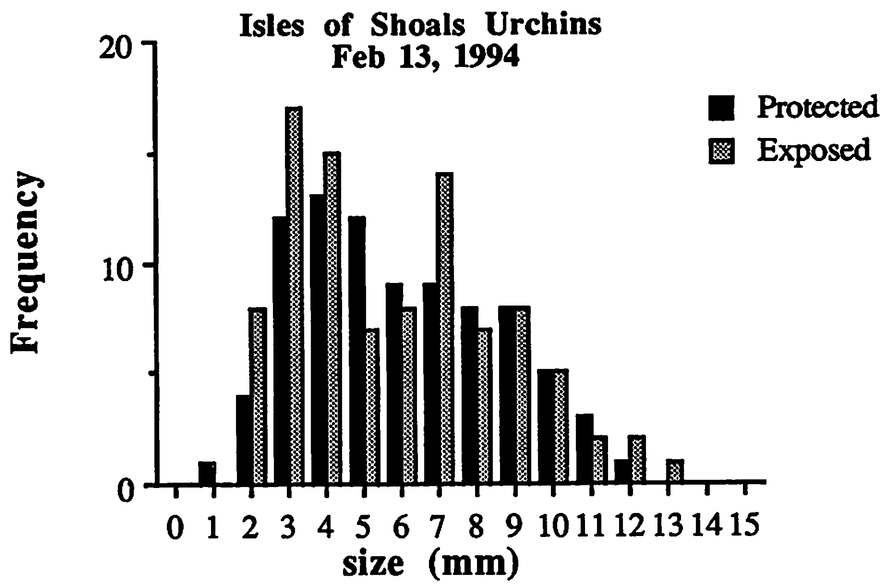
c.

Figure 5: Shows the changes in test diameter over time between the protected and exposed treatments in the sea urchins taken from the Isles of Shoals.

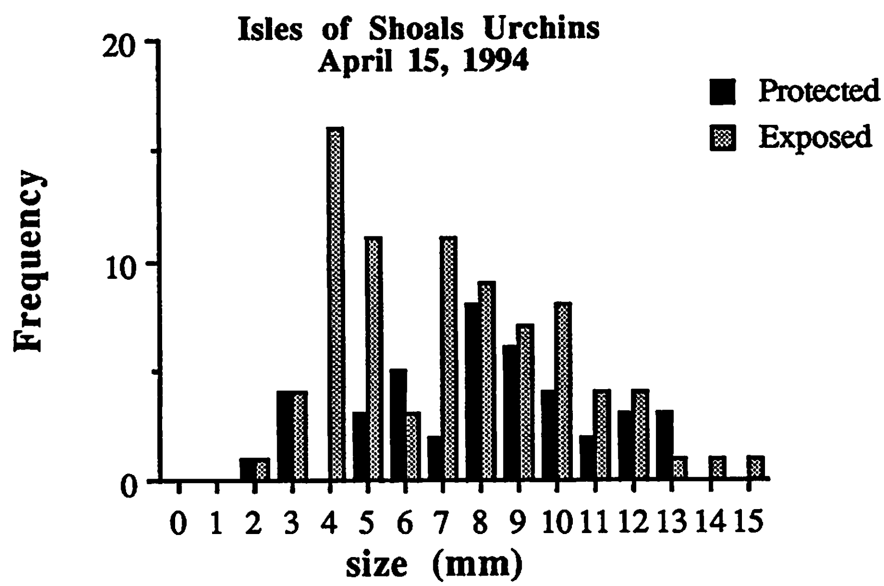
a.


Isles of Shoals Urchins
Nov 30, 1993
Protected
Exposed
Frequency
0
10
20
30
40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
size (mm)

b.


Isles of Shoals Urchins
Feb 13, 1994
Protected
Exposed
Frequency
0
10
20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
size (mm)

c.


Isles of Shoals Urchins
April 15, 1994
Protected
Exposed
Frequency
0
10
20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
size (mm)

exposed and protected urchins from both the Isles of Shoals and Nubble Light at (a) the beginning of the experiment, (b) mid-experiment, and (c) at termination of the experiment. When the urchins were measured again in February to prepare for the alternating exposure experiment, the animals in the exposed aquaria for both sites had experienced the largest amount of growth (Figures 4 and 5).

In April, when the experiments were terminated, the fastest growing urchins continued to be those in the exposed treatments. In both the protected and the exposed treatments, the Nubble urchins had at least double the percent increase of their Shoals counterparts. The largest measure of growth for a single urchin was 11mm, representing a 183.3% growth increase. In the protected aquarium containing Shoals urchins, there was a significant amount of mortality toward the end of the experiment. The percent survival from beginning to end was only 39.8%, while in the other three treatments percent survival ranged from 61.8% to 78.6%.

Similarly, in the exposure transplant experiment the largest urchins experienced the most growth in the exposed treatment, with the exception of the protected control from Shoals. The protected control urchins from Shoals grew only 1.5% more than the exposed control from the same site (Table 2). The small urchins from Nubble switched from the protected to the exposed treatment grew the most of all the minimum sized urchins, experiencing a 77.8% increase in size (Figure 6). Table 3 shows percent increase in growth for the exposure manipulation urchins.

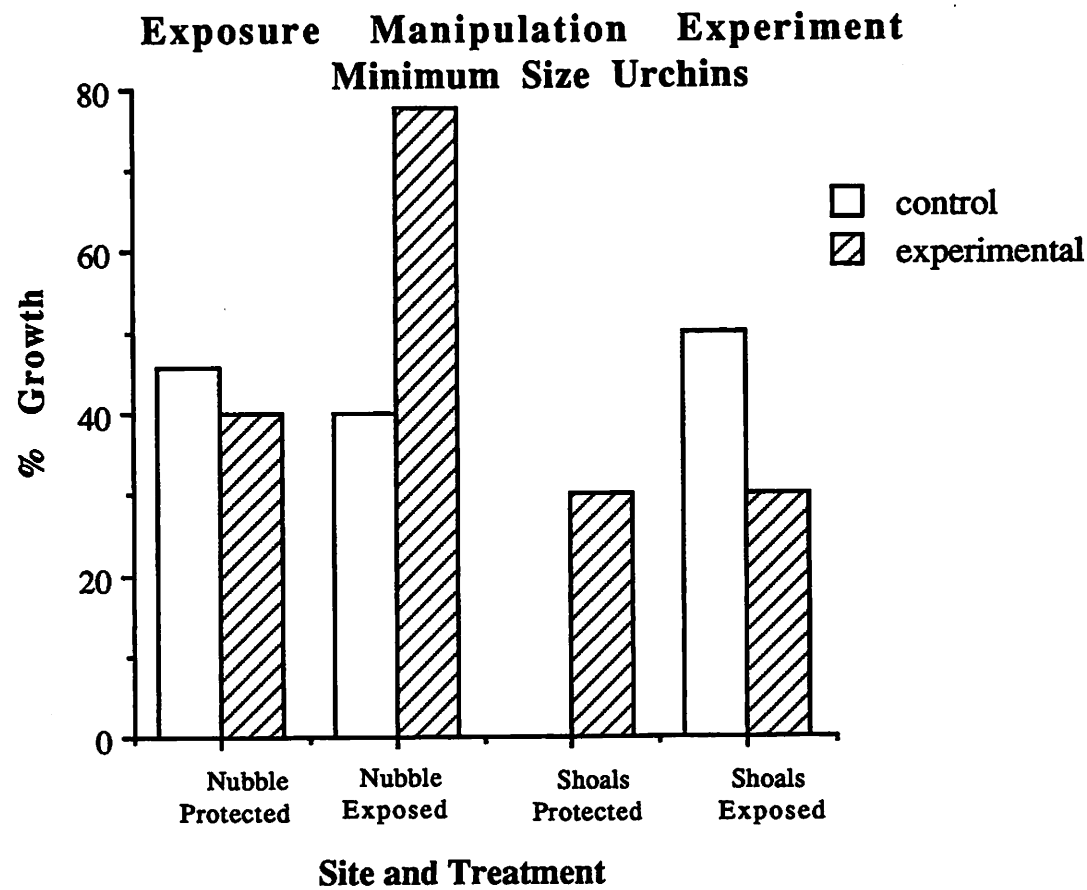
Mark-Recapture Field Experiment

Exposure Table

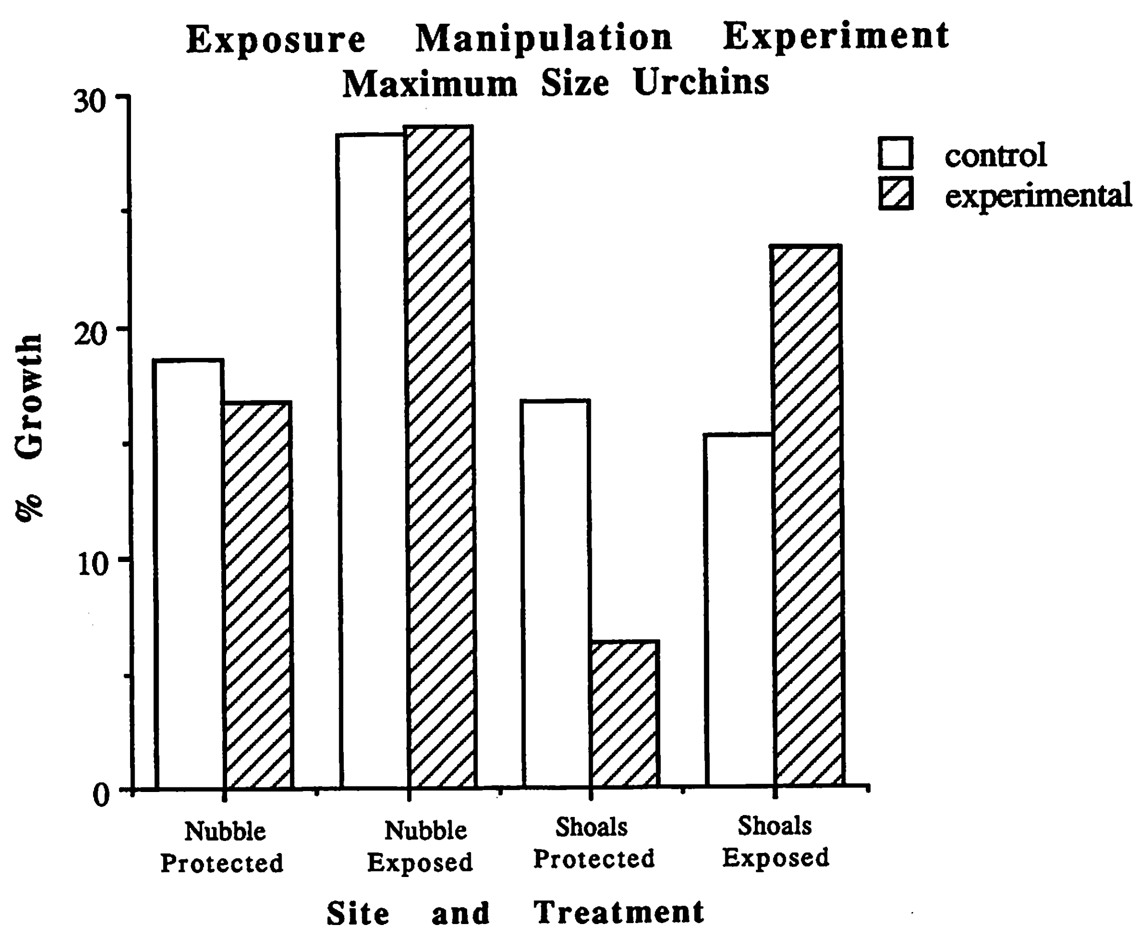
	Isles of Shoals Urchins Exposed	Isles of Shoals Urchins Protected	Nubble Light Urchins Exposed	Nubble Light Urchins Protected
Survival				
#Begin	103	103	110	110
#End	81	41	68	74
%Survival	78.5	39.8	61.8	67.3
Mean Size				
Begin	4.0	4.0	3.0	3.0
End	7.0	7.0	7.0	8.0
% Increase	75.0	75.0	133.3	166.7
Minimum Size				
Begin	1.0	1.0	1.0	1.0
End	2.0	2.0	3.0	3.0
% Increase	100.0	100.0	200.0	200.0
Maximum Size				
Begin	9.0	10.0	6.0	5.0
End	15.0	13.0	17.0	12.0
% Increase	66.7	30.0	183.3	140.0

Table 2: Summary of exposure experiment data

Figure 6: Shows the percent growth of *Strongylocentrotus droebachiensis* , comparing reciprocal transplant and control organisms.


Exposure Manipulation Experiment
Minimum Size Urchins
80
60
40
20
0
% Growth
control
experimental
Nubble Protected
Nubble Exposed
Shoals Protected
Shoals Exposed
Site and Treatment

a.


Exposure Manipulation Experiment
Maximum Size Urchins
30
20
10
0
% Growth
control
experimental
Nubble Protected
Nubble Exposed
Shoals Protected
Shoals Exposed
Site and Treatment

b.

	Nubble Light Urchins		Isles of Shoals	
	Percent Growth		Percent Growth	
minimum urchin size	Exposed	Protected	Exposed	Protected
Experimental	77.8	40.0	30.0	30.0
Control	40.0	45.5	50.0	0.0
maximum urchin size				
Experimental	28.6	16.7	23.3	6.4
Control	28.3	18.6	15.2	16.7

Table 3: Summary of percent growth in exposure transplant experiment

Table 4 shows the data from the Mark-Recapture Field Study. Percent recapture was 25% for site A and 44% for site B. The percent increase in growth over the 5 months was 20.7% for site B. Figure 2 is the linear regression (R^2=0.947) of jaw length to test diameter used to calculate percent increase in growth. The average increase in test diameter was 4.08 mm (+/- .31 S.E.) for site B urchins. The Calcein did not take in the site A urchins, therefore percent increase in growth and average increase in test diameter could not be calculated for that group.

DISCUSSION

Diet Experiments

It was apparent from the results that an omnivorous diet of *Laminaria saccharina* with *Membranipora membranacea* produces the greatest increase in test diameter in *Strongylocentrotus droebachiensis* . This diet may provide the best balance of proteins and carbohydrates for optimal growth. Results by Nestler and Harris (1994) showed similar results for shorter term experiments.

The diet of *Laminaria* and *Mytilus edulis* had much lower growth in test diameter. There were at least two possible reasons for this. Firstly, it may have cost more energy to chew through the mussels than the amount of energy obtained from the mussels themselves (Briscoe and Sebens, 1988). Secondly, the urchins in this treatment had a choice of which food to eat - kelp or mussels or both. Some may have exclusively eaten kelp and never made an attempt to eat the mussels (Briscoe and Sebens, 1988). Similar percent increases in growth in the exclusively *Laminaria* diet

Mark-Recapture Field Study Data

	Site A	Site B
% Recapture	25%	44%
% Increase in Growth	---	20.7%
Average increase in Test Diameter	---	+4.08mm (.31 SE)

Table 4: Summary of mark-recapture field study data

(26.1%) and the *Laminaria* and *Mytilus* diet (25.08%) supported this possibility.

The urchins that were fed only *Mytilus* had the lowest percent increase in diameter in the laboratory (23.29%). The urchins in this treatment may have lacked necessary nutrients that are obtained from an algal food source. Also, cold water (<1.8° C) may have caused the urchins' metabolism to drop so low that they could no longer efficiently digest the animal protein (Briscoe and Sebens, 1988). Briscoe and Sebens (1988) also showed that the *Laminaria* diet to be of greater nutritional value than the *Mytilus* diet . The urchins from the mark-recapture field study may have had the lowest percent increase in diameter (20.7%) because of the lack of available food and greater energy expenditure searching for food (see Mark-Recapture Study discussion).

Exposure Experiments

The results of the wave exposure experiment provide preliminary evidence that degree of water motion does have some effect on the growth of young sea urchins. Despite the fact that there was no difference in the mean size of urchins at each measurement stage (Table 2), an assessment of cumulative growth and size ranges indicate the fastest growing urchins at both sites were in the exposed treatments. This trend seems to be logical, given that the collecting sites were both exposed, open coast sites. Also, there is large variation in growth rate for first year urchins.

At the Isles of Shoals site where the wave exposure was the greater of the two sites, the young urchins placed in the protected aquarium had both the poorest survival rate as well as smallest percent of growth. The large numbers of dead urchins at the end of the experiment when spring runoff lowered the salinities at the Coastal Marine Lab indicate the combination of a low-flow environment and salinities measuring as low as 8ppt have a drastic negative impact, particularly on the smallest sized urchins (Figure 5c). In contrast, the exposed treatment for this site had the highest survival rate of all four treatments.

The Nubble urchins which began as a smaller sized and more uniform group, ended with similar survival rates between treatments, and overall growth for the largest urchins exceeded doubling the initial maximum size. As with the Shoals urchins, the growth trends from this site indicate a preference for a high wave action environment. These results suggest a hypothesis that urchins may be predisposed to better survival in a particular settling environment.

The manipulation study produced a less conclusive set of results with no clear trends emerging. In general, the urchins that were transplanted into the exposed treatments had a higher percent growth than the reciprocal transplants. The control sets of urchins followed no patterns of growth, regardless of urchin size or exposure treatment. The lack of significant analysis to be made from this manipulation experiment may be due to the small sample size as well as a short running time of only two months.

The analysis of the initial comparison of this exposure experiment creates more questions about the effects of water motion on the growth of *S. droebachiensis*. If more was known about ideal growing environments, particularly for first year urchins, there would be greater feasibility of successful urchin aquaculture.

Overall, the evidence gathered from this experiment points toward favorable urchin settlement and development in open coast, high wave action environments. More research is called for in this area to achieve reproducible and statistically significant results utilizing a larger populations of young urchins.

Mark-Recapture Field Experiments

In the mark-recapture study, the percent recapture was almost double for site B urchins (44%) than for site A urchins (25%). This is probably due to greater amounts of drift algae in site B. With this quasi-permanent food source, site B urchins had little reason to leave the study area in search of food. On the other hand, site A had less constant and abundant drift algae, so urchins may have had to search farther for food, thus leaving the study site.

Calcein did not mark the site A urchins sufficiently enough to determine jaw growth. One possible reason may be that site A urchins could not eat immediately after being returned to the study site after marking due to a temporal lack of food source in site A, and thus experienced "shrinkage" - or negative test growth. Reabsorption of test material in urchins of scarce food areas may result in negative growth (Ebert, 1968 and Regis, 1979).

In site A urchins, the percent increase in growth over the 5 months of the experiment was 20.7%, with an average increase in test diameter of 4.08 mm (.31 SE). This figure is much lower than the percent increase in growth of the laboratory urchins in the diet study. The laboratory urchins were fed an unlimited supply of food; the field urchins probably did not eat continuously and thus grew less.

The field experiment shows that Calcein is a viable method of marking urchins for mark-recapture and growth studies. The reliability of using Calcein, however, requires more research.

Our results suggest that an omnivorous diet and constant water flow are factors that optimize growth of the green sea urchin. If aquaculture is found to be feasible, over-harvesting of existing populations of kelp could be a potential problem. A method for growing food or creating an artificial substitute would be necessary.

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