The Influence of Temperature - Food Availability on the Shell Growth of Sea Scallop *Placopecten magellanicus* (Gmelin, 1791)

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Abstract

A study of the growth of the sea scallop, Placopecten magellanicus, under suspended culture conditions was carried out over a seven month period at a culture site in Graves Shoal, Mahone Bay,Nova Scotia – Canada. Scallop spat were cultivated in pearl nets at a density of 30-35 per net set at four locations corresponding to the surface (7 m) and bottom (14 m) at the outer edge and the center of the site. Shell height was measured at monthly intervals. Environmental conditions represented as temperature and food availability at the surface and bottom over the same period were also monitored. Shell Height growth rate was slightly greater at the surface than at the bottom. At the surface sites growth was greater at the outside (SUROUT) than at the center locations, but at the bottom growth was greater at the centre location (BOTIN). The only significant relationship between shell growth and temperature - food variables was chlorophyll a concentration.

Key words: *temperature, food availability, shell height, sea scallop*

Abstrak

Studi terhadap pertumbuhan kerang simping Placopecten magellanicus, yang dibudidayakan dengan metode “suspended culture” telah dilakukan selama tujuh bulan di lokasi budidaya di Graves Shoal, Mahone Bay, Nova Scotia, Kanada. Benih scallop muda dipelihara dalam pearl nets dengan kepadatan 30-35 ekor dan ditempatkan pada empat lokasi yang mewakili perairan permukaan (7 m), dasar perairan (14 m), di luar lokasi budidaya (outer edge), di tengah-tengah lokasi budidaya (centre). Pertumbuhan jaringan lunak (whole tissue weight) diamati setiap bulan sekali. Monitoring terhadap suhu dan ketersediaan pakan pada permukaan dan dasar perairan juga dilakukan. Tingkat pertumbuhan tinggi cangkang sedikit lebih besar di permukaan dibandingkan dengan di dasar perairan. Di permukaan, pertumbuhan yang lebih besar terjadi di bagian luar lokasi budidaya (SUROUT) dibandingkan dengan yang di lokasi budidaya (BOTIN). Hubungan yang nyata antara pertumbuhan cangkang dengan suhu dan keberadaan pakan hanya terjadi untuk klorofil a.

Kata kunci: suhu, ketersediaan pakan, tinggi cangkang, kerang simping

INTRODUCTION

The potential for scallop culture remains high in many countries but it will require a firm commitment by governments and industry to achieve this goal (Bourne, 2000).The sea scallop, also known as the giant scallop or smooth scallop, *Placopecten magellanicus* (Gmelin, 1791) it self is one of the most economically important species of shellfish on the east coast of Canada and the northern United States (Beninger, 1987). The environmental factors surrounding a site determine the water quality in providing food supply, proper temperature and salinity, and current velocity for growth of scallops (Grecian *et al*., 2000).

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More specifically, temperature and food availability have been considered the main factors affecting growth and production (Bayne and Newell, 1983; Shumway, 1991, 2016; Sokolova and Portner, 2001; Heilmayer, 2003). An investigation carried out in eastern Newfoundland and around St. Andrews, New Brunswick, Canada concluded that the more favorable temperature and food conditions are usually found in shallow water and result in greater somatic growth than in deeper water (MacDonald and Thompson, 1985). In the Gulf of Maine, Schick *et al.* (1988) found that in shallow water (15 and 25 meter depths) the scallop growth was greater than the growth of the deep water scallops (170 and 174 meter depths). But, interestingly in Passamaquoddy Bay, where the water column is thoroughly mixed by tidal forces, there is no difference in either shell growth or somatic growth of scallops from various depths (MacDonald and Thompson, 1985). Comparisons of growth rates at five depths ranging between 55-144 m in the Bay of Fundy resulted in similar conclusion (Caddy *et al*., 1970).

There is lack information on the specific food items preferred by bivalve species in their natural habitats (Shumway *et a*l., 1987). For *Placopecten magellanicus*, phytoplankton may be the primary sources of nutrition. Detritus alone is apparently a poor alternative but can be utilized as an additional food source when phytoplankton concentrations are low (Cranford and Grant, 1990). Others have reported that *P. magellanicus* is an opportunistic filter feeder that ingests a wide spectrum of pelagic and benthic organisms and detritus ranging in size from 10 to 350 um (Shumway *et al*., 1987). As pointed out by Levinton (1972), not only is the food supply constantly fluctuating, it is unpredictable and these suspension feeding organisms must maintain an adaptive strategy which maximizes the generality of their food requirement.

The objective of this study was to determine both the quality and quantity of temperature and food availability for the sea scallop, *P. magellanicus*, and their relation to the shell growth (shell height) at a culture site in Graves Shoal, Mahone Bay, NS Canada.

MATERIAL AND METHODS

Juvenile giant scallops 9-12 mm in shell height (summer spat cohort) were placed into pearl nets and deployed at a grow-out site located at Graves Shoal in Mahone Bay (Figure 1). Approximately 3,000 scallops were transferred to 84 pearl nets at a density of 30-35 individuals per net: 21 at a site located at a depth of 7 m and on the outside margin of the site (SUROUT); 21 at a depth of 7 m and located within the interior of the site (SURIN); 21 at depth of 14 m and on the outer margin (BOTOUT); and 21 at depth of 14 m located within the interior of the site (BOTIN). The depth used in this study was in accordance with the depth for *P. magellanicus* studied by MacDonald and Thompson (1985). At each site there were 7 arrays each of which contained 3 pearl nets representing 3 replicates.

Shell height (SH) was measured at monthly intervals over a seven month period beginning June 1992 and ending December 1992. Shell height, the maximum distance between dorsal (hinge) and ventral margins (Seed, 1980), was measured to the nearest 0.1 mm using a vernier caliper.

During May to December the following environmental factors were monitored on a weekly basis; water temperature, chlorophyll *a* concentration and particulate mater concentration. One l water samples for determination of chlorophyll *a* and particulate mater concentrations were taken at depths corresponding to the surface and bottom sites. Water samples for chlorophyll *a* were filtered through Whatman GF/C glass fiber filters under gentle vacuum (<20 mmHg) and the filters stored frozen until analysis. Chlorophyll *a* measurements were made spectrophotometrically (Strickland and Parsons, 1972) after extracting the pigment in 15 ml of 90% acetone for 24 h at 4^{o} C in the dark.

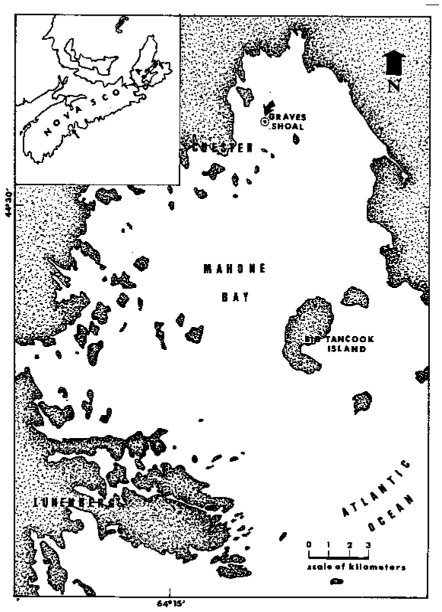

Figure 1. Map showing location of the study site at Graves Shoal, Mahone Bay, Nova Scotia – Canada

Three measurements of particulate matter were made: Total Particulate Matter (TPM), Particulate Inorganic Matter (PIM), and Particulate Organic Matter (POM). TPM was determined by filtering 1 l of water onto previously combusted and tarred Whatman GF/C filters. The filters were then dried at 60-70^oC for 24 h in a vacuum oven and reweighed. For PIM determination, the dried filters were combusted at 450^oC for 24 h in a muffle furnace and then reweighed. POM was calculated as the difference between TPM and PIM measurements.

A variety of statistical procedures were used to analyze the data set. These included Pearson correlation analysis and analysis of variance (ANOVA). For ANOVA analysis, pairwise mean differences and comparison probability matrices (based on Bonferroni probability levels) were presented to facilitate interpretation of results.

RESULTS AND DISCUSSIONS

Water temperature

During the study period water temperature ranged between 3-19 ^oC at 3 m depth (representing the surface site) and 2-17 ^oC at 14 m depth (representing the bottom site) (Figure 2). At both surface and bottom sites temperature peaked in mid-August. Up to this period stratification also increased, and at maximum stratification the mean difference between surface and bottom site was about 4 ^oC. Near the end of August a mixing event caused stratification to break down, but this was reestablished shortly afterwards and lasted until about mid-October when the system became destratified and remained so for the remainder of the study period.

Food Availability

Phytoplankton chlorophyll *a* at the surface site ranged between 0.19-1.92 $\mu g\ l^{-1}$ with a mean of 0.78 $\mu g\ l^{-1}$. Bottom site chlorophyll a concentrations were slightly lower than those at the surface ranging between 0.13-1.86 $\mu g\ l^{-1}$ with a mean of 0.71 $\mu g\ l^{-1}$ (Figure 3). Seasonally chlorophyll *a* values peaked during early June and late September. Between mid-June and early August chlorophyll *a* levels were generally low with surface values being slightly less than bottom values.

Total Particulate Matter Concentration over the study period ranged between 1.6-25.6 mg l^{-1} with a mean of 8.5 mg l^{-1} (Figure 4). There was little difference between concentrations at the surface and bottom. The seasonal variation in TPM was very erratic. Peaks occurred in early July and August, and in late October. Between the end of August and late October TPM values remained relatively constant and high. There was no clear relationship between TPM concentration and mixing events although the peak in late September did occur at the period of fall destratification.

POM concentrations at both depths were always much lower than PIM concentrations and ranged between 0.6-4.6 mg l^{-1} with a mean value of 1.7 mg l^{-1}. In general, POM accounted for about 20 percent of TPM indicating that most of the particulate matter present was inorganic. In addition, POM showed very little seasonal variation compared to that exhibited by PIM.

Shell growth (Shell height)

The mean values of shell height at the surface sites were greater than at the bottom sites (Figure 5). Result of ANOVA analysis indicated the differences between means were significant ($p<0.05$). The mean values, however, were not significantly different between the inside and outside sites (Table 1).

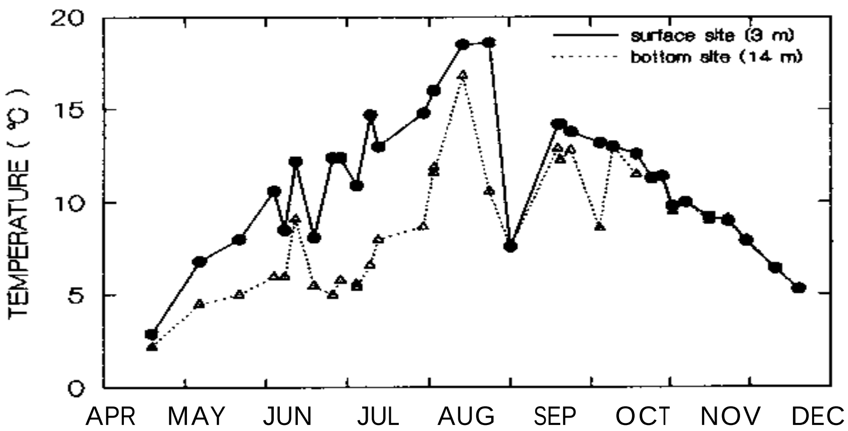

Figure 2. Seasonal variation of temperature at the surface site and bottom site at Graves Shoal, Mahone Bay

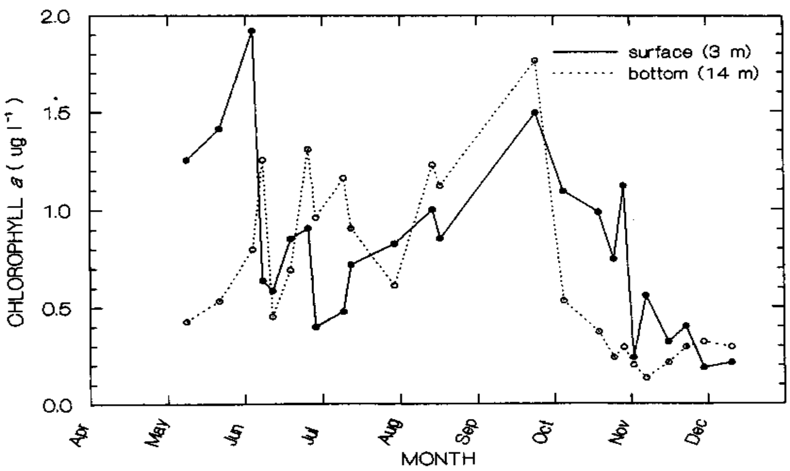

Figure 3. Seasonal variation in chlorophyll *a* concentrations at the surface site and bottom site at Graves Shoal, Mahone Bay

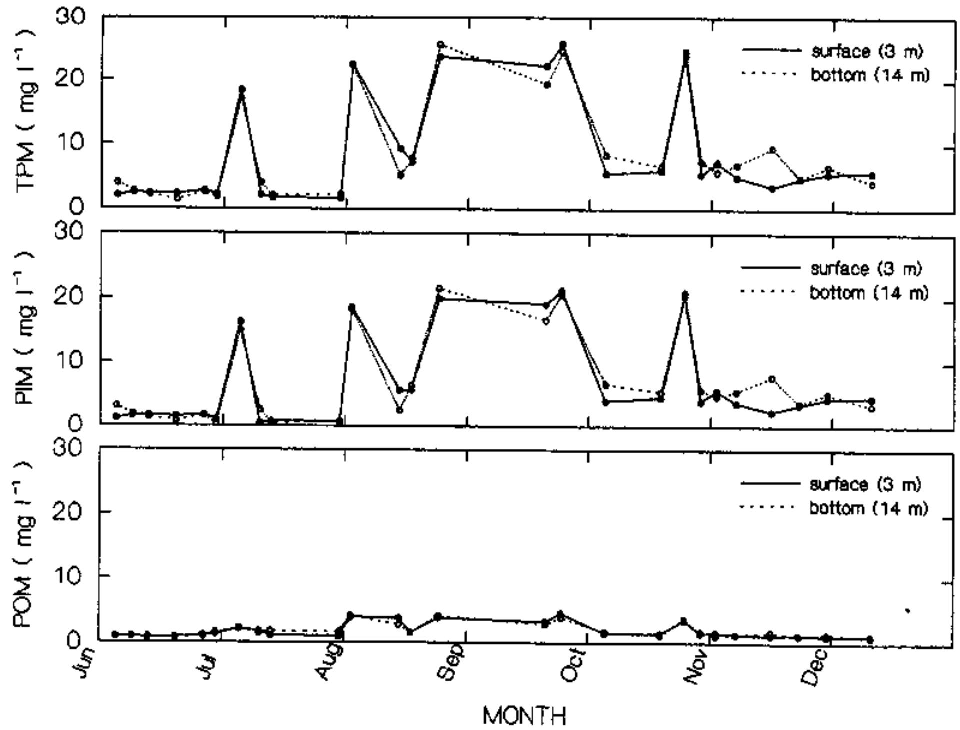

Figure 4. Seasonal variation in Particulate Organic Matter (POM), Particulate Inorganic Matter (PIM) and Total Particulate Matter (TPM) concentrations at surface site and bottom site at Graves Shoal, Mahone Bay

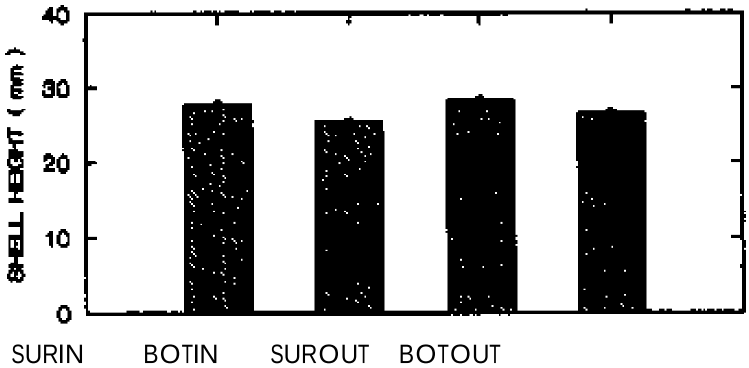

Figure 5. Comparison of the mean and standard error of Shell Height at each site

Figure 6 presents the value of Shell Height (SH) at each sampling time. ANCOVA, using time as the covariate, indicated a significant site effect ($p<0.05$) in terms of increase with time (Table 2).

Further analyses of these differences were carried out by performing simple linear regression analysis of growth versus time (Table 3), and by comparing the differences in the slopes (absolute growth rates) of Shell Height (SH) at each site. When multiple comparisons of slopes among sites for the growth were performed, the regression probabilities were Bonferroni adjusted (Table 4).

For shell height absolute growth rates were 0.155, 0.154, 0.160 and 0.149 mm d^{-1} for SURIN, BOTIN, SUROUT and BOTOUT, respectively. The differences were significant between all sites with exception of SURIN and BOTIN. This indicates that the increase of shell height at SUROUT was the greatest, equal at SURIN and BOTIN, lowest at BOTOUT.

Relationships between shell growth (shell height) and food availability

In order to examine the relationship between shell growth rate and the temperature - food variables, the mean daily of shell growth rates between each sampling period was compared to the mean value of temperature, chlorophyll a and Particulate Organic Matter (POM) over the same period. In only one instance was there a significant regression and this was between the growth rate of shell height and mean chlorophyll *a* (Table 5).

Table 1. ANOVA of the effect of Site on Shell Height (SH)

Dependant variable: SH N: 2754

Analysis of variance

Source	Sum-of-squares	DF	Mean-square	F-Ratio	P
Site	3355.192	3	1118.397	10.647	0.000
Error	288882.241	2750	105.048		

Matrix of pairwise mean differences :

SITE	SURIN	BOTIN	SUROUT	BOTOUT
SURIN	0.000			
BOTIN	-2.255	0.000		
SUROUT	0.676	2.930	0.000	
BOTOUT	-1.075	1.179	-1.751	0.000

Matrix of pairwise comparison probabilities :

SITE	SURIN	BOTIN	SUROUT	BOTOUT
SURIN	1.000			
BOTIN	0.000	1.000		
SUROUT	1.000	0.000	1.000	
BOTOUT	0.309	0.217	0.008	1.000

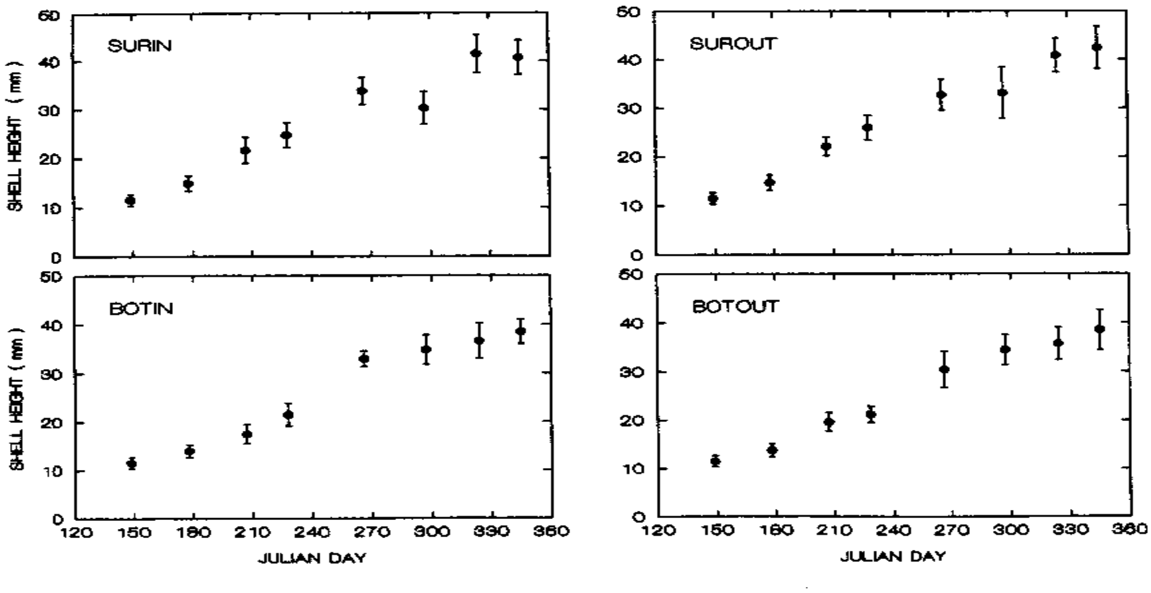

Figure 6. The change in mean value of Shell Height over the study period (error bars are one standard deviation of the mean)

Table 2. ANCOVA of Shell Height (SH) with Site using Julian Day as the covariate

Dependant variable: SH N: 2754 Square multiple R: 0.892

Source	Sum-of-squares	DF	Mean-square	F-Ratio	P
Site	72.376	3	24.125	2.103	0.098
JD	256496.228	1	256496.228	22355.007	0.000
Site*JD	182.372	3	60.791	5.298	0.001
Error	31506.975	2746	11.474		

Table 3. Linear regression analysis of SH at each site on Julian Day

Site	N	Regression	R^2
SURIN	695	y=-11.284+0.155x	0.865
BOTIN	644	y=-13.015+0.154x	0.919
SUROUT	730	y=-11.990+0.160x	0.886
BOTOUT	685	y=-11.453+0.149x	0.897

Table 4. Regression probabilities [1)] for comparison of slopes based on linear regressions (ANCOVA)

SITE	SURIN	BOTIN	SUROUT	BOTOUT
SURIN	-			
BOTIN	0.140	-		
SUROUT	0.019 *	0.008 *	-	
BOTOUT	0.005 *	0.004 *	0.000 *	-

[1)] Bonferroni adjusted
[*)] Significant at 95% level

Table 5. Summary of multiple regression results for prediction of mean growth of Shell Height (GASH) using mean temperature, chlorophyll *a* and Particulate Organic Matter as predictors.

Dep Var: GASH N:26 Squared Multiple R:0.211 Adjusted Squared Multiple R:0.178
Standard Error of Estimate:0.072

Variable	Coefficient	Std Error	P(2 tail)
Constant	0.055	0.038	0.162
Chla	0.129	0.051	0.018

Analysis of Variance

Source	Sum-of-Squares	DF	Mean Square	F-Ratio	P
Regression	0.033	1	0.033	6.414	0.018
Residual	0.125	24	0.005		

The Influence of Temperature - Food Availability on the Shell Growth

In most studies, there has been a general agreement that growth of sea scallop is depth dependent; with increasing depth representing deteriorating environmental suitability (Shick *et al*, 1986).Therefore, in stratified systems, growth in the upper mixed layer is generally greater than that in the bottom waters. In this study, the difference in growth rate between the surface and bottom was significant (Figure 5). The greater growth rates of *P. magellanicus* at surface sites was probably a result of more favorable environmental conditions within the water column as opposed to bottom sites, especially during the system stratified up to the mid October. In this case surface waters tended to have higher temperatures (Figure 2), but there was little difference between food availability as measured by phytoplankton chlorophyll *a* (Figure 3) and POM (Figure 4) concentrations. The mean chlorophyll *a* level was 0.7 μg l^{-1}, whereas the mean POM level was 1.8 mgl^{-1}. Bacher *et al*. (2003) measured that the both values were 4.3 mg l^{-1} for chlorophyll *a* and 1.5 mgl^{-1} for POM in developing a model for the scallop growth in Sungo Bay, China.

Attempts to relate scallop growth in shell height to temperature - food variables showed that between shell height and chlorophyll *a* there was a significant relationship exist. It also suggests that in general chlorophyll *a* may be a better indicator of food availability than variables related to particulate matter concentration. Particulate matter concentrations include both inorganic and organic materials and there is some evidence that the ratio of these components, in addition to their absolute concentration, may be important in determining their ability to be utilized. Vahl (1980), in a study on the Iceland scallop, *Chlamys islandica*, reported that POM could not be absorbed as food when PIM comprised more than 80 percent of the seston. In another study on the same species, Wallace and Reinness (1985) showed that growth was seriously reduced when the ratio of PIM to POM in seston exceeded a critical value of 3.5. In the present study the ratio of PIM to POM averaged about 4 (Figure 4) and this may indicate relatively poor food quality, especially if *P. magellanicus* exhibits the same response to the relative proportions of PIM and POM as does *C. islandica.*

Chlorophyll *a* concentrations peaked during late May and late September (Figure 3) while temperature peaked during early August (Figure 2). As result, the increase in filtration rates would have occurred at a time when food concentrations were low and the benefits of increased filtration rates would not have been realized.

Variation in shell growth between scallops located on the outside edge of the site relative to those located within the interior of the site were relatively minor. Scallops located near the margins of a culture site, compared to those located within the interior, are less likely to be affected by depletion of food materials as water flows through the site. The lack of any clear difference in growth rates suggests that food depletion was not a problem at the scallop densities used in this study.

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