PPENDIX D

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT

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PART I — PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
Mercenaria Manufacturing R.D. 1, Box 293B Millsboro, DE 19966	**SBIR — 1984 Phase I**	OCE-8460471
	4. Award Period From 3/1/85 To 8/31/85	5. Cumulative Award Amount

6. Project Title: Inexpensive Feeds as Dietary Supplements to Accelerate Growth of Juvenile Surf Clams (Spisula solidissima)

PART II — SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

Increased demand for live and processed clams has been accompanied by a decreased supply of wild clams. The surf clam, Spisula solidissima, was utilized extensively for processed clam products until overfishing reduced the surf clam harvest. Surf clams can be produced in one growing season, for use in markets currently supplied by slower growing hard or soft-shell clams. The purpose of this research project was to determine if inexpensive supplements could be used to cost-effectively accelerate clam growth in a commercial-scale open system. Addition of rice starch to the natural algal supply resulted in significant increases in clam weight and length. Increased value of larger clams was not great enough, however, to offset increased labor and feed costs. The results of this study will not allow immediate commercialization of the supplementation process. Rather, these results may encourage further research with supplemental feeds. Before commercialization can take place, better diets must be developed and unit labor costs must be reduced. Cost-effective supplemental feeding could provide surf clam seed for grow-out to supply markets for live and processed clam products.

Key Words to Identify Research or Technology (8 maximum)

Surf clam, Spisula, feeds, supplements, growth, profit

Note from Ed Urban (28 July 2010): This final project report was submitted to NSF in 1985. In scanning this report for digital archiving, I found that the pages are mis-numbered, in that there are no pages 7, 13, 17, 18, 20, 24, or 25. The text reads as though this is simply a problem with page numbering and not a problem of missing pages.

The data presented in this report have not appeared in the peer-reviewed literature. John D. Monte died in 1996.

Inexpensive Feeds as Dietary Supplements to Accelerate Growth of Juvenile Surf Clams (*Spisula solidissima*)

by

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Introduction

The demand for live and processed clams has increased in the past 60 years (Snow, 1979). Harvests of softshell clams (Mya arenaria) and surf clams (Spisula solidissima) have declined during the same period (Glude, 1977; Snow, 1979). Major clam processors, such as Borden, Inc., consider cultured clams as a possible source to augment wild clam supplies in the future (Snow, 1979).

Methods have been developed for growing juvenile surf clams in land-based raceways and upwelling systems, and bay-bottom cages (Goldberg, 1980; Rhodes et al., 1981). Goldberg (1980) determined that 18 mm surf clams fed on natural algae could be grown to 55 mm in one growing season (May to October) in a land-based system, in contrast to the 2 to 3 years required by oysters and hard clams to reach market size.

In land-based systems, providing the amount of algae required to meet the nutritional requirements of large bivalves is economically and logistically prohibitive. The high cost, unpredictability and/or limited nature of algal supply has prompted years of research with non-algal food materials for bivalve molluscs. Many different supplements have been previously tested, with varied success (Haven, 1965; Chanley and Normandin, 1967; Sayce and Tufts, 1967; Dunathan et al., 1969; Castell and Trider, 1974;

Winter, 1974; Turgeon and Haven, 1977; Burle and Kirby-Smith, 1979; Epifanio, 1979). Urban and Langdon (1984) described inexpensive feed substitutes that allowed the removal of 50% of the algae from oyster (Crassostrea virginica) diets, with no decrease in growth. Growth was particularly enhanced by addition of kaolinite clay particles.

Materials and Methods

Experiments 1 and 2

Clams used in all three experiments were produced in 1984 and held over the winter at the Mercenaria Manufacturing site at Massey's Landing, Delaware. The first two experiments were carried out at the University of Delaware Center for Mariculture Research, and the third experiment was conducted at Mercenaria Manufacturing. Clams ranging in length from 1.8 to 2.2 cm were selected, weighed and randomly assigned to treatment groups. Each group was held in 15 liters of seawater in its own plastic bucket, and culture water was changed daily. The seawater used had a salinity of 30 ppt and a temperature of 25 ^{0}C. Buckets were aerated to maintain adequate oxygen concentrations in the culture water and to help keep food and silt particles in suspension.

Daily rations were fed in two equal portions, one in the morning and one in the evening. The algal portion of the rations was comprised of a 50/50 mixture (on a dry weight basis) of Isochrysis galbana (clone T-ISO) and Thalassiosira pseudonana (clone 3H). Algae were cultured according to the method of Bolton (1982). Stock solutions of dry supplements were mixed twice daily by dispersing them in seawater and agitating the mixtures for about one minute in an electric blender. A lignosulfonate dispersant (Lignosite®) was added to the buckets at a concentration of 5 mg/liter, to reduce particle clumping and settling. Lignosulfonate dispersants improve the growth of oysters fed on algae and non-algal supplements (Urban, unpub. data).

Each clam was marked with waterproof ink to determine individual weight gains during the experimental period. The initial relationships between live, dry and ash weights were determined from a sample of 20 clams. Clams were weighed weekly and the supplement portion of the rations was increased in direct proportion to weight gained by clams in the previous week. The algal portion of the ration was maintained at 0.5% of initial live weight, however, to simulate the limited supply of algae in open-system bivalve culture.

The first experiment tested six feeds at three supplementation levels, for 28 days. The six supplements were rice starch, cheese whey, Purina Experimental Marine Ration #25, Lake States yeast, TOPOL yeast and Zeigler

AP-100 (see Appendix I for product information). The first three supplements (Urban and Langdon, 1984) and the Lake States yeast (Urban, unpub. data) produced increased growth of oysters, <u>Crassostrea virginica</u>, in past experiments. TOPOL yeast is a brine shrimp feed developed in Belgium. It contains higher levels of long-chain polyunsaturated omega fatty acids than most yeasts. Omega fatty acids are known to be important in the nutrition of some bivalves (Langdon and Waldock, 1981). Finally, Zeigler AP-100 is a small sized fraction that is left over after the commercial AP-100 product is screened off. It is a complete diet like Purina EMR #25, with the further advantage that no grinding is required to reduce it to the proper particle size.

Experiment 1 Treatment Matrix

Supplement	Supplement Level (% of clam live wt.)			
		0.25	0.50	0.75
Lake States Yeast				
Rice Starch				
Cheese Whey				
Purina EMR #25				
Zeigler AP-100				
TOPOL Yeast				
Algae alone				
Unfed Control				

The second experiment lasted 40 days, testing the three supplements producing the best growth in the first experiment, Zeigler AP-100, Purina EMR #25 and rice starch, alone and in combinations. In addition, a clam diet from the Virginia Institute of Marine Science (VIMS) was tested alone. Each of the supplements, as well as the 0.5% algal ration, was fed to clams with or without the addition of 50 mg/liter of natural silt. Silt was obtained from the raceways at Mercenaria Manufacturing, dried at 50 ^{o}C and ground using an electric blender. Algal rations of 0.75 and 1.0% of clam live weight were also tested.

Experiment 2 Treatment Matrix

% Supplement

VIMS	AP-100	Starch	EMR #25	Silt	No Silt
	0.125	0.375			
	0.25	0.25			
	0.375	0.125			
		0.375	0.125		
		0.25	0.25		
		0.125	0.375		
	0.125		0.375		
	0.25		0.25		
	0.375		0.125		
	0.5				
			0.5		
		0.5			
0.5					
0.5% Algae alone					
1.0% Algae alone					
0.75% Algae alone					

At the end of the experiments, clams were individually weighed. Weight gain data were analyzed by two-way analysis of variance (ANOVA). Groups were dried at 60 ^{0}C for at least one week, weighed, ashed at 450 ^{0}C for 48 hours and reweighed. This allowed the determination of gross growth efficiencies.

Experiment 3

The purpose of the third experiment was to use the best diet from Experiment 2, a mixture of Purina EMR #25 and rice starch, in a commercial-scale open system to grow surf clams. Two mixtures of the chosen diet were added to raceways under two feeding regimes, continuous and batch feeding. The effect of position in the raceway was also tested (Figure 1). Clams with an average weight of 7.91 g and average length of 37.2 mm were randomly assigned to 24 groups. Each group contained 500 clams. Fifty additional clams were randomly selected to determine initial lengths and initial live, dry and ash weights, and the relationships between these parameters. Each group was initially weighed and four groups were placed in each of 6 raceways. Raceways were partitioned into four equal quadrants to keep groups separate. Raceways were covered with vinyl covers, to inhibit growth of epiphytes on the clam shells. The average salinity was 32 ppt, and the experiment lasted 89 days.

Experiment 3 started with two supplement mixtures added at 0.5% of live weight and a control group that received no supplement. These three conditions were tested using batch or continuous feed addition. One supplement mixture initially contained 75% rice starch and 25% Purina EMR #25 and the other contained 25% rice starch and 75% Purina EMR #25. Feeds were mixed daily. It was necessary to grind the Purina diet before feeding, to obtain the proper particle size. Grinding was done with an electric blender, reducing most of the particles to a diameter of less than 20 microns. The Purina supplement was used for only 25 of the 89 days, because the feed company ran out of the product and the next production run was delayed. Therefore, for most of the experiment, the supplemented raceways were fed either a high (0.375% of live weight) or low (0.125% of live weight) ration of rice starch.

Plastic measuring spoons and cups were calibrated in the laboratory, to determine the grams per volume of each supplement. This allowed daily feeding by volume, so that it was unnecessary to have a balance at the grow-out site. Supplements were dispersed in seawater using an electric blender. In batch-fed raceways, the water flow was stopped, and an equal amount of the supplement suspension was added to each of the four quadrants. The clams in batch-fed raceways were fed half their daily ration in the morning and half in the evening. Water remained turned off until the particles were cleared, usually requiring approximately one hour per feeding.

In continuously-fed raceways, the supplement suspension was added to a 200-liter barrel containing seawater. The diluted suspension was added to the raceway at a rate of approximately 360 ml per minute. Barrels were refilled in the evening and any settled supplement was resuspended.

One hundred randomly-sampled clams from each group were weighed bimonthly to allow construction of growth curves. Supplemental rations were increased in direct proportion to the estimated live weight increase in each raceway, adjusted for mortality. Random sampling was accomplished using a 21 square grid, with each square measuring approximately 15 cm on each side. A Mettler top-loading balance was used to weigh the clams in groups of ten.

At the end of the experiment, 100 clams were randomly sampled from each quadrant. Each clam was weighed and its anterior-posterior length was measured. Three-way ANOVAs were carried out on final live weights and final lengths, using diet, feeding method and position in the raceway as the three factors. Dry weights and organic percentages were determined by drying and ashing ten clams from each group.

Water samples were collected weekly from the inflow and outflow of each raceway, before and after feeding. Water samples were also collected from the batch-fed raceways immediately after feeding and just prior to re-starting the water flow. Two types of analyses were carried out on the water samples. First, the concentrations of suspended organic and inorganic particles were determined for each sample. One hundred to three hundred ml of each sample was filtered through a tared Whatman GF/F glass-fiber filter, having an effective retention size of 0.7 microns. Three replicates were obtained from each water sample. After filtration was completed, 5 ml of 0.5M ammonium formate was used to rinse seawater from the samples (Epifanio and Ewart, 1977). Filters were dried at 50 ^{0}C for at least 3 days and were re-weighed. Filters were then ashed at 450 ^{0}C for 48 hours and weighed again.

Water samples were also analyzed with a Coulter Counter to determine particle size distributions. The numbers of particles in the following size ranges were determined: 2 to 3, 3 to 5, 5 to 7, and 7 to 15 microns.

Sediment samples were collected weekly from each quadrant to determine if more organic material was accumulating in the supplement-fed raceways. Sediment samples were dried at 50 ^{0}C for at least 4 days, weighed, ashed at 450 ^{0}C for 48 hours and reweighed.

The dissolved oxygen concentration in the raceways before and during feeding was determined with a YSI Model 57 dissolved oxygen meter. The change in oxygen concentration from the inflow to outflow ends of the raceways was also measured. Water temperature was recorded twice daily, at feeding times.

Summary of Research Results in Relation to Objectives

The project objectives were as follows:

1. *To determine the best types and levels of non-algal supplements for juvenile surf clams under small- and large-scale conditions.* The best clam growth in small-scale experiments occurred with mixtures of rice starch and Purina EMR #25 fed at a level of 0.5% of live weight. The large scale experiment showed that rice starch fed at 0.125% of clam live weight produced a greater weight increase than a 0.375% ration of starch. There was no significant difference in length due to the two rations, however.

2. *To determine if silt-reduction methods should be developed for the large-scale system.* The addition of 50 mg/liter of natural silt with diets in the second small-scale experiment had no significant effect on surf clam growth.

3. *To determine if supplements significantly increase growth in large-scale systems.* Feeding two different

levels of rice starch to surf clams significantly increased the weight and length of clams held in open-system raceways.

4. *To determine if supplements increase profitability of surf clam production.* The revenue gained by adding supplement was less than the extra cost for feed, labor and equipment.

5. *To develop methods for adding non-algal feeds to large-scale systems.* Continuous feed addition improved growth more than batch additions of feed.

6. *To determine if position in the raceway affects growth.* Position in raceways had a significant effect on clam growth. Clams grown in the two quadrants closest to the inflow had about equal weight increases; clams in the third and fourth quadrants weighed less. Position in the raceway also has a significant effect on length, with the longest clams growing in the second and third quadrants.

Results

Experiment 1

In the first experiment, none of the supplements produced significantly better growth than controls (Figure 2), since all the 95% confidence intervals overlap with the confidence interval of the 0.5% algal ration. Neither the diet ($F_{(5, 355)}=1.84$, $p=0.104$) nor the supplement level ($F_{(2, 355)}$=2.09, p=0.125) caused a significant difference in weight gain. The three best supplements, Zeigler AP-100, Purina EMR#25 and rice starch were used in Experiment 2.

Relationships between live, dry and ash weights for an initial sample of clams allowed the estimation of the initial organic weights (i.e., ash-free dry weights) of each experimental group (Table 1). The final group dry and ash weights and the dry weight of food added were directly measured, allowing the estimation of the efficiency of conversion of food into clam organic matter, the gross growth efficiency (GGE, Urban et al., 1983). The GGE was 22.1% for clams fed algae alone. GGEs estimated for clams fed the same level of algae plus supplemental feeds were always lower than for clams fed only algae, ranging from 0.4% to 17.8%. The 0.75% supplement level produced lower GGEs than the 0.25% level, except in the case of the Lake States yeast. Rice starch produced the highest mean GGE over the three supplement levels, followed by Zeigler AP-100, TOPOL yeast, Purina EMR #25, cheese whey and Lake States yeast. The GGE for the 0.25% level of Lake States yeast seems to be anomalously low, possibly due to an error in weighing. Diets producing the most growth generally had the highest GGEs, although the rankings of these two measures did not correspond exactly.

Table 1. Experiment 1. Gross Growth Efficiency Determination

Diet	Initial[1] group organic wt. (g)	Final group organic wt. (g)	Group organic weight increase (g)	Dry weight of food (g)	Gross[2] Growth Efficiency
0.5% algae	1.67	2.46	0.79	3.567	22.1%
unfed control	1.72	0.82	-0.90	-	-
0.5% algae + 0.25% LS Yeast	1.75	1.77	0.02	5.632	0.4%
" " + 0.50% LS Yeast	1.71	2.39	0.68	7.711	8.8%
" " + 0.75% LS Yeast	1.76	2.77	1.01	9.730	10.4%
" " + 0.25% Rice Starch	1.69	2.53	0.84	5.676	14.8%
" " + 0.5 % Rice Starch	1.68	3.05	1.37	7.709	17.8%
" " + 0.75% Rice Starch	1.82	2.57	0.75	9.873	7.6%
" " + 0.25% Whey	1.79	2.55	0.76	5.639	13.5%
" " + 0.5 % Whey	1.73	1.98	0.25	7.633	3.3%
" " + 0.75% Whey	1.68	2.51	0.83	9.624	8.6%
" " + 0.25% EMR #25	1.73	2.44	0.71	5.646	12.6%
" " + 0.5 % EMR #25	1.69	2.50	0.81	7.757	10.4%
" " + 0.75% EMR #25	1.74	2.61	0.87	9.850	8.8%
" " + 0.25% AP-100	1.75	2.63	0.88	5.699	15.4%
" " + 0.5 % AP-100	1.69	2.80	1.11	7.794	14.2%
" " + 0.75% AP-100	1.70	2.32	0.62	9.913	6.3%
" " + 0.25% TOPOL Yeast	1.82	2.51	0.69	5.690	12.1%
" " + 0.5 % TOPOL Yeast	1.76	2.73	0.97	7.621	12.7%
" " + 0.75% TOPOL Yeast	1.80	2.61	0.81	9.933	8.2%

[1] It was not possible to determine the initial organic weight for each group directly, so a group of initial animals was dried and ashed to determine the relationship: Initial organic wt. = 0.0704 (Initial live wt.).

[2] Gross Growth Efficiency = (Increase in clam dry organic weight/Total dry weight of food presented) x 100.

LS Yeast = Lake States Yeast

Experiment 2

In Experiment 2, four supplement combinations produced significantly greater clam growth than for clams fed only 0.5% algae (Figure 3):

1. 75% Rice starch + 25% Purina EMR #25
2. 75% Rice starch + 25% Purina EMR #25 + silt
3. 50% Rice starch + 50% Purina EMR #25 + silt
4. 25% Rice starch + 75% Purina EMR #25 + silt

In a two-way ANOVA, the overall effect of diet was significant ($F_{(1, 548)}=3.028$, $p=0.000$), but the effect of silt was insignificant ($F_{(1, 548)}=0.799$, $p=0.372$). The GGEs are similar with and without silt, and no trends between the GGEs produced by the different diet combinations are apparent (Table 2). These results indicated that reducing natural silt in the culture water would not be necessary in Experiment 3. It was decided that the two supplement combinations tested in Experiment 3 should be a 75% rice starch/25% Purina EMR #25 mixture and a 25% rice starch/75% Purina EMR #25 mixture.

Experiment 3

Clams grew best in the two raceways with continuous feed addition, followed by the two batch-fed raceways, and the two control raceways (Figures 4 and 5). The growth of the fastest growing clams (Raceway 3) could be described by the following equation:

Table 2. Experiment 2. Gross Growth Efficiency Determination.

Diet	Initial[1] group organic wt. (g)	Final group organic wt. (g)	Group organic weight increase (g)	Dry Weight of food (g)	Gross Growth Efficiency
1% algae	1.79	3.63	1.84	9.316	19.8%
0.75% algae	1.72	1.71	-0.01	6.987	-
0.5 % algae	1.73	2.45	0.72	4.658	15.5%
Starved control	1.72	0.93	-0.79	-	-
0.5% algae/0.125% Z/0.375% RS	1.76	4.60	2.84	7.833	36.3%
" " /0.25% Z/0.25% RS	1.77	2.91	1.14	7.714	14.8%
" "/0.375% Z/0.125% RS	1.73	2.88	1.15	7.708	14.9%
" "/0.125% P/0.375% RS	1.76	3.37	1.61	7.780	20.7%
" "/0.25% P/0.25% RS	1.80	3.09	1.29	7.766	16.6%
" "/0.375% P/0.125% RS	1.75	3.57	1.82	7.852	23.2%
" "/0.125% Z/0.375% P	1.80	2.89	1.09	7.658	14.2%
" "/0.25% Z/0.25% P	1.78	2.68	0.90	7.726	11.6%
" "/0.375% Z/0.125% P	1.75	3.00	1.25	7.673	16.3%
" "/0.5% Z	1.74	2.80	1.06	7.649	13.9%
" "/0.5% P	1.74	2.90	1.16	7.786	14.9%
" "/0.5% RS	1.72	3.07	1.35	7.600	17.8%
" "/0.5% VIMS diet	1.77	2.61	0.84	7.554	11.1%
" "/silt	1.78	2.58	0.80	4.658	17.2%
Starved/silt	1.77	1.04	-0.73	-	-
0.5% algae/0.125% Z/0.375% RS/S	1.80	3.22	1.42	7.876	18.0%
" " /0.25% Z/0.25% RS/S	1.80	3.39	1.59	7.864	20.2%
" "/0.375% Z/0.125% RS/S	1.79	3.23	1.44	7.782	18.5%
" "/0.125% P/0.375% RS/S	1.74	3.20	1.46	7.816	18.7%
" "/0.25% P/0.25% RS/S	1.77	3.37	1.60	7.824	20.4%
" "/0.375% P/0.125% RS/S	1.74	3.27	1.53	7.865	19.5%
" "/0.125% Z/0.375% P/S	1.75	3.12	1.37	7.738	17.7%
" "/0.25% Z/0.25% P/S	1.72	2.80	1.08	7.640	14.1%
" "/0.375% Z/0.125% P/S	1.75	4.01	2.26	7.691	29.4%
" "/0.5% Z/S	1.77	2.62	0.85	7.726	11.0%
" "/0.5% P/S	1.79	2.37	0.58	7.763	7.5%
" "/0.5% RS/S	1.73	2.85	1.12	7.670	14.6%
" "/0.5% VIMS diet/S	1.77	3.05	1.28	7.792	16.4%

[1] It was not possible to determine the initial organic weight for each group directly, so a group of initial animals was dried to determine the relationship: Initial organic wt. = 0.0704 (Initial live wt.).

Z = Zeigler AP-100
RS= Rice Starch
P = Purina EMR #25
S = Silt

Log_{10} (weight per clam) = 0.028(# of weeks) + 0.9

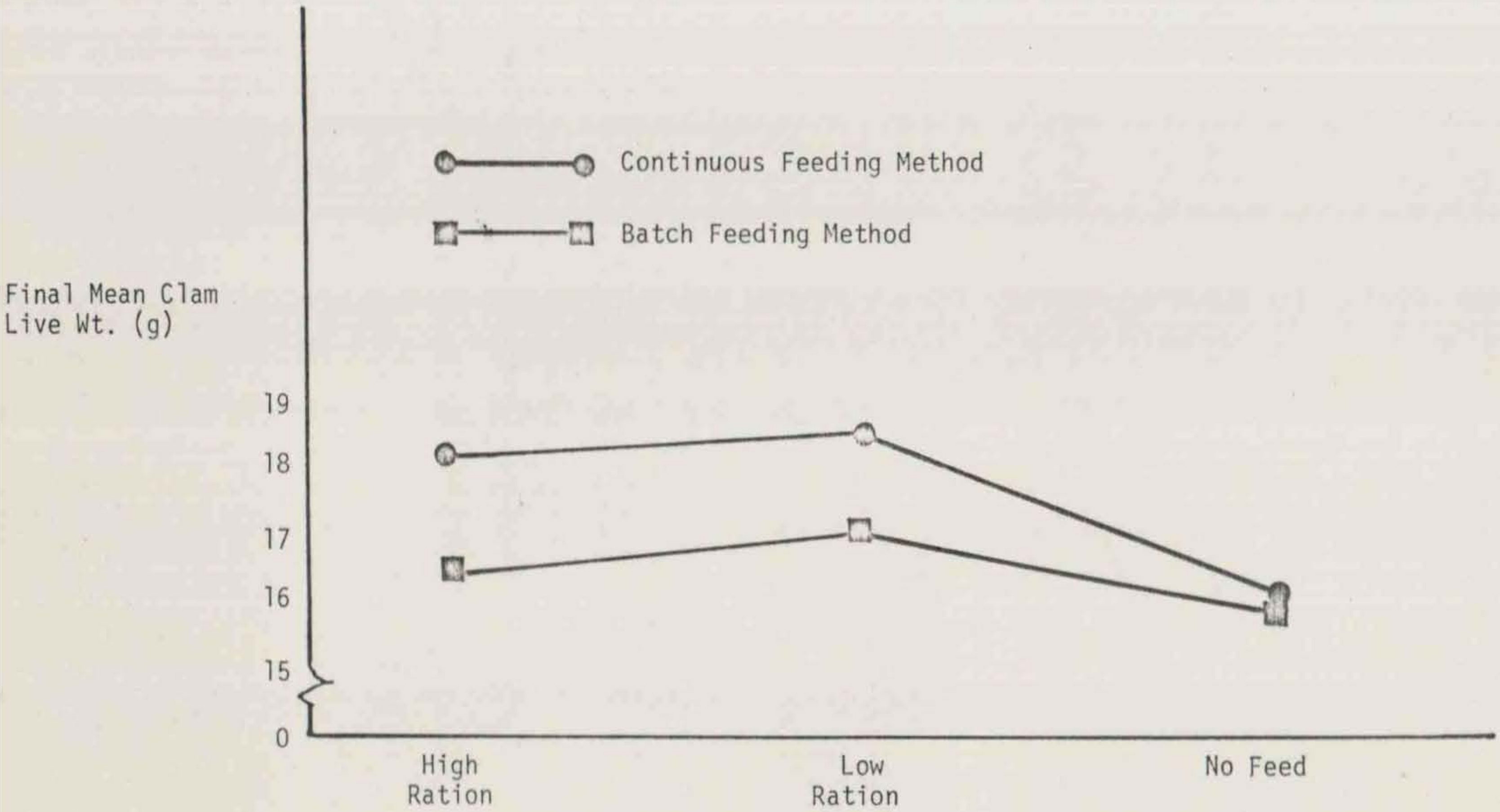
At this rate, it would take 122 weeks for a clam to grow from 0.001g (about 1 mm) to the 26.4g estimated to correspond to the 55mm market size of Goldberg (1980).

In a three-way ANOVA, clam weights were significantly affected by:

1. the feeding method ($F_{(1,2399)}$=52.553, p=0.000),
2. the feed used ($F_{(2,2399)}$=41.552, p=0.000), and
3. the position of the clams in the raceway ($F_{(3,2399)}$=8.809, p=0.000).

The two-way interactions between the feeding method/raceway position and between feed/raceway position were insignificant. The interaction between the feeding method and feed was significant ($F_{(2,2399)}$=8.614, p=0.000), however, indicated by the convergence of the lines connecting the points in Figure 6. This interaction is to be expected, indicating that as the amount of supplemental feed is decreased, the difference in growth resulting from the two different feeding methods decreases. Each of the two supplement mixtures produced better growth than the unfed control. The low starch ration produced greater weights than the high starch ration ($F_{(1,1599)}$=6.486, p=0.011).

Figure 6. Experiment 3. Effect of feeding method on surf clam growth resulting from different rations.



The feeding method ($F_{(1,2399)}$=48.57, p=0.000), feed level ($F_{(2,2399)}$=44.547, p=0.000) and position in the raceway ($F_{(3,2399)}$=6.661, p=0.000) also produced significant differences in final clam length (Figure 7). A two-way interaction between feeding method and feed was again observed, consistent with the statistical analysis on the final weight data. The other two-way interactions were insignificant. There was no significant difference between the lengths of clams fed the two levels of starch ($F_{(1,1599)}$=2.198, p=0.138). Each supplement level produced significantly greater clam length than in unfed controls.

Mortality occurred at a low steady rate for about the first 55 days, after which the rate increased. Approximately half of the mortality occurred in the last 13 days of the experiment (Figure 8). It appears that the increased mortality at the end of the experiment may have been caused by high water temperatures.

Water samples

Analysis of water samples by the filtration method indicated that in approximately half of the cases there was a greater concentration of organic particles in the raceway outflow than in the inflow (Table 3 and Appendix II). Only a few of these cases could be explained by the amount of food continuously added to raceways. Assuming that all the

Table 3. Experiment 3. Percentage of organic particles removed from the inflow to outflow ends of the raceways, determined by the filtration method.
* cases in which the concentration of organic particles was higher at the outflow end than the inflow end.
1 dates when continuously-fed raceways were fed before water samples were collected.

DATE

Raceway	5/25[1]	6/6[1]	6/13[1]	6/20[1]	6/27[1]	7/4[1]
1	*	32%	11%	*	*	*
2	*	*	*	*	*	*
3	*	26%	8%	*	*	*
4	4%	*	8%	*	*	*
5	13%	7%	18%	57%	*	*
6	17%	64%	*	21%	19%	*

	7/11	7/18[1]	7/25	8/1	8/7	8/15
1	35%	*	*	7%	*	*
2	52%	*	*	*	*	*
3	*	*	35%	4%	13%	7%
4	34%	*	28%	6%	14%	*
5	*	*	*	*	*	*
6	18%	*	*	8%	*	*

food in the feed container was evenly distributed and evenly dispersed in the raceways, the addition of feed should have raised the concentration of organic particles by a maximum of 4.4 mg/liter. Resuspension of bottom sediments in the raceways by movement of the clams was observed and may be responsible for the unexpectedly higher concentration of organic particles in the outflow. The average weekly concentration of particulate organics in the inflow water ranged from 8.6 to 24.0 mg/liter (Appendix II). The inorganic concentration ranged from 11.8 to 73.6 mg/liter (Appendix III). When the outflow had a lower content of organic particles than the inflow, from 4 to 70% of the organic particles were removed, with an average of 22% removed.

The increase in concentration of particulate organics in batch-fed raceways should have ranged from 134 to 176 mg/liter for the high ration and from 100 to 59 mg/liter for the low ration, from the beginning to the end of the experiment. The measured values were variable, but in general agreement with the expected values (Appendix II).

Clams in batch-fed raceways removed 70 to 100% of the added food, although it is unknown how much of the feed was rejected as pseudofeces. In the high ration raceway, #4, abundant pseudofeces were often observed during feeding periods. After a few weeks of feeding, the sediment in raceway #4 became black, with the sulfur odor characteristic of anoxic sediments. Rejected food may have accumulated and promoted growth of bacteria.

The naturally available ration as a percentage of live weight was calculated, assuming one of three conditions: 1) clams removed 100% of the particulate organic material, 2) the maximum observed value, 70%, of the particles were removed, or 3) the average observed value, 22%, of the particles were removed (Table 4). The percentages in Table 4 are valid for the inflow ends of the raceways, but should be lower for the outflow ends due to removal of food along the raceway. These percentages assume that all the particles filtered are also ingested, which may not be the case. By the end of the experiment, the high supplement level could have added 25% organic material to the natural particulate organics available, assuming that 22% of the 0.375% rice starch ration was removed, with no selective filtration of the rice starch.

Even though the size and type of particles counted by the Coulter Counter differed from the size and type of particles caught on filters, there was good agreement between the average particle reduction determined by the two methods. The Coulter Counter method counted particles ranging in diameter from 2 to 15 microns, and did not distinguish between organic and inorganic particles. The filtration method included both larger and smaller particles, and was able to isolate the reduction in organic

Table 4. Experiment 3. Daily ration expressed as a percentage of clam live weight, with estimates of the portion of the particulate material that might be removed. Values were averaged for all six raceways.

Date	Average organic input (mg/l)	Dry wt.[1] of food per day (kg)	Average live wt. in raceways (kg)	% RATION Total	% RATION Maximum observed removal (.7Total)	% RATION Average observed removal (.22Total)
5/25	14.7	0.96	15.82	6.0%	4.2%	1.3%
6/6	12.9	0.84	18.84	4.4%	3.1%	1.0%
6/20	17.2	1.12	20.50	5.5%	3.8%	1.2%
7/4	12.5	0.82	23.05	3.6%	2.5%	0.8%
7/18	12.9	0.84	25.56	3.3%	2.3%	0.7%
8/1	17.5	1.14	28.01	4.1%	2.9%	0.9%
8/15	6.2	0.40	28.31	1.4%	1.0%	0.3%

[1]kg of food per day was determined by multiplying the average organic input by the liters of water passing through a raceway during the day, estimated to be 6.53×10^4 liters/day.

particles. The Coulter Counter measurements indicated that an average of 18% of the 2 to 3 micron particles were removed, whereas 41% of the 3 to 5 micron particles were removed, with most of the natural particles measured in the smaller size category (Table 5a). The average combined decrease in the number of particles in the two fractions was 24%, similar to the 22% determined by the filtration method. When rice starch particles were added, the efficiency of removal of particles in the 2 to 3 micron range was increased (Table 5b).

Like the filtration method, the Coulter Counter indicated that particle counts sometimes increased from the inflow to the outflow end of the raceway (Table 5). This was most common in the larger size fractions, indicating that particles may have clumped along the length of the raceways, or that larger particles were resuspended. Counts of rice particles from the supplement container indicated that about 36% of the particles were in the 2 to 3 micron fraction and 60% were in the 3 to 5 micron fraction. Because the 3 to 5 micron fraction also had a higher efficiency of removal, it is likely that the clams could remove rice starch particles from suspension more efficiently than they could remove natural particles.

Table 5a. Experiment 3. Reduction in particle concentrations from the inflow to the outflow end of the raceway, as determined by the Coulter Counter method; before food addition.

*indicates a higher particle count in the outflow than in the inflow.

			Particle size classes		
Date	Raceway	2 - 3 μ	3 - 5 μ	5 - 7 μ	7 - 15 μ
7/25	1	34%	50%	83%	93%
	2	53%	51%	42%	33%
	2	42%	33%	*	*
8/1	1	18%	44%	42%	22%
	2	10%	*	*	*
	2	*	*	*	*
8/7	1	26%	26%	40%	33%
	2	39%	53%	76%	74%
	2	29%	28%	2%	*
	4	23%	18%	*	*
	5	39%	54%	*	*
8/15	1	5%	*	*	*
	2	*	*	*	*
	3	4	*	*	*
	4	18%	49%	*	*
	5	15%	*	*	*
	6	*	*	*	*
	AVERAGE	18%	41%		
			24%		

Table 5b. Experiment 3. Reduction in particle concentrations when rice starch particles were added to the raceway.

Date	Raceway	2 - 3 μ	3 - 5 μ	5 - 7 μ	7 - 15 μ
7/25	1	41%	35%	22%	17%
8/1	1	23%	40%	47%	41%
8/7	1	30%	58%	40%	33%
	AVERAGE	31%	44%		

Sediment Analysis

In general, sediment in the first quadrant of each raceway consisted of fecal pellets, with only a small amount of material accumulating, because of turbulence caused by the inflowing water. The amount of sediment generally increased toward the outflow end of the raceways. The first quadrant often had the highest organic percentage of the entire raceway (Table 6). The organic content of the sediments in all quadrants was almost always below 20% and often close to 10%. There was little difference between the values obtained for different raceways, although Raceway 4, the one with anoxic sediments, may have had a slightly higher organic percentage than the other raceways.

Dissolved Oxygen and Temperature

The average decrease in oxygen concentration before and after feeding was 0.04 ppm for continuously-fed raceways (Table 7b). The dissolved oxygen in the batch-fed raceways dropped an average of 2.5 ppm during the feeding period. The raceway that received the high starch ration (#4) consistently exhibiting the largest decrease. The greatest temperature increase measured during one feeding period in a batch-fed raceway was 3 ^{0}C, from 26 ^{0}C to 29 ^{0}C.

Table 6. Percentage of organics in raceway sediment.

	DATES											
Quadrant	5/25	6/6	6/13	6/20	6/27	7/4	7/11	7/18	7/25	8/1	8/7	8/15
1	12.2	10.1	9.4	9.9	11.7	12.2	18.7	26.0	7.8	-	16.4	7.3
2	11.5	10.4	9.6	9.5	9.3	10.7	10.1	11.1	11.2	3.2	10.6	8.1
3	11.6	10.1	10.6	10.0	9.1	13.4	10.0	13.1	11.7	11.7	11.7	10.2
4	10.7	9.4	7.9	8.6	10.0	12.0	25.0	13.2	12.4	11.1	11.8	8.4
5	12.2	11.4	11.1	11.6	10.2	15.9	15.2	20.2	20.4	16.2	13.6	14.3
6	11.7	9.8	9.9	8.2	8.8	14.3	10.3	15.9	12.9	10.8	11.3	10.4
7	11.1	9.5	10.7	8.4	8.8	12.1	7.8	9.6	10.3	8.1	9.5	9.0
8	9.2	9.0	10.4	10.1	8.6	13.7	8.9	12.9	10.7	10.6	9.9	8.7
9	12.6	11.2	12.0	12.1	9.8	10.7	8.3	11.4	12.4	9.9	8.5	9.0
10	12.1	10.6	9.4	11.7	9.1	10.6	8.3	12.0	10.9	9.3	10.0	6.8
11	12.1	9.5	10.0	9.3	8.3	13.5	8.9	13.1	12.9	13.2	12.4	11.8
12	11.2	10.6	10.3	9.3	10.3	11.8	12.4	13.1	10.5	11.0	10.5	10.3
13	12.4	9.5	14.3	17.7	18.9	18.0	17.3	19.0	21.2	-	21.8	13.3
14	11.8	9.7	14.5	12.4	11.6	15.5	11.1	13.0	13.9	14.4	13.4	10.4
15	12.9	10.5	14.5	17.0	11.5	15.7	10.6	12.7	12.4	13.4	11.6	10.7
16	12.6	10.3	15.0	36.4	10.8	13.3	12.2	14.8	13.5	12.9	11.4	19.5
17	11.9	11.3	12.7	15.9	10.6	14.9	17.5	19.3	13.9	-	16.4	-
18	11.7	8.6	12.1	11.5	11.3	13.9	52.5	8.4	16.8	16.0	15.3	17.1
19	11.5	9.2	11.7	15.5	13.1	19.2	12.0	14.7	17.4	13.2	14.8	16.6
20	9.3	10.9	12.5	11.2	10.9	20.1	12.1	14.6	15.0	12.0	12.7	13.5
21	13.5	9.9	14.0	22.3	12.7	13.6	12.0	14.7	13.5	28.7	14.6	16.8
22	13.3	11.2	13.0	10.8	8.7	9.0	9.5	12.8	15.8	12.7	11.8	11.3
23	12.1	10.0	14.3	13.4	9.4	12.2	10.0	23.7	10.5	11.6	10.6	10.1
24	10.5	10.7	14.7	13.3	12.3	12.2	11.3	13.8	29.3	11.9	11.9	10.4

Table 7a. Experiment 3. Dissolved oxygen concentrations (in ppm) before and after feeding each raceway.

	DATE							
	7/18		7/25		8/1		8/7	
Sampling site	Before	After	Before	After	Before	After	Before	After
1 In	6.6	6.5	6.3	6.0	6.5	6.5	6.0	6.2
1 Out	6.1	6.4	5.7	5.7	5.8	6.4	5.6	5.9
2 In	6.7	6.4	6.3	6.2	6.4	6.2	6.0	6.1
2 Out	6.5	6.3	6.0	6.1	6.1	6.1	5.8	6.0
3 In	6.5	5.7	6.2	5.9	6.1	5.9	6.0	5.8
3 Out	6.0	5.7	5.9	5.7	5.8	5.7	5.6	5.8
4 In	6.8	3.7	6.3	3.0	6.4	3.5	5.8	2.6
4 Out	6.2	2.7	5.8	2.3	5.7	3.3	5.5	3.1
5 In	6.7	3.7	6.3	3.4	6.4	4.1	5.9	4.2
5 Out	6.3	3.5	6.0	4.4	5.7	4.3	5.6	4.9
6 In	6.8	4.0	6.5	3.4	6.5	4.4	6.2	3.7
6 Out	6.5	3.7	6.1	4.2	5.8	4.3	5.5	3.5

Table 7b. Experiment 3. Change in average dissolved oxygen concentration after feeding.

	DATE				
Raceway	7/18	7/25	8/1	8/7	
1	+0.10	-0.15	+0.30	+0.25	
2	-0.25	0.00	-0.10	+0.15	Ave. for 1-3: -0.04
3	-0.55	-0.25	-0.15	0.00	
4	-3.30	-3.40	-2.65	-2.80	
5	-2.90	-2.25	-1.85	-1.20	Ave. for 4-6: -2.50
6	-2.80	-2.50	-1.80	-2.25	

Economic Analysis

Instead of determining the absolute profit resulting from each raceway, an incremental analysis was performed. Assuming that fixed costs are the same for fed and unfed raceways, the only necessary factors to include in the profit equation are:

Profit = (Revenue/clam x # of clams surviving)
- labor cost/raceway
- feed cost per raceway
- amortized feeding equipment cost/raceway

Feed costs, and labor and equipment costs associated with feeding are independent of the number of animals surviving, and will be non-existent for the unfed raceways. Revenue per clam was determined by two different methods, each based on a price structure estimated from our experience with wholesale and retail sale of surf clams:

Length	Revenue/clam
20 mm	\$0.04
30 mm	\$0.06
40 mm	\$0.08
50 mm	\$0.12
60 mm	\$0.16

The first method assumed that all clams between two of the sizes above would sell at the lower price. For example, all clams between 30 and 40 mm would sell for $0.06 each. The second method used prices interpolated for 1 mm increments between the 10 mm increments, in an attempt to capture all the benefit gained from adding supplements. The final lengths of the 100 randomly-sampled clams were used to estimate the percentage of surviving animals in each size class. These percentages were multiplied by the number of surviving clams to estimate the number of survivors in each size class.

Labor was estimated to be 11.25 minutes per supplemented raceway per day, for 86 days of feeding. Assuming a wage rate of $5.00 per hour, the total labor cost per raceway was $80.62. The amount of Purina EMR #25 and rice starch used was determined, and multiplied by the dollars per kg for these products (Appendix I). The equipment required for feeding the supplements included the plastic supplement reservoirs, plastic measuring cups and an electric blender. Of these items, only the blender should be allocated a significant annual cost. A new blender would probably have to be purchased each year, because of heavy use. The $20 purchase price was allocated among the four supplemented raceways.

The 1 mm and 10 mm price increment methods determined similar revenue improvements from using supplements, although the absolute revenue values were greater for the

1 mm increment method (Table 8). The greatest revenue increase occurred for clams in the raceway with continuous addition of the low rice starch ration. Due to labor and feed costs, however, the profit from clams in the comparable unfed raceway was $71.91 greater than for the supplemented clams. The profit difference between batch-fed raceways and their control raceway was even greater. The labor cost of feeding proved to be the dominant cost, being eight times greater than the cost for feed.

Discussion

Silt effect

The affect of suspended inorganic particles on bivalve growth varies with the bivalve species and perhaps even the type of particle. Positive growth responses due to silt have been determined for mussels (Mytilus edulis; Winter, 1976; Kiorboe et al., 1981) and for another surf clam species (Spisula subtruncata; Mohlenberg and Kiorboe, 1981). Kaolinite clay particles improved growth of oysters (Crassostrea virginica) fed algae and supplements (Urban and Langdon, 1984).

Bricelj et al. (1984) determined that the addition of up to 25 mg/liter of natural silt to the algal diet of the hard clam (Mercenaria mercenaria) did not affect growth, and that higher levels depressed growth. A previous study with Spisula solidissima showed that surf clams fed

Table 8. Experiment 3. Computation and comparison of profits from each raceway. Values for the 10 mm increments are given first, followed by the values for the 1 mm increment method.

Raceway	Revenue	-	Labor	-	Feed Cost	-	Equip. Cost.	=	Profit
1	$149.50 $179.74		$80.62 "		$10.26 "		$5.00 "		$53.62 $83.86
2	$140.98 $171.62								$140.98 $171.62
3	$157.92 $189.32		$80.62 "		$ 3.99 "		$5.00 "		$68.31 $99.71
4	$141.80 $170.56		$80.62 "		$ 9.81 "		$5.00 "		$46.37 $75.13
5	$139.52 $168.96								$139.52 $168.96
6	$140.12 $167.94		$80.62 "		$ 3.95 "		$5.00 "		$50.55 $78.37

Comparison	10 mm increment method	1 mm increment method
2 - 1	$87.36	$87.76
2 - 3	$72.67	$71.91
5 - 4	$93.15	$93.83
5 - 6	$88.97	$90.59

algae in the presence of the clay mineral attapulgite (Robinson et al., 1984) had decreased filtration and digestion rates. Our research also showed no growth improvement due to natural silt included with surf clam diets.

Continuous vs. batch feed addition

Continuous addition of each ration produced significantly greater weight and length than batch addition of supplements. It is unlikely that the difference in growth was due to the two less hours of natural feed received by batch-fed clams each day, because the lengths and weights were similar for clams in both unfed control groups (Figure 6). For the same reason, the effects of decreased dissolved oxygen and increased temperature due to stopped water flow in batch-fed raceways also cannot solely account for the slower growth in batch-fed raceways. It is possible, however, that decreases in the dissolved oxygen concentration may have been exacerbated by the addition of feed to the raceways. The greater decrease in the dissolved oxygen concentration in raceways fed the high starch ration than the low starch ration provides evidence for this explanation.

Clams in raceways that were batch-fed may have grown less than continuously-fed clams for several reasons. Even though batch-fed clams were able to remove a larger percentage of the food presented than could the clams in continuously-fed raceways, in the former case much of the food may have been unavailable for clam nutrition, being rejected as pseudofeces. The accumulation of uneaten food may have caused the anoxic sediments in the high supplement raceway, resulting in low oxygen concentrations that reduced clam growth. The growth of clams in the two batch-fed raceways slowed in the final two weeks of the experiment, possibly caused by increases in the ambient water temperature to an average of 25 °C, the highest temperature during the experiment.

High vs. low rice starch ration

The low starch diet produced a significantly greater weight than the high starch diet, although there was no significant difference in the length caused by the two supplement levels. The greater growth when a low starch ration was fed verifies the result in Experiment 1 that showed that the lowest level of rice starch (0.25% of live weight) produced the best growth (Figure 2). Experiment 1 also demonstrated that the lowest ration resulted in a higher gross efficiency than the highest ration. A higher supplementation level (0.5%) was used in Experiment 3 because Purina EMR #25 was to be mixed with the diet and because it was correctly assumed that much of the food would be uneaten in the large-scale system.

Effect of position in raceway

It appears that food is a factor limiting clam growth in the raceways, particularly at the outflow end of the raceways. There was a statistically significant effect of position in the raceway on both clam weight and clam length, with lower values at the outflow end. Of the particulate organic material that is actually available for the clams' nutrition, only a small portion is actually removed (Table 3). Rice starch particles may have been more efficiently filtered from the water than natural particles. Once filtered, the rice starch particles were more likely to be nutritious than natural organic particles. Many natural organic particles are refractory and would contribute little to surf clam nutrition, although some of the natural particles provide a source of protein and other nutrients missing from rice starch.

The effect of position in the raceway on growth could be counteracted by adding additional feed further down the raceway or by periodically moving clams to different locations in the raceway. Lowering densities could also reduce the position effect, although the cost-effectiveness of the supplementation process might be further reduced.

Technical and Economic Feasibility

This project has demonstrated that it is technically feasible to feed non-algal supplements to surf clams in an open system, resulting in statistically significant gains in weight and length. The supplementation process was not demonstrated to be cost-effective, however. This result does not eliminate the possibility of cost-effective feeding of supplements to surf clams under different conditions or feeding other species. The information provided by this research could serve as a starting point for future research.

Many factors largely beyond our control in the limited time frame of this study prevented us from carrying out this research as we had originally planned. It is possible that the production methods as initially proposed would have improved the profitability of using supplements. First, we proposed to use surf clams of about 5 mm in length, for the purpose of accelerating the growth of clams to increase the size at planting for the grow-out phase. We were unable to condition surf clams for spawning, however, and thus were unable to obtain enough juveniles by the time the large-scale experiment started. It was necessary to use larger animals produced the previous year, left over after their faster growing siblings had been harvested. Surf clam seed animals are not regularly available on a commercial basis.

The fastest growing clams in our study grew one third to one half as fast as clams grown by Goldberg (1980) and Rhodes et al. (1981). Several factors may have caused this difference. The retention time of water in our raceways was about 7 minutes, much less than the 48 minute retention time in the raceways of Rhodes et al. (1981), with a similar flow rate. A lower retention time allows the animals less time to remove food from the water. We did not have sand in our raceways for the clams to burrow into. Clams in raceways without a substantial sediment layer are very active, possibly using energy that would otherwise be available for growth. Use of smaller, faster-growing clams that can be stocked at higher densities in the raceways could result in economic feasibility of supplement use. The culture of surf clam seed in upwelling units could increase the amount of food removed, without encountering the problems of using a batch-feeding scheme.

Second, the proposed large-scale experiment would have used mixtures of rice starch and Purina EMR #25. New batches of EMR #25 are made infrequently, because it is not yet a commercial feed, and our previous supply ran out early in the experiment. The Ralston Purina company was as cooperative as possible, but was unable to provide the necessary feed until the end of the experiment. The diets we used contained only carbohydrate, essentially fattening the clams, as has been previously accomplished with oysters

(Haven, 1965; Dunathan et al., 1969). The results of Experiment 2 showed the superiority of a mixture of rice starch and Purina EMR #25 to a supplement of rice starch alone. Combinations of Purina EMR #25, Lake States yeast, TOPOL yeast or the VIMS diet with rice starch could be fed to surf clams.

From our experience in this study we can make the following recommendations:

1. Supplements should be inexpensive, about $1 to $2/kg,
2. Supplements should regularly be available in large quantity, and
3. Supplements should preferably require no additional processing, having the proper particle size distribution when purchased.

The first two requirements may prove to be so restrictive that the last recommendation may need to be ignored. Most research diets and diets produced abroad will fail to meet the first two requirements. Even the first requirement could be relaxed if a given supplement produces a greater length increase and/or greater densities allow the spreading of feed costs over a greater number of animals.

Finally, we discovered that the major cost in using supplements was the labor cost. It is likely that increasing the number of raceways receiving supplements and feeding smaller clams could improve profitability by economies of scale and lower unit labor costs. Automatic feeders might reduce labor costs, but would also increase the initial capital outlay required for feeding equipment.

In summary, the use of inexpensive supplements may be economically feasible if:

1. Smaller, faster-growing clams are used,
2. More nutritionally complete supplement mixtures are used, and
3. Unit labor costs are reduced by growing more clams and developing labor saving methods.

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APPENDIX I. Supplement Product Information

Product	Source	Price
Rice Starch	American Key Products, Inc. 10 East 40th Street New York, NY 10016	$1.77/kg
Purina Experimental Marine Ration #25	Ralston Purina Company Purina Mills Inc. Special Chows Research 800 Chouteau Avenue St. Louis, MO 63164	$0.95/kg
Cheese Whey	Kraft, Inc.	$0.44/kg
Lake States Torula Dried Yeast	Lake States Division Rhinelander Paper Co. Rhinelander, WI 54501	$1.71/kg
VIMS Diet	Virginia Institute of Marine Science Wachapreague, VA 23480	?
TOPOL Yeast	Artemia Systems N.V. F. Laurentplein 29, B-9000 Ghent Belgium	$35/kg plus delivery
Lignosite Dispersant	Georgia-Pacific Corp. P. O. Box 1236 Bellingham, WA 98227	$0.28/kg
AP-100	Zeigler Bros. Inc. P. O. Box 95 Gardners, PA 17324	$54/kg

APPENDIX II. Experiment 3. Concentration of organic particles in water samples determined by filtration method.

	DATE			
	5/25	6/6	6/13	6/20
1 In	14.3 ± 4.1	19.0 ± 10.2	16.0 ± 1.4	19.7 ± 3.3
1 Out	17.1 ± 6.2	13.0 ± 4.8	14.2 ± 0.6	24.4 ± 9.6
2 In	15.5 ± 3.1	10.2 ± 0.9	14.5 ± 0.3	17.2 ± 1.1
2 Out	21.5 ± 2.9	10.8 ± 0.7	16.7 ± 2.3	18.1 ± 0.8
3 In	11.9 ± 1.4	12.8 ± 3.5	16.5 ± 2.2	23.3 ± 1.0
3 Out	17.1 ± 4.7	9.5 ± 7.0	15.2 ± 1.0	24.9 ± 0.3
4 In	17.8 ± 4.5	9.1 ± 0.8	18.9 ± 0.6	20.1 ± 1.3
4 Mid Start			145.0 ± 18.1	278.4 ± 9.8
4 Mid End	18.1 ± 2.3	20.4 ± 2.4	16.1 ± 9.4	29.5 ± 4.7
4 Out	17.2 ± 6.9	16.6 ± 0.8	17.3 ± 1.2	21.8 ± 1.1
5 In	15.5 ± 1.7	12.3 ± 4.3	18.5 ± 1.1	38.9 ± 5.2
5 Mid Start			15.4 ± 1.3	48.8
5 Mid End	11.0 ± 3.5	17.2 ± 0.8	16.3 ± 2.1	24.5 ± 15.8
5 Out	13.5 ± 0.9	11.5 ± 6.8	15.1 ± 3.7	16.8 ± 0.8
6 In	13.3 ± 1.0	14.0 ± 3.1	18.6 ± 1.3	25.2 ± 1.4
6 Mid Start			131.9 ± 4.8	99.7 ± 9.4
6 Mid End	13.5 ± 3.3	15.6 ± 5.6	31.2 ± 10.7	36.9 ± 3.5
6 Out	11.1 ± 2.4	5.6 ± 4.0	22.5 ± 1.9	20.0 ± 1.2
Average In	14.7 ± 3.1	12.9 ± 5.3	17.2 ± 2.0	24.0 ± 7.7

	6/27	7/4	7/11	7/18
1 In	8.6 ± 3.8	12.6 ± 0.7	7.8 ± 2.6	9.6 ± 1.6
1 Out	9.8 ± 4.4	12.7 ± 0.4	5.0 ± 3.9	30.8 ± 12.8
2 In	9.2 ± 3.5	14.9 ± 5.0	8.8 ± 1.9	11.7 ± 0.6
2 Out	13.2 ± 4.4	26.6 ± 5.4	4.2 ± 0.8	23.1 ± 11.1
3 In	10.1 ± 4.5	14.8 ± 2.4	6.0 ± 2.0	10.8 ± 0.8
3 Out	10.8 ± 2.0	26.6 ± 12.9	8.6 ± 0.3	18.7 ± 5.1
4 In	11.6 ± 1.5	10.2 ± 0.5	11.7 ± 6.6	11.1 ± 0.7
4 Mid Start	103.8 ± 17.8		101.0 ± 15.5	19.6 ± 1.1
4 Mid End	16.3 ± 9.8	18.6 ± 0.4		7.9 ± 4.3
4 Out	11.9 ± 2.7	15.2 ± 1.7	7.7 ± 2.0	14.8 ± 1.6
5 In	7.3 ± 4.4	11.5 ± 1.5	7.1 ± 0.4	13.2 ± 0.8
5 Mid Start	15.3 ± 4.9		6.0 ± 2.5	26.9 ± 11.6
5 Mid End	14.1 ± 0.8	20.5 ± 4.1	24.2 ± 3.1	11.4 ± 1.5
5 Out	12.3 ± 2.9	20.2 ± 8.0	7.7 ± 1.5	19.1 ± 4.6
6 In	14.0 ± 2.9	11.1 ± 0.4	10.3 ± 2.1	20.7 ± 5.7
6 Mid Start	40.5 ± 12.0		31.2 ± 7.4	29.9 ± 9.0
6 Mid End	5.5 ± 2.7	19.5 ± 5.8	8.5 ± 6.5	14.5 ± 4.7
6 Out	11.3 ± 4.9	14.0 ± 1.1	8.4 ± 1.3	26.5 ± 10.5
Average In	10.1 ± 3.8	12.5 ± 2.7	8.6 ± 3.4	12.9 ± 4.3

APPENDIX II. continued

	7/25	8/1	8/7	8/15
1 In	5.3 ± 1.6	16.6 ± 1.9	12.8 ± 1.4	5.1
1 Out	16.8 ± 5.2	15.5 ± 0.6	15.5 ± 0.6	18.7 ± 6.0
2 In	12.7 ± 5.0	19.0 ± 1.8	13.7 ± 0.5	10.4 ± 0.5
2 Out	15.7 ± 3.9	20.8 ± 2.0	14.8 ± 0.9	12.3 ± 2.0
3 In	13.3 ± 6.4	16.9 ± 0.5	13.4 ± 0.8	15.2 ± 9.0
3 Out	8.7 ± 4.9	16.3 ± 0.8	11.7 ± 0.4	4.6 ± 2.0
4 In	10.9 ± 4.3	17.6 ± 0.4	17.4 ± 6.6	0.7 ± 0.2
4 Mid Start	127.0 ± 11.6	143.7 ± 42.5	217.3 ± 14.3	
4 Mid End	8.4 ± 3.4	24.1 ± 5.2	20.0 ± 2.8	
4 Out	7.9 ± 1.7	16.6 ± 0.9	14.9 ± 1.1	5.2 ± 1.6
5 In	5.6 ± 1.2	16.6 ± 1.0	12.2 ± 3.1	2.6 ± 1.0
5 Mid Start	8.8 ± 0.2	21.4 ± 9.4	23.6 ± 3.4	
5 Mid End	6.7 ± 3.3	18.5 ± 1.5	16.6 ± 1.5	
5 Out	18.0 ± 7.8	19.8 ± 5.5	16.4 ± 3.7	2.9 ± 2.0
6 In	13.8 ± 2.5	18.1 ± 2.0	7.6 ± 1.0	2.5 ± 0.8
6 Mid Start	18.2 ± 6.2	58.5 ± 14.6	32.0 ± 1.4	
6 Mid End	11.5 ± 6.0	19.3 ± 1.4	13.4 ± 2.6	
6 Out	15.4 ± 4.9	16.7 ± 0.8	11.7 ± 1.6	2.5 ± 1.1
Average In	10.2 ± 4.9	17.5 ± 1.5	12.8 ± 3.9	6.2 ± 6.5
	Water samples collected before feeding	Water samples collected before feeding	Water samples collected before feeding	

APPENDIX III. Concentration of Inorganic Particles in Water Samples.
*Excluded from average

	5/25	6/6	6/13	6/20
1	62.8 ± 7.9	71.1 ± 0.4	22.9 ± 3.2	12.0 ± 5.8
2	67.6 ± 2.2	75.5 ± 1.4	17.2 ± 1.2	8.4 ± 2.1
3	66.1 ± 5.7	74.4 ± 5.5	17.5 ± 3.3	20.7 ± 2.1
4	72.3 ± 11.1	75.5 ± 2.5	18.6 ± 2.4	12.0 ± 3.6
5	69.7 ± 3.5	72.2 ± 4.6	15.6 ± 2.5	*131.5 ± 24
6	62.9 ± 8.0	73.1 ± 3.0	17.6 ± 3.9	24.7 ± 1.1
Average	65.9 ± 7.5	73.6 ± 3.3	18.2 ± 3.4	15.6 ± 6.9

	6/27	7/5	7/11	7/18
1	16.3 ± 4.6	14.4 ± 3.2	21.1 ± 4.8	16.1 ± 4.2
2	12.6 ± 5.3	17.9 ± 8.8	20.9 ± 4.1	14.4 ± 2.4
3	14.5 ± 3.0	15.0 ± 2.7	22.0 ± 3.0	18.4 ± 3.0
4	15.0 ± 3.7	9.8 ± 2.4	19.6 ± 1.6	17.7 ± 3.3
5	14.5 ± 1.4	10.4 ± 2.8	19.2 ± 4.7	12.7 ± 0.5
6	13.3 ± 0.9	11.9 ± 0.8	19.6 ± 2.7	18.4
Average	14.5 ± 3.0	13.0 ± 4.0	20.0 ± 3.4	16.0 ± 3.3

	7/25	8/1	8/7	8/15
1	32.8 ± 0.9	10.7 ± 4.4	22.3 ± 2.9	27.0
2	34.9 ± 5.3	8.8 ± 0.3	19.7 ± 0.4	23.1 ± 6.8
3	*101.6 ± 51.3	9.9 ± 1.9	20.0 ± 2.5	23.9 ± 0.6
4	50.5 ± 6.8	9.8 ± 2.3	18.3 ± 0.7	26.6 ± 1.5
5	38.4 ± 6.9	12.6 ± 3.1	22.2 ± 0.3	27.1 ± 1.8
6	38.8 ± 4.5	18.9 ± 4.8	25.5 ± 0.6	29.9 ± 2.6
Average	39.1 ± 7.8	11.8 ± 4.4	21.5 ± 2.7	26.3 ± 3.8