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Proceedings of the National Shellfisheries Association
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MERCENARIA CULTURE USING STONE AGGREGATE FOR PREDATOR PROTECTION[1]

Michael Castagna and John N. Kraeuter

VIRGINIA INSTITUTE OF MARINE SCIENCE
WACHAPREAGUE, VIRGINIA 23480

ABSTRACT

A low technology method utilizing hatchery-raised seed clams and field grow-out techniques is presented. This technique appears to be economically feasible and can be carried out by non-technical personnel with a minimum of training.

The hatchery uses the Wells-Glancy (centrifuged, incubated seawater) method for raising food for the larval clams. The larvae set in 8 - 10 days and the seed are supplied with flowing seawater until they grow to 2 mm. The 2 mm seed were placed in nursery plots and protected from predation by a layer of gravel or crushed stone aggregate. Movement of the small clams was prevented by a system of baffles which enclosed and dissected the nursery areas. Field survival of a 1975 test group of 600,000 clams approached 75%. Costs of raising the clams for the first year are included.

INTRODUCTION

The hard clam or quahog, *Mercenaria mercenaria* (Linne, 1758), is a commercially important bivalve species along the Atlantic coast of the United States. Larval culture of *Mercenaria* has been carried out in laboratories (Calabrese and Davis, 1966; Chanley, 1961; Chanley and Andrews, 1971; Davis, 1958; Davis and Calabrese, 1964; Loosanoff, 1937, 1954; Loosanoff and Davis, 1950, 1963; Loosanoff, et al, 1951; and Wells, 1924, 1926) and a series of growth rate data for hybrid and natural populations in a number of geographical areas have been summarized by Ansell (1968). Most other work of commercial interest centers on enumeration of local stocks or the examination of habitat variables (Kerswill, 1941; Loesch and Haven, 1973; Pratt, 1953; Pratt and Campbell, 1956).

In spite of this extensive knowledge, no economic culture system for quahogs has been developed. In order to be economically feasible and competitive with wild harvest, mariculture of *M. mercenaria* must be based on simple inexpensive hatchery and culture techniques. In order to grow clams inexpensively, it appears that they must be grown in natural waters for at least part of their lives and harvested when they reach the most desirable size. Control of the seed population during field growth is critical. Predation and loss of small clams that are washed out of the substrate by currents and/or wave action are the most serious problems in field maintenance of clams.

The method described here eliminated or controlled many of these problems. Seed clams as small as 2 mm were successfully reared in prepared beds and predation was controlled to acceptable levels. This simplified method appears to be adaptable to culture of other infaunal species, if appropriate alterations are incorporated for local conditions. We have chosen to explain in detail the equipment and methods utilized because there are no literature sources we are aware of that provide this information.

The methods adopted and described provided a

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[1] Contribution No. 707 from Virginia Institute of Marine Science.

1-6

compromise between cost-effective methods and available technology.

Description of Area

The hatchery and grow-out facilities were located on the eastern side of the Delmarva Peninsula in Wachapreague, Virginia. The nursery area was located in Bradford's Bay about ¼ mile from the hatchery. This small shallow bay was part of a logoon system separated from the Atlantic by a series of barrier islands on the east and the peninsula to the west (Newman and Munsart, 1968). The bay has a muddy substrate fringed with *Spartina alterniflora*-dominated salt marshes and a mean tidal amplitude of 1.2 m. The salinity and temperature of this area ranged from 17-32‰ and 2-28 C respectively. Due to the winds, tide and the shallowness of the bay, it was usually extremely turbid. Ice cover formed over the entire bay for short periods in cold years, and fringing ice was common in January and February.

The nursery area was subtidal except for spring tides when approximately half to two-thirds of the bottom was exposed. At mean low tide it was covered by about 20 cm of water.

EQUIPMENT AND METHODS

Larval rearing facilities

The larval food and larvae culture was housed in a 7.3 × 19.2 × 3.2 m wood-framed solarium covered by corrugated fiberglass panels. The 8 tanks for culturing unicellular algal food were 1.2 × 2.4 × 1.2 m and held about 3000 L. The tanks for growing larvae were 1.2 × 1.2 × 1.2 m and held approximately 950 L. Both types of tanks were constructed of plywood coated with fiberglass and had exterior wood and metal braces. In addition, larvae were also grown in cylindrical tanks referred to as conicals. The conicals held 1000 L and were 1.2 m in diameter and 70 cm tall with a 30 cm deep cone shape bottom. These containers were formed fiberglass and were used interchangeably with the wooden larval containers.

Screens

Assorted screens were used for separating eggs and larvae from seawater, and for sorting larvae and post-set plantigrades into different size groups. These screens were constructed of 25 or 30 cm diameter plexiglass tubing cut to the proper length to act as frames for the various screens. Woven nylon mesh cloth (Nitex) was then glued to the tubing using 1, 2-dichloroethane.

Heat exchanger

A 7.6 m coil of polyethylene tubing 1.2 cm in diameter immersed in a fresh water bath was used to raise water temperature in the spawning trough. The water bath was a 75 liter polyethylene container (trash can) with a 40 amp electric calrod immersed in the water. The temperature of the water in the spawning trough was controlled by diluting the flow of warmed seawater (flowing through the tubing in the water bath) with ambient seawater.

Seawater system

Seawater was pumped from a tidal creek in front of the laboratory. Water temperature ranged from 12.0 C to 28 C during the period of operation, and salinity was similar to that reported for Bradford's Bay.

The pumps were 5 cm cast iron centrifugal single volute pumps driven by a 3 hp electric motor. The intake and all saltwater lines and valves were plastic. Seawater entering the grow-out facility was used without modification. The seawater pumped to the solarium passed through an industrial model (Sharples AS-14 clarifier) continuous flow centrifuge which spun the water at 15,000 RPM in a 15 cm stainless steel tube, exerting a centrifugal force of 13,200 x G.

Centrifuging seawater removed most of the silt and clay particles, larger diatoms and all zooplankton and eggs from 1700 L/hr and only particles and algae with a density about equal to seawater remained. The centrifuged water was piped to 3000 L algal growing tanks, where the water was gently aerated to prevent the algae from settling. This water remained in these tanks while the algae bloomed. At temperatures over 22°C blooms occurred within 24 hours, but at lower temperatures (14 C) 48 hours or longer were necessary. A typical mid-summer bloom would contain *Heteromastix*, *Chaetoceros*, *Nitzschia*, *Chlorella* and others. This culture of mixed wild algal species varied in quantity and composition from season to season, but under most conditions there was more than sufficient food for the developing larvae. The incubated water was used undiluted as the growing media for the eggs through early post larval seed.

Ultraviolet light

To control bacterial infections of larvae, the incubated seawater was flowed through an ultraviolet radiation unit similar to the Kelly-Purdy unit (described by Kelly, 1961) before it was pumped into the larval tanks. The UV unit is 2.8 m long, 90 cm wide, 10 cm deep, and water being sterilized flowed over a series of staggered baffles 1.5 cm high. A reservoir and dam at the intake end of the unit and an overflow reservoir at the discharge end controlled the depth of the water being treated to 5 mm. The unit had 12 40-watt sterilamps 92 cm long spaced equidistant across the unit. Tests indicated the Kelly-Purdy unit reduced the bacterial content of seawater to acceptable densities at a flow rate of 150 L/min (Presnell and Cummins, 1972). Since the maximum flow in our system was 126 L/min, it was assumed that bacterial densities were reduced to acceptable levels. This ultraviolet unit was used only when high mortality rates, high densities of bacterial-feeding protozoans or obvious bacteria swarms were observed in cultures.

Cleaning

All containers used for larvae were washed after each use with mild biodegradable detergent and fresh water, thoroughly rinsed with hot water and allowed to drain dry. Immediately before use they were rinsed with clarified seawater, drained and filled with clarified incubated water.

Larval culture technique

Spawning stocks. Adult clams were collected primarily from wild populations. By utilizing clams from the southern coastal states of Georgia, South Carolina and North Carolina, culture of larvae was started in early March without conditioning. Spawning was accomplished through October by selecting clams from different regions, moving north as the wild clam stocks become ripe. Since clams were easily shipped from place to place, this system eliminated the need, equipment and cost of conditioning. In addition, the faster growing clams from previously grown groups were also used as spawners when they became ripe.

Spawning. Spawning was accomplished in a fiberglass trough 3 m long x 30 cm wide x 13 cm deep. Incubated seawater at about 22-24°C was streamed over 50 to 100 clams for about 30 minutes or until most of the clams had siphons extended. The temperature of the seawater was then increased to as high as 32°C and dropped back to 24 C by draining and adding cooler water at about 30-minute intervals to induce spawning. If these temperatures and depth fluctuations did not induce spawning, a clam was sacrificed, and the gonadal material stripped and added to the trough. This usually induced spawning in a few individuals, and since clams are gregarious spawners, a mass spawning followed. The water containing the sperm and eggs was drained through a 25 μ nylon screen. The sperm water passing through the screen was collected in a container and, if necessary, returned to the spawning trough to further stimulate the clams. The eggs were trapped on the screen. As the screen clogged with eggs, cultured water was used to rinse them into a calibrated 20 L container. When several million eggs were in the container, they were thoroughly mixed by stirring with a plastic plunger and subsampled. The 1 ml subsample was withdrawn by pipette and placed on a 1 ml Sedgwick-Rafter counting cell and the eggs were counted under a microscope.

While the eggs were being counted, the larval growing containers were filled with the clarified incubated seawater. The eggs were distributed into the filled containers at a density of approximately 15-20 eggs/ml.

About 40 hours after fertilization the larval tanks were drained through 35 μ mesh screen which caught the veliger larvae. These were concentrated in 10-15 liters of clarified water and poured through a series of screens ranging from 80 μ to 35 μ mesh. The larvae collected by each screen were placed in separate 20 L calibrated containers, the containers were filled to 10 or 15 liters and subsampled and counted using the same technique described above. The larvae were measured and observed microscopically. If large numbers of abnormal or poorly developing larvae were present in a given screen size, they were usually discarded. After counting, larvae were redistributed in clean larval growth tanks filled with new clarified and incubated water. This procedure was followed on Monday, Wednesday and Friday until the larvae metamorphosed and set.

Setting. Metamorphosis and setting occurred after 8-12 days under normal operating temperatures. During this process the velum degenerates and the plantigrades creep about with a well-developed foot or fasten to the slide with a byssus (Carriker, 1961). Setting was apparent when the larval tanks were drained. The set clams were attached by a byssus to the tank sides and bottom and often required a jet of water to dislodge them. The larvae did not all set at the same time, but the set clams were easily separated from the veliger larvae by pouring the water and swimming veligers from the containers in which they were concentrated into another container. The set clams remained attached to the bottom by their byssus and were then taken to the grow-out facility.

Grow-out facility

Equipment. The grow-out wet tables were 1.2 x 2.4 m and 6 cm deep constructed of wood and coated with fiberglass resin. There was a dam 8 cm high at the head end and a 6 cm dike at the outlet end. The tables were supplied with a continuous flow of unaltered seawater.

The salt water system in the grow-out facility was similar to that in the solarium. It had duplicate intakes, pumps and pipes, which allowed one set to be in use for one week while the other system was allowed to stand without draining. The stagnant water in the pipes becomes anoxic, causing the death of fouling organisms which may have attached in the pipes. After a week this line was flushed out and put into use while the other line was allowed to stagnate.

Grow-out techniques

Grow out of seed The newly settled clams were moved from the larval facility and washed onto the grow-out tables. The flow rate was regulated to about 1 L min when clams were first placed on the table, and later increased to about 10 L/min.

Fouling organisms, especially sea squirts, *Molgula manhattensis*, were a problem on the grow out tables. The *Molgula* larvae entered with the water, set on the tables, and smothered the clams. The *Molgula* were controlled by draining the tables and allowing the clams on the tables to air dry for about 3 hours per day, 5 consecutive days of each week. Any remaining squirts were removed during the two to three week screening when accumulated sediments were removed and the clams sorted by size.

The clams were kept in this system about 6 weeks or until they could be collected on a 2 mm mesh sieve. They were then planted in the field nursery plots.

Field nursery techniques

Equipment. Current baffles were constructed of 1 cm diameter steel rod and 7 × 7 mm mesh plastic screen. The steel rod was made into a rectangular frame 0.6 m high and 1.5 m long with a 0.9 m leg extending down on each side. The plastic screen was fastened to the 0.6 × 1.5 m frame with 3 mm polypropylene line. To install current baffles the legs were pushed into the bottom until the plastic touched the substrate.

A 13 mm mesh plastic net 2 m tall surrounded the clam planting site. This net was supported by 10 × 10 cm poles pushed into the bottom approximately every 3 meters. The net bottom was weighted down by a 6 mm chain fastened to the bottom with 3 mm polypropylene line. This chain was embedded about 10 cm into the soft mud bottom.

Predator protection. A major predator of small clams is the blue crab, *Callinectes sapidus*. Preliminary experiments indicated that crushed rock aggregate provided some protection against this predator. Approximately 75% more small clams survived in aggregate than in control plots. To further reduce crab predation, baited commercial crab traps were also placed in the clam planting area and fished 3 to 5 times per week.

Another group of major predators on juvenile and adult clams are rays of the families Dasyatidae, Myliobatidae and Rhinopteridae. Large schools of these rays may enter an area and destroy the clam populations. The 2 m high net protects the seed clams against these predators and prevents larger blue crabs from entering the plots.

Wash out prevention. The second major problem, when 2 mm seed clams were used, was that they pushed out or were washed out of the bottom by waves and were carried away by tidal currents. Laboratory experiments indicated that clams 3 mm in width could be moved by current velocities as low as 15 cm/sec (0.3 knot current). The baffles prevented the current from moving small clams from the aggregate bed.

Preparation and planting of nursery plot. The nursery area was prepared by first placing a series of current baffles in squares. To conserve baffles, they were placed next to each other to share a common panel between two squares (Fig. 1).

A crushed stone aggregate of 1-3 cm chips was then broadcast into each square to a depth of approximately 4 cm. The aggregate was then leveled with a rake and allowed to stand. After about one week the nursery pens were examined. The pens should contain a thin layer of silt over the gravel or aggregate. If this layer does not appear, the currents across the bottom are too strong and more baffles should be implanted. If the silt becomes too heavy, some baffles should be removed or the small clams will work up into this layer above the protecting aggregate. Once the area had been stabilized, small clams were broadcast over the aggregate at an average density of approximately 31/sq. m.

3100

RESULTS

Hatchery production utilizing this method has yielded sets of 120, 97 and 55 × 10^6 *Mercenaria* in 1975, 1974 and 1973 respectively. Additonal species have been produced concurrently. Estimated hatchery production to field size for *Mercenaria* (again as one of several species) is 15 - 20% of set for each year. These latter estimates could be substantially improved with greater care given to one species.

At the growth rate exhibited by these clams, it was estimated that they would reach the desired little neck size (1" depth) in 22 to 28 months. This estimation later proved to be correct.

The cost for 600,000 clams planted in the field averaged $0.015 per clam. This cost included estimated interest on a loan sufficient to begin a hatchery, labor, utilities and all supplies. The only additional charges would be maintenance of the field plots and harvesting. Maintenance costs for two years should not exceed $0.005 per clam and harvesting cost is estimated to be about $0.002. The curent market value for prime sized little neck clams in this area is about $0.05.

Following the first winter's growth, five samples were taken in each of 41 squares of aggregate (1/2 of the test squares). Average survival was in excess of 75%, and included samples of 5 squares of clams planted at less than 2 mm which were lost.

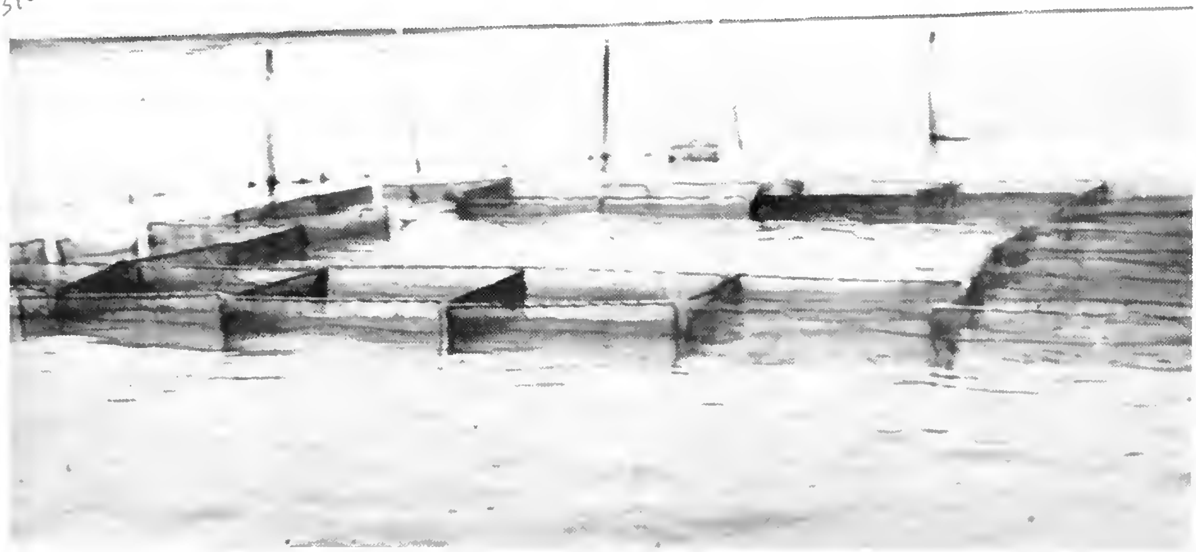

FIG. 1. *View of nursery area showing baffles in foreground and 2 m net in background.*

During the summer some severe predation was observed, but this was controlled by raising the height of the fence so that it was submerged only during spring tides. In addition the number of crab pots inside the fence was increased from 4 to 8. Preliminary calculations indicated that a commercial operation would be economical with 40% survival of the planted clams.

Experiments to reduce the cost of the clams planted in the field are being conducted this summer. These experiments are designed to eliminate unnecessary components and thus reduce costs.

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FOOD CONSUMPTION AND GROWTH OF LARVAE OF THE PACIFIC OYSTER, *CRASSOSTREA GIGAS* (THUNBERG), IN A CONSTANT FLOW REARING SYSTEM[1]

Robert E. Malouf and Wilbur P. Breese

OREGON STATE UNIVERSITY
DEPARTMENT OF FISHERIES AND WILDLIFE
NEWPORT, OREGON 97365

ABSTRACT

This study of food consumption and growth of larvae of the Pacific oyster, Crassostrea gigas, *Thunberg, is intended to provide some of the basic information necessary for the efficient operation of commercial oyster hatcheries. As a part of the study, the caloric content of larvae of various sizes was determined to provide a meaningful measure of mass. The effects of algal concentration* (Monochrysis Lutheri) *and larval density on the growth of larval oysters was measured in a flow-through feeding system. Algal concentration and larval food consumption can be optimized in a flow-through system to provide for maximum larval growth and efficient use of algal food. Removal of algae at the rate of 2,600 algal cells per larva per hour does not result in appreciably better growth than the removal of 1,300 algal cells per larva per hour. A modified flow-through feeding system, applied to a commercial oyster hatchery, could improve utilization of cultured algae, and yield increased larval growth.*

INTRODUCTION

The principal commercial oyster grown in the Pacific Northwest, the Pacific oyster, *Crassostrea gigas*, was originally introduced from Japan. The industry has been dependent for years on seed oysters imported from Japan, supplemented by seed collected at a few locations in Washington and British Columbia. However, the price of imported seed is increasing, and there have been periodic failures of oyster spawning in Northwest waters. The lack of a dependable seed source has depressed the oyster industry.

To provide a reliable source of oyster seed, a number of commercial oyster hatcheries have been built in the Pacific Northwest in recent years. The purpose of this study was to determine some of the basic relationships between algal food density, food consumption, and growth in oyster larvae. A clear understanding of the interactions of these variables is needed for the operation of a successful oyster hatchery. Our secondary objective was to evaluate a technique for continuously feeding oyster larvae as an alternative to batch feeding in hatchery operation.

METHODS

An apparatus was designed to maintain a constant flow of algal cells at a known density through test chambers containing a known number of oyster larvae (Fig. 1). The test chambers consisted of 76 cm sections of 4" diameter PVC pipe which were fitted on one end with 116 micron nylon screen. The screen served to retain the larvae while allowing uneaten algae and feces, to pass

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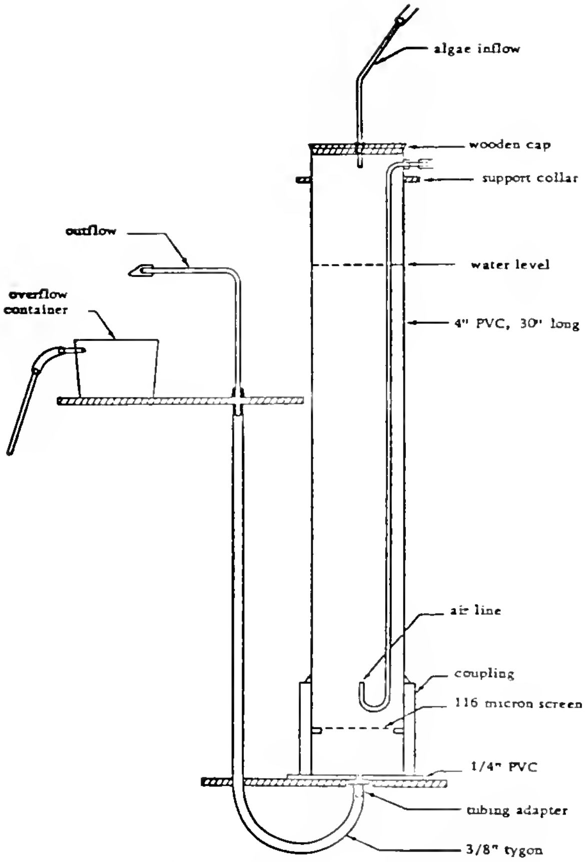

FIG. 1. *Apparatus used for constant flow experiments.*

through. These chambers, filled to a depth of 61 cm, contained five liters of salt water. Forty-five L. carboys fitted with siphons were used to maintain a flow of 14 ml per minute of algae suspension of the appropriate cell density to each test chamber. Only the algal densities and the number and size of the larvae varied. The total volume of water passing through the chambers was kept constant. All experiments were conducted at a temperature of 20 C and at a salinity of 25 ppt.

The density of the algae entering and leaving the test chambers was determined at least once every 24 hours. The difference in algal density between the inflow and the outflow of the test chambers gave a measure of larval food consumption at different algal and larval densities.

Monochrysis lutheri, cultured in five gallon carboys, was used as larval food. This naked flagellate is easily cultured and has been shown to be an excellent food organism for larval bivalves (Walne, 1970). Algal densities in the cultures and in the test chambers were determined using a Coulter Counter model B, following the procedures outlined by Sheldon and Parsons (1967). The algal cultures generally reached a density of about two million cells per ml within seven days. Cultures having densities of two to five million cells per ml were used in all feeding experiments.

In preliminary tests, the Coulter Counter model J plotter was used in conjunction with the counter to make size frequency determinations of cells from stock algal cultures and from test chambers containing larvae. No differences in particle size distribution were evident between the stock cultures and algal populations that had been grazed upon by oyster larvae for several hours in a flowing water system. The similarity of the histograms indicated that counts made on samples taken from the test chambers in which grazing was being measured did not contain a significant amount of cell fragments and detritus that were within the size range of the counter.

The Pacific oyster larvae used in this study came from the pilot oyster hatchery at the Oregon State University Marine Science Center. The adults were spawned artificially (Loosanoff and Davis, 1963). The larvae used in any one experiment were drawn from a single hatchery tank after they had been thoroughly mixed. No attempt was made to control parentage.

Larvae were caught on a stainless steel screen and concentrated in a beaker for counting and measuring at the start of each experiment. It was found that reproducible counts could be obtained by withdrawing 1 ml samples with an automatic pipette while the water in the beaker was being gently agitated by raising and lowering a perforated plexiglass disc in the beaker. Preliminary 1 ml counts gave a rough approximation of the volume of water containing the desired number of larvae for each test chamber. Ten 1 ml subsamples were subsequently withdrawn from the aliquots prepared for each test chamber, and adjustments were made in the number of larvae in each aliquot before they were added to the test chambers.

Counts were also made of the larvae while the experiments were in progress. The larvae were uniformly suspended in each chamber with a plex-

TABLE 1. *The results of dichromate oxidations showing the relationship between larval shell length and the caloric content per larva of Pacific Oyster larvae.*

Length of larvae in microns[a]	96±2	100±2	133±5	189±4	249±7	274±5	306±5
Number of larvae used per sample	7,400	5,360	8,325	16,550	10,280	9,080	4,200
Calories per larva (sample No. 1)	.00033	.00039	.00075	.0019	.00372	.00581	.00655
Calories per larva (sample No. 2)	.00038	.00039	.00077	.0019	.00369	.00578	.00666
Mean caloric content per larva	.00036	.00039	.00076	.0019	.00371	.00579	.00661

[a] Means with 95 percent confidence interval estimate.

iglass plunger before a piece of 11 mm diameter glass tubing was extended down into the chamber to collect larvae from the entire length of the water column. This procedure was repeated three times so that a total of about 200 ml was collected from each chamber and placed in a small beaker. Ten subsamples were then withdrawn from the beakers using the method described above. These larvae were killed with AFA, counted, and measured with the use of an ocular micrometer. The remainder of the 200 ml sample was returned to the test chamber.

Biomass Determination. The growth of larvae is most easily observed from increases in the average shell length. These measurements were made on larvae which were sampled for periodic determination of larval density in the test chambers. Shell length does not adequately reflect the animal's mass. It is difficult to compare the realtive biomasses of populations consisting of larvae of different sizes where shell length is the only criterion used. To overcome this problem, a relationship was established between shell length and total biomass in terms of organic content.

The method used is a modification of the dichromate chemical oxygen demand determination described in the 10th edition of *Standard Methods for the Examination of Water, Sewage, and Industrial Wastes* (American Public Health Association, 1955). A known excess of oxidant (potassium dichromate) was added to a sample of a known number of larvae in distilled water. After oxidation was completed, the amount of oxidant remaining was determined by titration. The amount of reacting oxygen was calculated from the difference between the initial and the final quantity of oxidant. These values were then multiplied by an oxycalorific coefficient of 3.42 caloreis per mg O_2 to obtain an estimate of the caloric content of the sample (Maciolek, 1962).

Determinations of the caloric content of seven batches of Pacific oyster larvae are given in Table 1 and are shown graphically in Figure 2. Larval length in microns when plotted against the caloric content per larva on a semi log scale (Fig. 2) yields

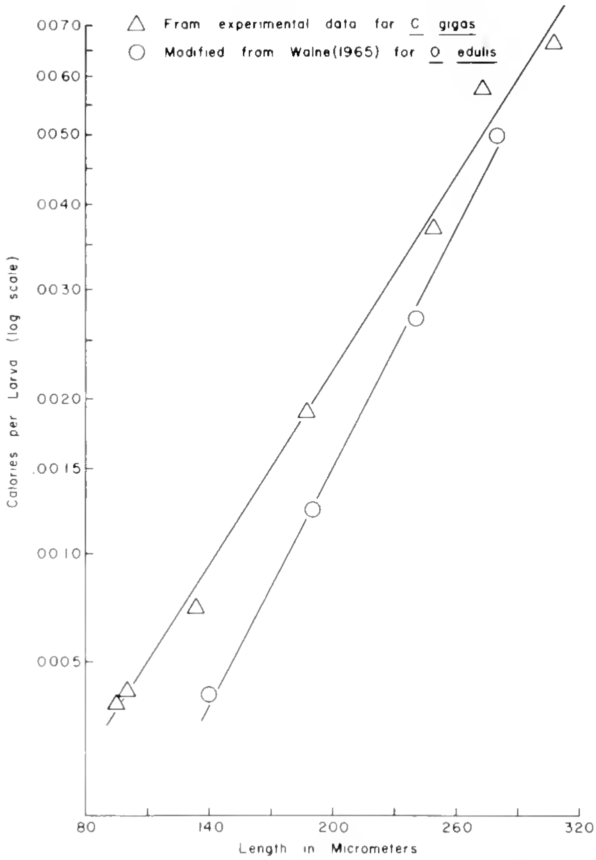

FIG. 2. *The relationship between shell length and caloric content of Pacific and European oyster larvae.*

a straight line. This shows that there is an exponential increase in the caloric content of Pacific oyster larvae with increases in shell length. Walne (1965) found a similar relationship between the shell length of European oysters and their total dry weight. He also found that the shell of an oyster larva comprises a constant 75 per cent of its total dry weight. Miller and Scott (1967) confirmed that the shell of European oyster larvae makes up about 75 per cent of the total dry weight.

Walne's (1965) data for the total dry weight of European oyster larvae were multiplied by .25 to obtain an approximation of the organic matter per larva and then by 5,000 calories per gram to estimate the caloric content of the animal tissue (Davis and Warren, 1968; Maciolek, 1962). these values are compared with data obtained experimentally in the present study in Figure 2.

Three experiments with the constant flow apparatus provided information on the relationships between larval growth and food consumption and algal density in a flowing system. The experiments will be described individually.

Growth rates were determined from periodic measurements of shell length for a sample of larvae. The mean length was converted to caloric content by use of the experimentally determined curve in Figure 2.

Instantaneous growth coefficients, K, were calculated for each test group from the formula:

$$K = \frac{\log_e C_2 + \log_e C_1}{t} \times 1{,}000$$

Where: C_1 = The initial caloric content per larva
C_2 = the final caloric content per larva
t = the time in days

The use of the instantaneous growth coefficient, K, facilitates comparison of larval growth obtained in a number of experiments of differing duration and using larvae of different initial and final size. This equation was applied to mussel larvae by Bayne (1965) and to oyster larvae by Walne (1963), based on changes in shell length.

These experiments were intended to describe general relationships between larval density and algal inflow density as reflected by the growth of

TABLE 2. *Stocking rate, mortality, final mean length, and instantaneous growth coefficient of Pacific oyster larvae fed at four different algal densities (Experiment 1). Initial larval length was 189 microns.*

Chamber number	Initial number of larvae/ml.	Percent mortality	Length of larvae (microns) Final mean value	Standard error	Mean algal inflow density	Mean algal outflow density	Instantaneous growth rate (K)
1	1	43	268	5.18	6,474	4,350	82.1
2	2	21	263	3.79	6,783	2,751	75.0
3	4	16	222	3.90	6,845	2,192	37.6
4	8	18	195	4.45	6,714	1,641	3.3
5	1	97	——	——	11,762	10,738	——
6	2	53	237	5.77	11,812	9,760	50.5
7	4	94	——	——	11,704	10,302	——
8	8	30	208	3.50	11,747	2,026	22.2
9	1	49	309	4.33	21,318	13,869	118.9
10	2	23	303	6.51	22,077	11,359	114.9
11	4	100	——	——	22,079	17,782	——
12	8	39	240	5.09	21,834	3,338	76.6
13	1	38	254	5.45	40,482	33,097	26.8
14	2	18	283	6.03	41,388	25,868	36.4
15	4	95	——	——	41,630	26,098	——
16	8	40	276	4.66	42,286	11,834	34.4

larvae. Because of inherent differences among broods of larvae and procedural differences among the experiments, growth data from the three experiments were analyzed separately. The procedures did not involve replication of individual experiments, so a valid error term for testing differences in responses was not available.

Experimental Design. In Experiment 1, four algal inflow densities (5,000, 10,000, 20,000 and 40,000 cells per ml) were given in all possible combinations to larval cultures with one, two, four, and eight larvae per ml.

In Experiment 2, four algal inflow densities (10,000, 20,000, 40,000, and 80,000 cells per ml) were given in all possible combinations to larval cultures with two and sixteen larvae per ml.

In the final experiment, Experiment 3, algal inflow densities were increased to 20,000, 40,000, 80,000, and 160,000 cells per ml and were fed in all possible combinations to larval cultures with two and sixteen larvae per ml.

RESULTS

Larval Growth

Experiment 1. Mortality exceeded 50 per cent in five test chambers (Table 2). Because of unpredicted high mortality in the five chambers, an analysis of variance was not carried out. Instead, 95 per cent confidence intervals of the mean sizes of the larvae at the end of the experiment were calculated. From these data it is possible to make some general conclusions concerning the effects of algal inflow density and larval density on larval growth in this system.

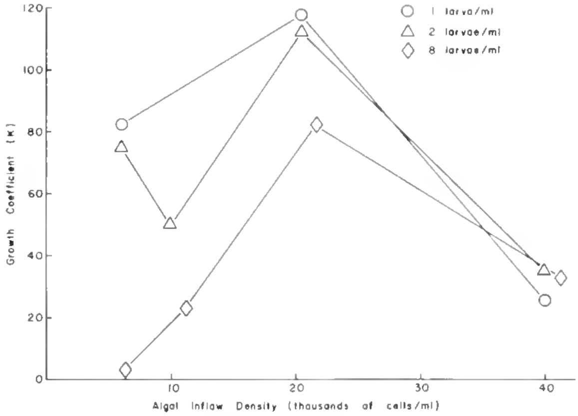

FIG. 3. *General relationship between algal inflow density and larval growth rate at four larval densities (Experiment 1).*

Larval growth rate increased with increasing algal density up to 20,000 cells per ml, but declined at an algal inflow density of 40,000 cells per ml (Fig. 3). Maximum growth rates in Experiment 1 were achieved at a mean algal outflow density of 11,000 to 14,000 cells per ml (Table 3). These algal outflow densities resulted when an inflow density of 20,000 cells per ml was passed through test chambers initially stocked with one or two larvae per ml (chambers 9 and 10).

TABLE 3. *Stocking rate, mortality, final mean length and instantaneous growth coefficient of Pacific oyster larvae fed at two different algal inflow densities (Experiment 2). Initial larval length was 193 microns.*

			Length of larvae (microns)				
Chamber number	Initial number of larvae/ml.	Percent mortality	Final mean value	Standard error	Mean algal inflow density	Mean algal outflow density	Growth rate (K)
1	2	0	242	3.04	10,927	3,389	83.7
2	16	9	199	2.23	10,943	1,237	9.4
3	2	0	272	3.15	20,923	6,397	131.7
4	16	12	202	2.03	20,770	2,143	18.2
5	2	100	——	——	——	——	——
6	16	100	——	——	——	——	——
7	2	6	296	2.34	79,477	49,588	153.4
8	16	17	247	2.72	77,997	3,500	88.2

Two fold increases in larval density had a marked effect on larval growth rates at an algal inflow density of 5,000 cells per ml (Table 3). At an algal inflow density of 40,000 cells per ml, larval density had no effect on larval growth rates.

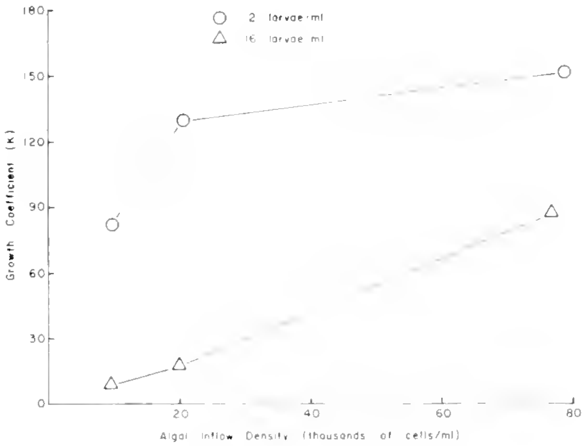

FIG. 4. *Relationship between algal inflow density and larval growth rate for two larval densities (Experiment 2).*

Experiment 2. Larval mortality rates in chambers receiving 40,000 cells per ml (chambers 5 and 6) were high early in the experiment and approached 100 per cent at the conclusion of the study. A flow of algae was maintained through both chambers 5 and 6 for the duration of the experiment despite the heavy mortality. This was done to measure the effects on algal density of a large population of an unidentified ciliate that developed in the chambers as the larval population declined. It was found that the densities of algae in the inflow and outflow of these chambers were not significantly different. As in Experiment 1, no cause was determined for the extreme mortality in the two chambers.

It is apparent that the growth rate of the larvae was directly related to the density of algae in both the inflow and the outflow in Experiment 2 (Table 3). In all cases higher algal inflow densities resulted in higher growth rates in this experiment (Fig. 4). Maximum growth rate was achieved at an algal inflow density of 80,000 cells per ml through a test chamber containing two larvae per ml (chamber 7).

The results of Experiment 2 differed in several respects from those of Experiment 1. There was no indication of reduced larval growth at algal densities above 20,000 cells per ml (Figure 4). Growth rates of larvae at a density of 2 per ml appeared to level off above an algal inflow density of 20,000 cells per ml. However, the growth rates of larvae kept at a density of 16 per ml continued to increase at algal densities in excess of 20,000 cells per ml.

Experiment 3. Larval mortalities were high in only one test chamber during this experiment. Although the mortality in this chamber exceeded 50 per cent, most of this mortality occurred during the last two days of the experiment. Careful examination of dead and dying larvae revealed what appeared to be fungus infection. Stained with neutral red, the fungus was very similar in appearance to one described and tentatively identified as *Sirolpidium sp.* by Davis and Loosanoff (1954) and Vishniac (1955). Although it appeared that the fungus attacked still living larvae, We cannot be certain that the fungus was the cause of the recorded mortalities.

The data from Experiment 3 (Table 4 and Fig. 5) indicate that larval growth rate increased in algal inflow density for those chambers having a larval density of 16 per ml. However, increases in algal inflow density did not result in higher larval growth rates in those test chambers that had an initial larval density of two per ml. In fact, as Figure 5 shows, larval growth rate declined as algal inflow density exceeded 40,000 cells per ml in those chambers containing two larvae per ml.

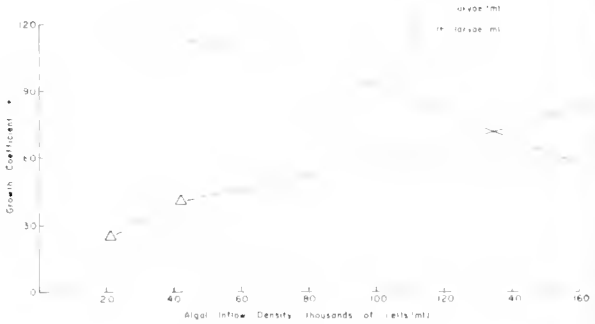

FIG. 5. *Relationship between algal inflow density and larval growth rate for two larval densities (Experiment 3).*

TABLE 4. *Stocking rate, mortality, final mean length, and instantaneous growth coefficient of Pacific oyster larvae fed at four different algal inflow densities (Experiment 3). Initial larval length was 199 microns.*

			Length of larvae (microns)				
Chamber number	Initial number of larvae/ml.	Percent mortality	Final mean value	Standard error of the mean	Mean algal inflow density (cells/ml.)	Mean algal outflow density (cells/ml.)	Growth rate (K)
1	2	29	267	4.99	20,749	8,193	107.5
2	16	11	215	2.85	21,008	1,514	25.8
3	2	25	285	3.63	40,916	21,453	113.4
4	16	8	223	3.82	41,472	2,458	39.2
5	2	24	265	4.05	80,402	58,906	104.4
6	16	58	233	5.01	80,716	14,951	53.6
7	2	29	233	4.39	164,353	138,897	56.6
8	16	14	249	4.60	166,582	28,051	82.3

Chambers 1 and 8 are of particular interest in this experiment. Chamber 1 contained 10,000 larvae and were fed at an algal inflow density of 20,000 cells per ml. Chamber 8 contained 80,000 larvae that were fed at 160,000 cells per ml. Although chambers 2 and 8 were fed the same amount of food per larva, the larvae in chamber 1 showed significantly better growth than those in chamber 8.

The results from Experiment 3 were similar to those obtained in Experiment 2 at similar algal densities. However, it appears that the maximum larval growth rate at a density of 16 larvae per ml may occur at an algal density of 160,000 cells per ml or higher.

DISCUSSION

There are a number of possible explanations for the growth differences among the three experiments. The relatively low maximum growth rate and rapid decline in growth at higher algal densities during Experiment 1 may have been due, in part, to the procedures employed in that experiment. Larvae used in experiment 1 were subjected to slightly cooler temperatures than were those used in Experiments 2 and 3. The profound effect of temperature on larval growth has been shown by a number of workers including Bayne (1965), Davis and Calabrese (1964), Loosanoff and Davis 1963, and Walne (1956, 1965). Results of these studies showed that larval growth rates increased rapidly with increasing temperature.

In part, the growth differences could have been due to genetic differences among larvae produced by different parents. In studies of *C. gigas*, Lannan (1973) found a statistically significant genetic component of the variance of larval growth and survival through metamorphosis. Our experience with larval growth in hatchery tanks suggests that progeny from different parental crosses produce widely different growth rates among batches of larvae that are treated similarly.

Since the experiments were not conducted concurrently, differences in the quality of the algal cultures among the three experiments are possible and may have affected larval growth. Taub and Dollar (1965) reported that the chemical composition of the alga *Chlorella* varied significantly as light intensity and culture medium were varied. It is possible that the composition and therefore the food value of *M. lutheri* varied in the present experiment.

Despite the existence of variation in larval growth among the three experiments, there are certain features that are common to all three growth curves. Growth rates of the larvae increased as the mean algal inflow density was increased to 20,000 cells per ml in all three experiments. Subsequent increases in algal density yielded less significant increases in larval growth rates. these results indicate that at larval densities of eight per ml or less there was little or no advantage to an algal inflow density of more than 20,000 cells per ml.

The reduction of larval growth rates at high algal densities shown in Figures 4 and 6 is similar to results reported by other workers. Loosanoff *et al.* (1953) reported that the growth of clam larvae was retarded by over-feeding. They also found that larvae of the mussel, *Mytilus edulis*, grew best at intermediate algal densities, and that any increase beyond the optimum caused a reduction in growth rates for the larvae of the Eastern oyster, *Crassostrea virginica*. They concluded that at high algal densities the larvae were adversely affected by metabolic products of the algae. Walne (1966) reported similar results in his experiments with batch feeding of *Isochrysis galbana* to the larvae of the European oyster. He concluded that there was no advantage to batch feeding at a concentration of 120,000 cells per ml compared to 30,000 cells per ml under the conditions of his experiments.

Our observations indicate that another important cause of reduced growth at high algal densities is the excessive formation of pseudofeces. Yonge (1926) described the pseudofeces of oyster larvae as long strings of mucus with algal cells embedded singly and in clumps along the length of the mucus string. These strings trail behind and often entangle and trap a swimming larva.

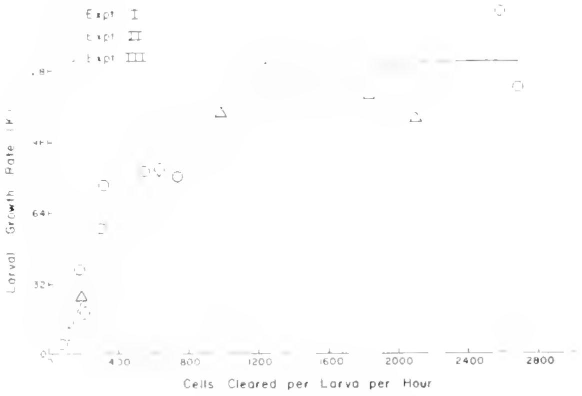

FIG. 6. *The relationship between the rate of clearance by oyster larvae of suspended algal cells and the resultant growth rate of the larvae. Data from three experiments plotted by inspection.*

A normally-feeding larva produces a continuous flow of mucus in which food particles are trapped and are carried to the mouth to be ingested (Yonge, 1926). Normally, the bulk of the mucus that is produced is reingested. A larva that is producing excessive pseudofeces is not only removing its food supply from suspension and making it unavailable for consumption, but is producing and losing large amounts of mucus.

The consequences of this type of superflouous feeding is shown in Figure 6, which relates the apparent food consumption rate of larvae and their resultant growth rate for all three experiments. The data are from all test chambers in the three experiments which showed less than a 50% mortality during the growth period, received between 5,000 and 80,000 cells per ml in the inflow water, and had initial larval densities of from one to sixteen larvae per ml. Food consumption data, expressed as the number of cells cleared per larva per hour, are based upon mean values determined throughout the growth period. as previously described, the larvae were about 200 μ long at the beginning of the growth period, and all three experiments were terminated as soon as any setting occurred in any chamber. Obviously, the absolute value of growth and food consumption obtained under different conditions and for different growth periods would vary, but the general relationship would very likely resemble Figure 6.

The removal, by larvae, of 2,600 algal cells per hour did not result in appreciably greater growth than did the removal of 1,300 algal cells per hour. These results suggest that many of the cells that were removed by the larvae at the higher feeding rates were not ingested and assimilated but were ingested and incompletely assimilated or were simply cleared and rejected as pseudofeces.

Millar (1955) described the mechanisms of food movement in the gut of larvae of the European oyster. He described a muscular pulsation of the digestive diverticulua, the site of absorption, that withdrew partially digested food materials from the stomach. He concluded that it was entirely a matter of chance whether food particles drawn off into the midgut and into the rectum had been in the stomach and diverticula for a long or short time, and therefore to what extent they had been digested and assimilated. It appears then that a larva exposed to a very high concentration of algae could ingest algal cells and pass them through its system without gaining any nutritional benefit from them. This would further reduce the rate of growth relative to the number of algal cells consumed.

This study has shown that a constant flow system for feeding larvae can be regulated to maintain some algal density that is most favorable for larval growth. If such a system could be adapted to a hatchery operation it would provide maximum return in terms of larval growth from algae used in feeding.

The commonly used technique of batch feeding larvae is subject to a number of disadvantages. In order to supply larvae in one feeding with enough food to last them 24 or 48 hours, it is necessary to raise the algal density to a high level. As has been shown the larvae feed actively at this initially high algal density, but an undetermined amount of their food supply is tied up as pseudofeces or otherwise utilized ineffeciently. Then, as the algal density declines with time, the larvae become less able to obtain food. As a consequence of batch feeding, larvae are overfed part of the time and essentially starved the rest of the time.

Since the conditions of the constant flow system differed in a number of ways from those commonly employed in hatchery operations it is difficult to compare growth rates with those typically recorded in a hatchery. These experiments were conducted at 20 C to enhance survival of the algae in the test chambers. Additionally, the experiments utilized only one species of algae for the sake of simplicity. Improved growth can be obtained by using a mixture of algal species (Davis and Guillard, 1958). In spite of these disadvantages, growth rates obtained from the experimental systems were found to be only slightly lower than those commonly experienced in the hatchery.

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ECONOMIC ANALYSIS OF PRODUCING PACIFIC OYSTER SEED IN HATCHERIES

Kwang H. Im and Don Langmo

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
OREGON STATE UNIVERSITY
CORVALLIS, OREGON

ABSTRACT

Total costs and average costs for the hatchery production of Pacific oyster (Crassostrea gigas) *seed were determined for 5 levels of output, ranging from 6,000 to 14,000 cases per year. Costs, returns, and economies of size for each model plant were further established for 5 different options (methods) of cultch preparation. Within the limits of the study, it was found that hatchery production of Pacific oyster seed in the Pacific Northwest is economically feasible, and as the plant capacity increased, the net returns increased.*

Among the 5 options of cultch preparation, Option 1, which pumps salt water with city power for the cleaning operation, is the most favorable; Option 2, which pumps salt water with own generated power, is the next most favorable; and Option 5, which buys already-cleaned cultch from a local dealer, is the least favorable in terms of production cost.

INTRODUCTION

Commercial oyster hatcheries in the Pacific Northwest have operating conditions — economic, location, technical, and biological — all of which, in one way or another, affect the cost of production.

In the past, most of the Pacific oyster seed has been imported from Japan at high cost, and often with an extremely low survival rate. Oyster growers could not depend entirely on imported oyster seed, mainly because of high cost and uncertainty of seed supply.

The importance of oysters can be seen readily if one considers that, in terms of ex-vessel value, oysters (all species taken together) rank seventh among seafoods landed in the United States. Table 1 shows the value of U.S. major seafood species in 1975. Even though the use of oysters is relatively important in the American diet, the supply of domestic hatchery seed for oyster propagation is not sufficient to meet the demand at current market prices. Figure 1 shows the historical trend of U.S. oyster supply for the last two and one-half decades.

As shown in Figure 1, oyster imports (mostly canned) have increased significantly, while domestic landings have decreased substantially, primarily due to high domestic production costs, pollution of oyster beds, and foreign competition. The quantity of domestic landings has decreased by 23.7, 30.4, 31.8, and 32.4 percent in 1960, 1965, 1970, and 1975, respectively, compared with a base period of 1950-54. Conversely, for the same years the quantity of oyster imports has increased tremendously by 821, 1,032, 1,874, and 1,532 percent, respectively, compared with the same base period. Nevertheless, in these same years the total supply of oysters for U.S. consumption has decreased by 15.6, 20.3, 13.6, and 17.4 percent.

Population growth and oyster supply, in terms of domestic landings plus imports, are expressed

TABLE 1. *Ex-Vessel Value of U.S. Seafood Species, 1975*

Species	Value
	million dollars
Shrimp	226
Salmon	116
Tuna	108
Crab	84
Lobster	59
Menhaden	49
OYSTERS	43
Clams	41
All others	245

SOURCE: U.S. Department of Commerce, *Fishery Statistics of the United States*, 1975.

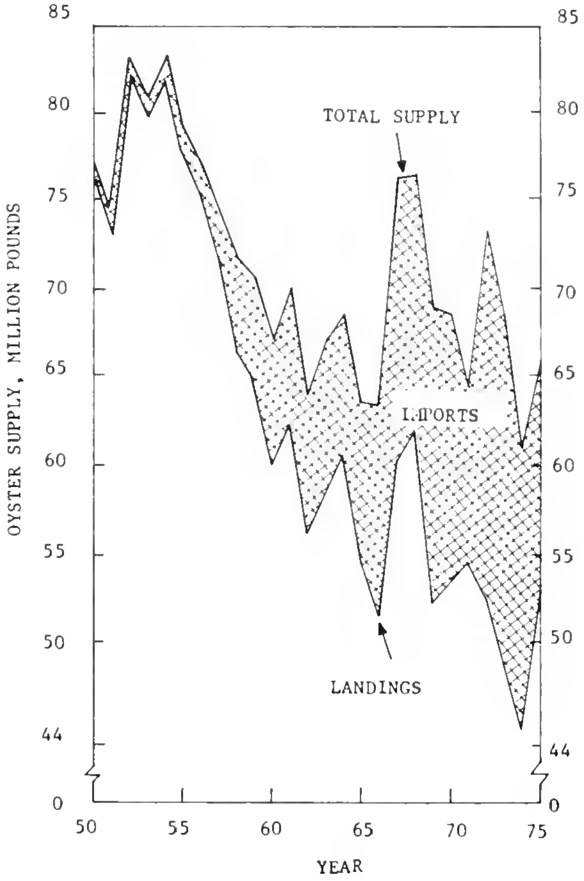

FIG. 1. *U.S. Oyster supply.*

SOURCE: U.S. Department of Commerce, Fishery Statistics of the United States, various issues.

as oyster consumption per capita in Figure 2. Oyster consumption per capita in 1950 was .51 pounds, but in 1975 it was only .31 pounds. Notably, oyster supply has not kept up with population growth.

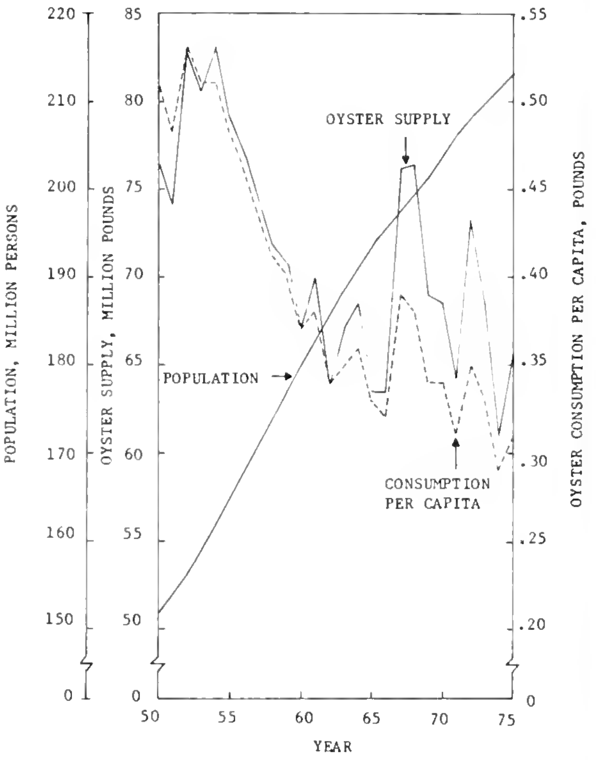

FIG. 2. *U.S. population, oyster supply, and oyster consumption per capita.*

SOURCE: U.S. Department of Commerce, Statistical Abstract of the United States, and Fishery Statistics of the United States, various issues.

METHODS

This study was initiated to provide expected cost and return data for hatchery-produced Pacific oyster seed and to investigate short-run and long-run cost-volume relationships. Factors that affect the cost of oyster *(Crassostrea gigas)* seed production were established for hypothetical plants with different capacities of output and with different methods of cultch preparation. Five different capacities were selected on the basis of conditions considered to be practical to commercial hatcheries under current technological capabilities. Data analyzed were adapted from existing commercial facilities.

Production techniques and operational methods differ by hatcheries. In general, commercial hatcheries operate nine months per year, and during the winter months the operators are laid off. However, in this study it was assumed that all employees (one manager, one supervisor, two operators, and one half-time bookkeeper), except for those involved in cultch preparation, work on a full-time basis all year round. They produce 15 batches per year, one batch in February, one and one-half batches each in March and April, two batches in each month from May through September, and only one batch during the winter period (October through January). During the winter months most labor is devoted to repairing and maintaining the facilities and equipment. Even though the business flow may not be sufficient at all times, especially during the winter months, to keep these operators working at capacity, it is necessary to employ them full-time in order to have these highly skilled operators available when they are needed.

Because of the variable production by seasons of the year, the cost analysis has been developed both month-by-month and on an annual basis. This provides a cost-and-income relationship by month as well as by year.

The basic model, Plant I, was synthesized to provide general information on building and equipment costs, labor inputs, and other costs incurred in producing oyster seed. Based on production costs for Plant I, which has a production capacity of 6,000 cases per year, costs for four other model plants, Plants II to V, were projected. Table 2 shows the capacities of the model plants, and Figure 3 shows the variation in projected oyster seed production by month and by plant.

Construction costs of a new hatchery building, based on interviews with several contractors in Oregon and Washington, were estimated, at current prices, to be $25 per square foot, including wiring and piping. Total costs were developed by an economic-engineering approach,[1] and analyzed for both short- and long-run conditions. In this study, "short-run" refers to the situation in which the plant's building and equipment are assumed to be invariant with respect to output, while the long-run situation permits changes in building and equipment levels with different output rates.

Cultch is the material (usually oyster shell) to which oyster seed attach themselves shortly after hatching. This material, which usually is automatically cleaned in the natural environment, must be cleaned by other means for use in a hatchery. Five different methods of cultch preparation were used in estimating costs and returns. Selection of an option will be governed by the utility services available at the hatchery site. The descriptions of the options are:

Option 1: Pump salt water with city power.
Option 2: Pump salt water with own generated power.
Option 3: Use city water and power.
Option 4: Use city water with own generated power.
Option 5: Buy already-cleaned cultch from a local dealer.

TABLE 2. *Capacities of Model Plants (15 Batches/Year)*

Plant	Number of cases[a] per year	Number of cases per batch
I	6,000	400
II	8,000	534
III	10,000	666
IV	12,000	800
V	14,000	934

[a]One case is equivalent to 2½ bushels, and will contain approximately 1,000 to 1,500 pieces of oyster shell, broken and unbroken with an average spat count of 20 spat per shell

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[1] The explanation of the economic-engineering approach which is given by Madden is that:

> In the economic-engineering or synthetic-firm approach, budgets are developed for hypothetical firms, using the best available estimates of the technical coefficients — resource requirements and expected yields — and charging market prices or opportunity costs for all resources. Hypothetical firms are developed in much the same way that an architect or engineer bidding for a construction contract designs a proposed factory or bridge, and estimates the performance and cost of the finished product.
>
> Economic-engineering or synthetic-firm analysis is an appropriate technique when either of two research questions is asked: (1) What is the average cost per unit of output or profit that firms of various sizes could potentially achieve using modern or advanced technologies, or (2) what are the differences in average cost per unit of output attributable strictly to the differences in size of firm.

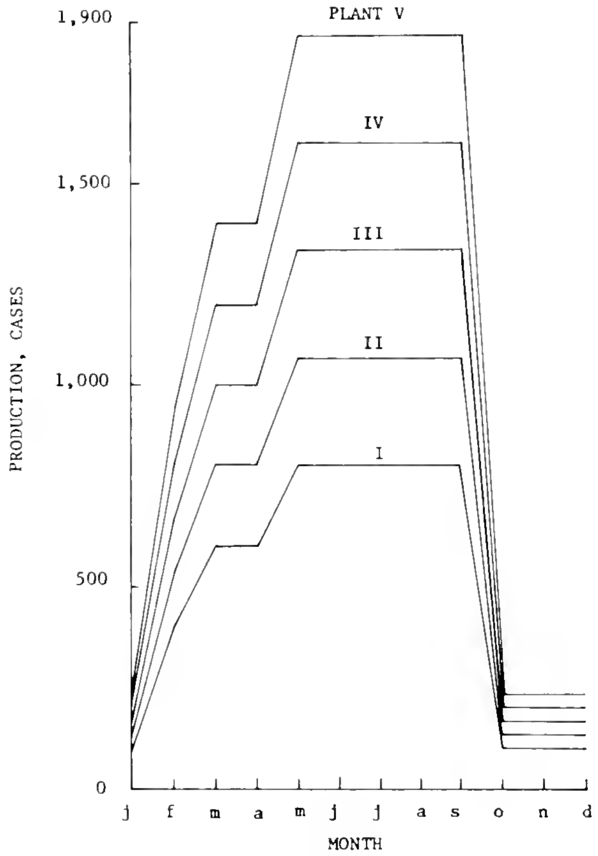

FIG. 3. *Production cycle, by plant.*

Oyster seed production is dependent on six main stages of operation: (1) conditioning adult oysters for spawning; (2) spawning; (3) algal food production; (4) larval rearing; (5) larval setting; and (6) cultch preparation. The only situation in which an operating stage occurs outside of the hatchery is the case in which precleaned cultch is purchased from a supplier. The current price of precleaned cultch is $4.50 per case F.O.B.

Initial investment costs consist mainly of land, building, and equipment. Cost of initial investment in land is highly variable in relation to location and site, and was omitted in this study. This is not a major item affecting the cost of production, and it is also non- depreciable. Initial investment costs for the oyster hatchery building were estimated on the basis of area requirements at $25 per square foot. Initial investment costs for equipment were estimated on the basis of process requirements for each plant and option.

Fixed costs are the costs that are not a function of the level of output, but are incurred regardless of output level. Costs considered in this study as being fixed include depreciation, interest on investment, insurance and taxes, repair and maintenance charges for building and equipment, and supervision, administrative, and full-time labor costs. Travel expenses for the manager and other personnel are considered to be fixed.

In estimating fixed costs, the following procedures and values were used.

Depreciation was calculated using the straight-line method, assuming no salvage value, on the basis of 10 years life for equipment and 30 years for the building. Interest on investment was calculated at 12 percent of undepreciated balance on building and equipment, i.e., 6.6 percent on equipment and 6.2 percent on building, according to the following formula:

$$\text{Average interest} = \frac{i}{2}\left(\frac{n+1}{n}\right)$$

where i = interest rate estimated as 12 percent, and
n = number of useful years

Insurance and taxes were equal to 1 percent and 1.6 percent, respectively, of the total initial investment costs. Repair and maintenance charges were allocated as 1.5 percent of the total initial investment costs for building and equipment. Four and one-half employees, allocated to supervision, administrative, and full-time labor were considered to be fixed labor for plants I through V. The total estimated wages and salaries, including fringe benefits, were $50,815.

Variable costs used in this study include such items as wages of part-time labor, costs of utilities, materials, and supplies, and other expenses directly related to oyster seed production. With the designed model and technology, 4 part-time workers are required to clean 200 cases of oyster shell per day. The labor requirements vary month by month with the plants and options chosen. Also, 2 additional part-time workers, 4 days per week for 5 months (May through September), are necessary for plants IV and V to support full-time workers. Wage rates for these workers, including fringe benefits, were estimated at $3.64 per hour.

In addition to having fixed costs associated with repair and maintenance, some machinery requires maintenance which varies with length of usage.

Some machinery is used for 24 hours per day, regardless of output level, and some is used depending on weather conditions. Costs for variable repair and maintenance for machinery were estimated at 0.5 percent of the initial investment costs for that machinery per 100 hours of operation. Some charge for items such as electrical demand, water and sewer, garbage, and telephone, are semi-fixed on a monthly basis, regardless of output level. Costs of packaging, advertising, and transportation were not included in the average and the total cost figures.

RESULTS AND DISCUSSION

Initial Investment Costs. The estimated initial investment costs for building and equipment are presented in Table 3. In each plant the equipment costs of Option 5 are the lowest among all options because, under this option, no equipment is needed for cultch preparation. In comparing Plants I and V, there is about a 40 to 54 percent increase in equipment investment costs, varying with cultch preparation options. In turn, Plant V has 133 percent greater output capacity than Plant I. The respective total initial investment costs for building and equipment varied from $184,572 to $199,872 for Plant I, and from $286,170 to $301,470 for Plant V. Initial investment costs for building alone accounted for up to 72 to 78 percent of the total.

Total Costs. Total costs and costs per case for Plants I through V are presented in Table 4. These costs, including both fixed and variable costs, are expressed as annual costs. Total costs vary with options, months of the year, and size of plant. In Options 1 to 4 for the five different plants, the proportion of fixed costs to total costs falls between the range of 61 and 76 percent, but in Option 5 for those plants, the proportion drops to the range of 52 to 67 percent. This is because, under Option 5, cultch preparation costs are more subject to variation with output levels than is the case under the other options.

Plant I's average costs vary between $18 and $20 per case, depending upon the option chosen, and Plant V operates between $11 and $13 per case. Since the current market price of hatchery seed is about $23 per case, the difference between market price and average costs in each option and plant would be the net returns per case for that particular option and plant.

Monthly and cumulative seed production, and total receipts and costs for Plant I, appear in

TABLE 3. *Total Initial Investment Costs for Building and Equipment for Each Option and Plant*

Item	Plant number I	II	III	IV	V
	cases				
Output capacity per year	6,000	8,000	10,000	12,000	14,000
	dollars				
Building	144,250	166,675	184,425	203,700	223,875
Equipment:					
Option 1	51,622	57,948	62,806	67,755	73,595
Option 2	55,622	61,948	66,806	71,755	77,595
Option 3	50,322	56,648	61,506	66,455	72,295
Option 4	54,322	60,648	65,506	70,455	76,295
Option 5	40,322	46,648	51,506	56,455	62,295
Total building & equipment:					
Option 1	195,872	224,623	247,231	271,455	297,470
Option 2	199,872	228,623	251,231	275,455	301,470
Option 3	194,572	223,323	245,931	270,155	296,170
Option 4	198,572	227,323	249,931	274,155	300,170
Option 5	184,572	213,323	235,931	260,155	286,170

TABLE 4. *Total Costs and Average Costs Per Case for Each Option and Plant*

	Plant number				
Item	I	II	III	IV	V
	cases				
Output capacity per year	6,000	8,000	10,000	12,000	14,000
	dollars				
Option 1:					
Fixed costs	82,119	86,478	89,897	93,543	97,495
Variable costs	26,364	32,601	38,845	50,529	56,768
Total costs	108,483	119,079	128,742	144,072	154,263
Average costs	18.08	14.88	12.87	12.01	11.01
Option 2:					
Fixed costs	82,947	87,306	90,725	94,371	98,323
Variable costs	26,286	32,639	38,998	50,797	57,153
Total costs	109,233	119,945	129,723	145,168	155,476
Average costs	18.20	14.99	12.97	12.09	11.10
Option 3:					
Fixed costs	81,850	86,209	89,628	93,273	97,226
Variable costs	29,760	36,974	44,005	56,405	63,345
Total costs	111,610	123,183	133,633	149,678	160,571
Average costs	18.60	15.40	13.36	12.47	11.47
Option 4:					
Fixed costs	82,678	87,037	90,456	94,101	98,054
Variable costs	30,070	37,414	44,574	57,102	64,173
Total costs	112,748	124,451	135,030	151,203	162,227
Average costs	18.79	15.56	13.50	12.60	11.58
Option 5:					
Fixed costs	79,780	84,139	87,558	91,203	95,156
Variable costs	39,687	50,507	61,334	77,595	88,415
Total costs	119,467	134,646	148,892	168,798	183,571
Average costs	19.91	16.83	14.89	14.07	13.12

Figure 4. This figure reveals the distribution of total receipts, total costs, and total returns which would be generated through the year for Plant I. The vertical distance between total receipts and total costs represents cumulated net returns. Cumulative total costs of Option 5 are the highest, and those of Option 1 are the lowest. Cumulative total costs of all other options, Options 2 through 4, fall within this range.

Average Costs Per Case. Average costs are estimated by taking total costs and dividing by cases produced. Average costs vary with options, size of plant, and months of the year. During the winter months (October through January), average costs per case for Plant I and Plant V are around $80 and $43, respectively. During the summer months (May through September), depending on the option, these costs for Plant I varied between $12 and $14, and for Plant V they varied between $8 and $10. These are the extreme cases — the highest and the lowest costs — through the year. But annual average costs for Plant I ranged from $18 to $20, and those costs for Plant V ranged from $11 to $13. Figure 5 shows these relationships.

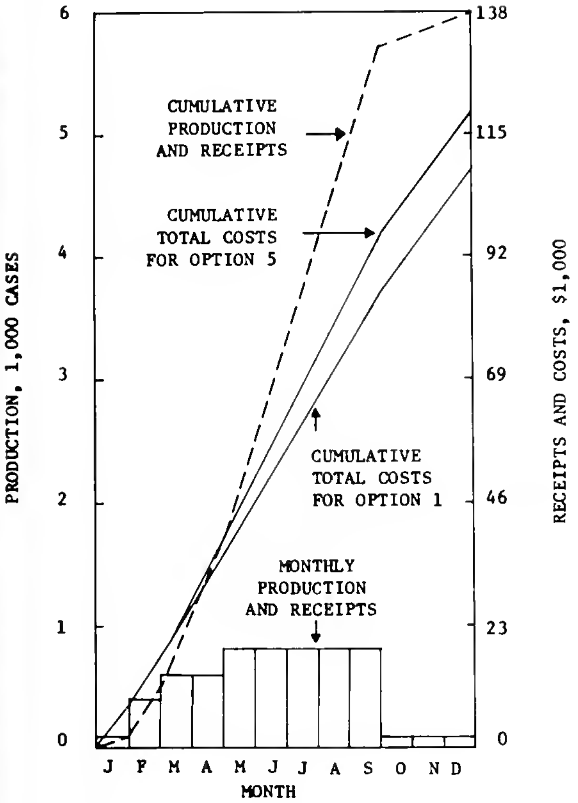

FIG. 4. *Monthly and cumulative oyster seed production, total receipts, and costs for Plant I.*

Net Returns. Net returns refer to the total receipts after deducting all costs incurred to the production of oyster seed. In general, winter months (October through January) are the only months which have negative net returns. Following this period, net returns increase and reach the peak during the summer months (May through September). Table 5 shows the efficiency between net returns and total costs for the various plant sizes and cultch preparation options considered. This table gives some idea how much average net returns would be created for each dollar of total costs for each option and plant. Table 6 shows the estimated average net returns per case for the various plant sizes and cultch preparation options considered. In this study the net returns per case increase with the capacity of the plant.

Costs of Cultch Preparation — As stated earlier, Option 5 does not have a cultch preparation stage. Therefore, in Table 6 the comparison of average net returns per case between Options 1 through 4 and Option 5 indicates by how much costs can be reduced in each operation if cultch is prepared within the hatchery's own facilities. More specifically, depending on the option chosen, $1.12 to $1.83 and $1.54 to $2.11 per case are saved in Plant I and Plant V, respectively, if cultch is prepared in the hatchery's own operations. This result is dependent, of course, upon the assumed cost conditions for cultch preparation and the assumed price of $4.50 per case of precleaned cultch.

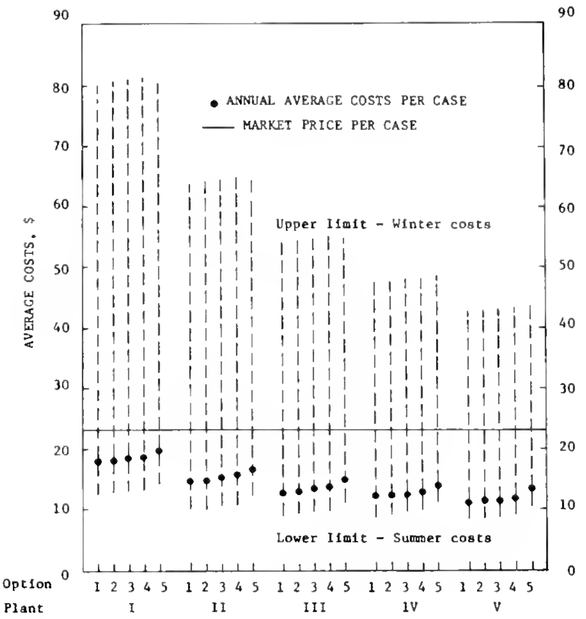

FIG. 5. *Range of average costs per case through the year for each option and plant.*

Table 7 shows the average costs per case associated with cultch preparation. Since there is no cultch preparation stage in Option 5, the current market price of $4.50 per case (as of April 1976) was assigned in Option 5. The average cultch preparation costs per case for Plant I ranged from $2.67 to $3.38, and for Plant V from $2.39 to $2.96. These costs decrease with increasing plant capacity, mainly because the charges of city water and power are lower per unit as use increases. Table 8 demonstrates that costs of cultch preparation contribute a substantial percentage of total costs required per case of oyster seed. For Option 5, purchased cultch accounts for about 23 to 34 percent of the total costs.

TABLE 5. *Efficiency: Average Net Returns Per Dollar of Total Costs*

Plant number	Cases capacity	Option				
		1	2	3	4	5
		dollars				
I	6,000	.27	.26	.24	.22	.16
II	8,000	.55	.53	.49	.48	.37
III	10,000	.79	.77	.72	.70	.54
IV	12,000	.92	.90	.84	.83	.64
V	14,000	1.09	1.07	1.01	.98	.75

TABLE 6. *Average Net Returns Per Case*

Plant number	Cases capacity	Option				
		1	2	3	4	5
		dollars				
I	6,000	4.92	4.80	4.40	4.21	3.09
II	8,000	8.12	8.01	7.60	7.44	6.17
III	10,000	10.13	10.03	9.64	9.50	8.11
IV	12,000	10.99	10.91	10.53	10.40	8.93
V	14,000	11.99	11.90	11.53	11.42	9.88

TABLE 7. *Average Costs Per Case Associated with Cultch Preparation*

Plant number	Cases capacity	Option				
		1	2	3	4	5
		dollars				
I	6,000	2.67	2.79	3.19	3.38	4.50
II	8,000	2.55	2.66	3.07	3.23	4.50
III	10,000	2.48	2.58	2.97	3.11	4.50
IV	12,000	2.43	2.52	2.90	3.03	4.50
V	14,000	2.39	2.48	2.85	2.96	4.50

TABLE 8. *Costs of Cultch Preparation as a Percentage of Total Costs Per Case*

Plant number	Cases capacity	Option				
		1	2	3	4	5
		percent				
I	6,000	14.8	15.3	17.2	18.0	22.6
II	8,000	17.1	17.7	19.9	20.8	26.7
III	10,000	19.3	19.9	22.2	23.0	30.2
IV	12,000	20.2	20.8	23.3	24.0	32.0
V	14,000	21.7	22.3	24.8	25.6	34.3

Major Components Affecting the Cost of Production. Labor costs are the major component affecting the cost of production, ranging from 39 to 50 percent of the total in Options 1 to 4 for most plants. But in Option 5 these proportions fall to a range of 30 to 43 percent, largely because of the higher costs devoted to purchased cultch.

Cost of utilities, materials, and supplies are the next major component affecting the cost of production, ranging from 19 to 29 percent of the total in Options 1 to 4, and from 31 to 43 percent in Option 5. Figure 6 shows these relationships. Costs of labor as a percentage of the total decrease as plant size increases, but the reverse is true for utilities, materials, and supplies. Costs other than these components, as a percentage of the total, are relatively stable for the several options and plants.

Economies of Size. As the size of plant and the scale of operation become larger, certain economies are usually realized. That is, after adjusting all inputs optimally, the unit cost of production can often be reduced by increasing the size of plant. Two broad forces — specialization of labor, and technological factors — enable producers to reduce unit cost by expanding the scale of operation. These forces give rise to the negatively-sloped portion of the long-run average cost curve. (Ferguson, 1969).

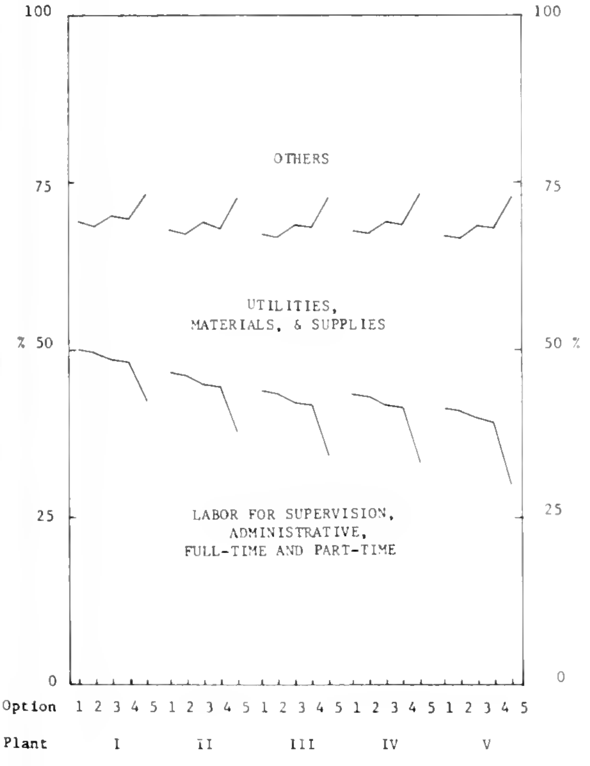

FIG. 6. *Costs categories as a percentage of total costs per case for each option and plant.*

Analysis of size economies is usually considered in terms of short- and long-run situations. According to Madden (1967), short-run economies are viewed as resulting from fuller utilization of the fixed plant, and long-run economies as resulting from efficiencies obtained by changing plant size, presumably involving a longer time period. The treatment of any resources as "fixed" is usually based on the length of the planning horizon being examined, the longevity of the resources involved, and the costs of changing these resources. Which resources are treated as "fixed" in the short-run has no effect on the eventual shape of the long-run average cost curve. The long-run average cost curve assumes **all** resources are variable, including those designated as fixed in the short-run. A curve that is drawn tangent to the short-run curves approximates the long-run economies-of-size curve for that range of output represented by the short-run curves. This curve indicates the average total cost of production that would be experienced by firms of different sizes under assumed price relationships and technologies.

The long-run production cost curve or function is a relationship between costs and output which shows the minimum average production costs for any level of output when all inputs are variable. Figures 7 and 8 show the relationship of short-run to long-run average production costs. These are "fixed" factors associated with each of these figures, however. In Figure 7 the Option 1, cultch preparation method, applies to all of the curves while, in Figure 8, the Option 5 is used.

As can be seen in these figures, the solid lines are the long-run average production cost curves or the long-run planning cost curves, and the dotted lines are the short-run average production cost curves for the fixed plants, Plants I to V. The long-run average cost curve is downward sloping, and means that as the size of plant increases, the average costs per case decrease when plants are

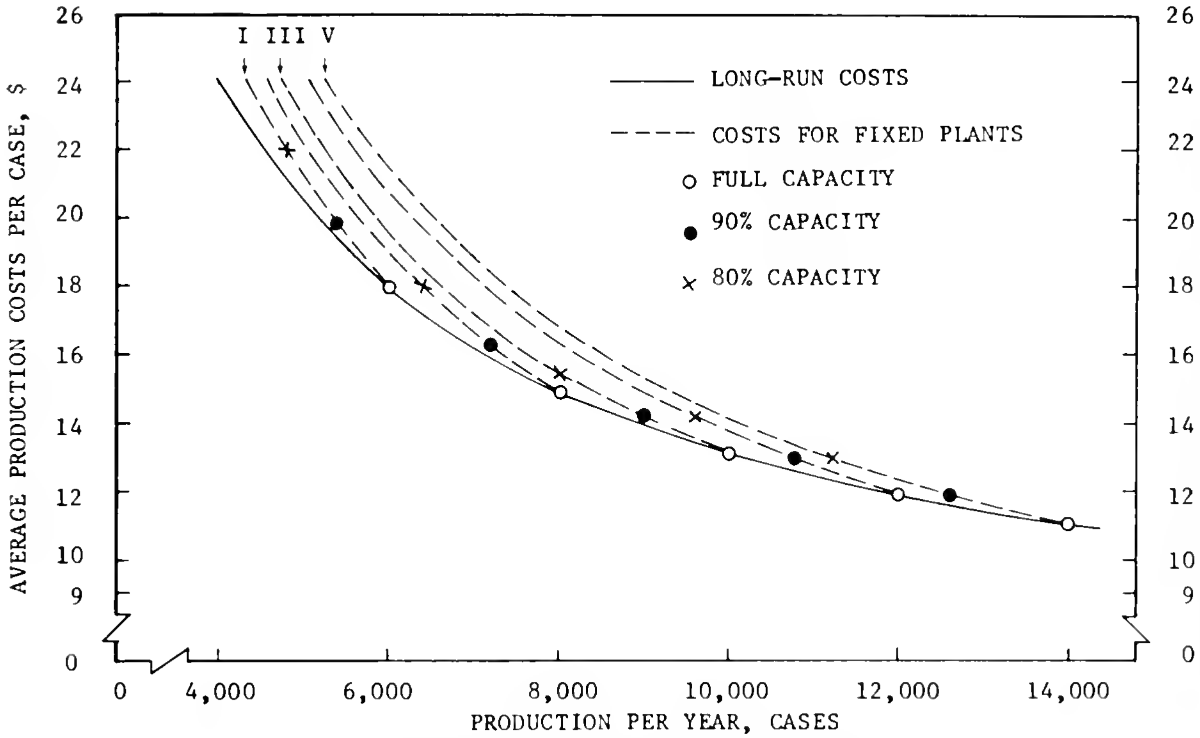

FIG 7. *Relation of short-run to long-run average production costs in Option 1 for Plants I to V.*

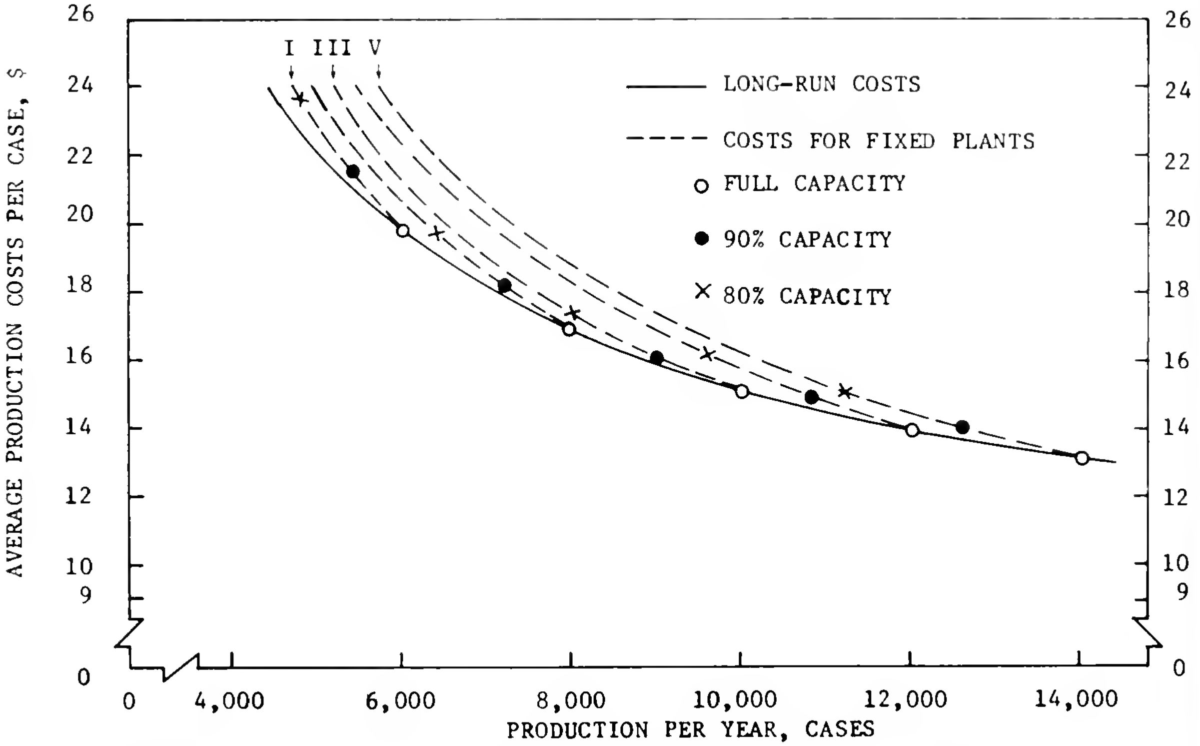

FIG 8. *Relation of short-run to long-run average production costs in Option 5 for Plants I to V.*

operating at near capacity. The short-run average production cost curves, all the dotted lines in Figures 7 and 8, are moving toward the long-run average cost curve until they coincide, when the rate of output nears capacity. For any plant, operating at below capacity increases average costs significantly.

There are definite economies of size with increased plant capacity. As the plant capacity increases from 6,000 to 14,000 cases per year, average costs per case decrease around 35 to 40 percent for all options. The downward-sloping long-run average production cost curve indicates that further economies of scale might exist for even larger plants. The slopes of the long-run average production cost curves are negative and, within the output range examined, do not become parallel to the horizontal axis, because each successive plant has a lower average cost per case when it operates at its planned capacity.

Figure 9 shows the long-run average production cost curves for the different options. Option 1 is the most favorable, and Option 2 is the next favorable situation, compared with other options, and Option 5 is the least favorable.

Finally, this study concludes that, under the conditions of current market prices, producing Pacific oyster seed in hatcheries is economically feasible in the Pacific Northwest.

ACKNOWLEDGEMENTS

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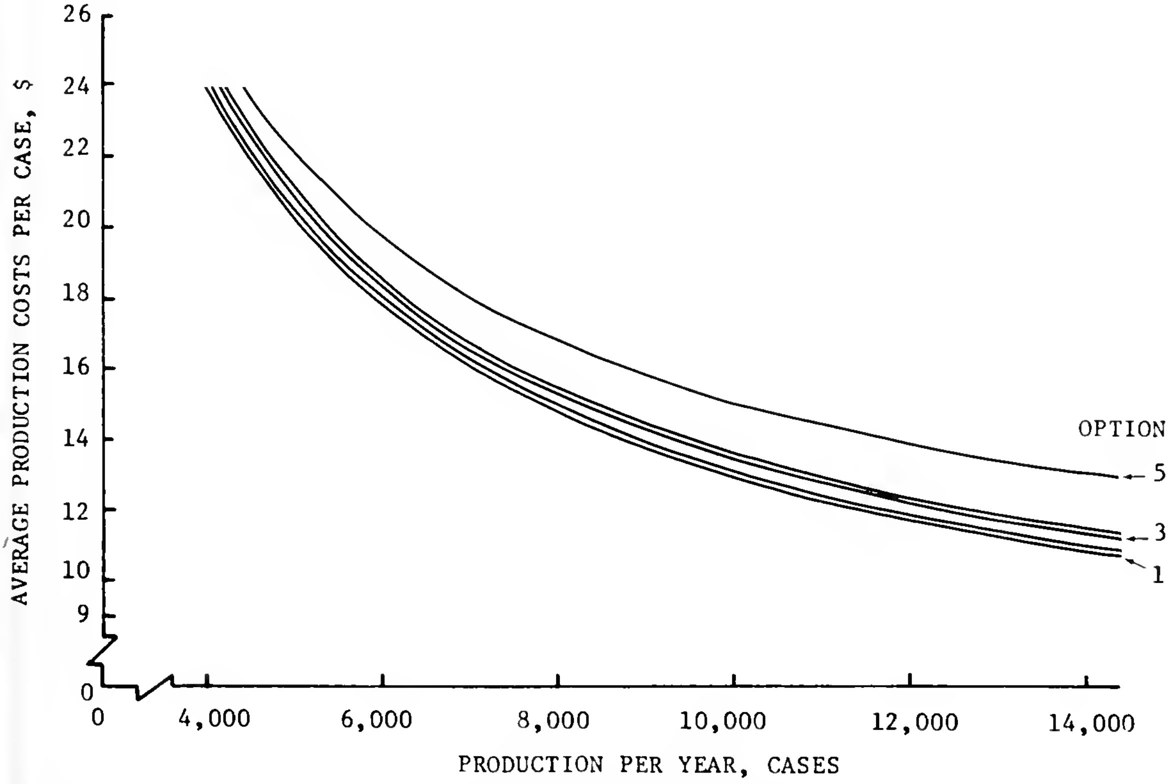

FIG. 9. *Long-run average production costs in different options for Plants I to V.*

jor cooperator in providing data and contributing ideas for this study.

Cooperation also was gratefully received from government agencies, industries, and commercial oyster farmers. Only the authors are, of course, responsible for any deficiencies that may be present in this study.

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ASSESSMENT OF SURF CLAM STOCKS IN NEARSHORE WATERS ALONG THE DELMARVA PENINSULA AND IN THE FISHERY SOUTH OF CAPE HENRY[1, 2]

Joseph G. Loesch and John W. Ropes

VIRGINIA INSTITUTE OF MARINE SCIENCE
GLOUCESTER POINT, VIRGINIA
and
NATIONAL MARINE FISHERIES SERVICE
MIDDLE ATLANTIC COASTAL FISHERIES CENTER
OXFORD, MARYLAND

ABSTRACT

In 1974 the abundance of surf clams was sampled from Delmarva Peninsula, Delaware south to North Carolina. Surf clams were not found in commercial densities in the inshore waters along the Delmarva Peninsula. Off shore and south of Cape Henry, an area of intense surf clam fishing, the estimated standing crop was 10 million bushels. A length-age relationship was estimated and it implies that recruitment to the fishery occurs at approximately age 2, at an average annual rate of about 8%. It is concluded that because of the low recruitment rate relative to the heavy fishing pressure that Virginia surf clam stocks have been overharvested in recent years.

INTRODUCTION

The fishery for surf clams, *Spisula solidissima*, presently supplies meats for about 80% of all clam products in the United States. In the late 1940's and early 1950's the surf clam was a relatively unknown resource, but the fishery has since experienced dramatic growth. In 1950, for instance, only 8 million lbs. of surf clam meats were landed; by 1974, however, the reported meat landings were 96 million lbs. (Current Fishery Statistics, 1974). Beds located off the New Jersey coast were the major source of surf clams until the late 1960's (Ropes, 1972). Since then effort has shifted to beds off the Delmarva Peninsula and Virginia. Virginia landings of 58 million lbs. of surf clam meats in 1974 were 60% of the United States total.

Declining surf clam densities in the overfished beds off New Jersey promoted consideration of management plans for the fishery. In June, 1973, representatives from industry, the National Marine Fisheries Service (NMFS) and the States of New York, New Jersey, Delaware, Maryland, and Virginia formed a Surf Clam Technical Committee and a Sub-Council. The functions of the Technical Committee are to direct investigations of the resource and identify management alternatives. The Sub-Council, guided by the findings of the committee, is to formulate management policy. These two bodies are part of a more comprehensive State-Federal Fisheries Management Program administered by the Northeast Marine Fisheries Council.

This report is an account and analysis of the investigation of the surf clam resource in October, 1974, in the inshore waters of the Delmarva Peninsula, and in the area offshore of Cape Henry, Virginia and south to upper North Carolina. The

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[1] Contribution No. 805, Virginia Institute of Marine Science, Gloucester Point, Virginia 23062.

[2] Research sponsored by NOAA, National Marine Fisheries Service, Contract No. 03-4-043-357.

inshore investigation along the Delmarva Peninsula complemented an offshore investigation in this region by NMFS in August, 1974. The main objectives of the study were to estimate the distribution and abundance of adult and juvenile surf clams along the Delmarva Peninsula and in areas of intense harvesting off the Virginia coast. The project was a joint undertaking by NMFS and the Virginia Institute of Marine Science (VIMS).

MATERIALS AND METHODS

Surf clams were sampled by a hydraulic tow dredge operated from the VIMS research vessel RETRIEVER. The dredge, supplied by the NMFS, is similar to those employed in the surf clam fishery, but smaller. It has a 76.2 cm (30 inches) blade versus blades ranging up to 254 cm (100 inches) on industrial models. The dredge has a retention bag constructed of 5.1 cm (2 inches) rings versus 7.6 cm (3 inches) rings or cage bars generally used throughout the industry. The relationships of sample catch and its size composition to the total population is unknown since the catch-efficiency of the dredge with respect to surf clams less than 5.1 cm is not known.

Vessel speed was estimated to be 0.5 knot while towing the dredge, thus it was assumed that a standard 5-minute tow provided a sampling unit of 58.8 m^2 (632.9 ft^2) for stock assessment.

Arbitrarily, a surf clam catch $\geqslant$ 45 clams was considered satisfactory in the sense that the immediate area would warrant future replicate sampling to determine a reliable average catch and the extent of the local distribution. This figure (45) was derived in consideration of the necessity to maintain a constant sampling unit, whereas an experienced fisherman would make gear adjustments to enhance catch according to sea conditions and bottom type.

Sampling stations along the coast of the Delmarva Peninsula were established along lines of latitude at intervals of 1.8, 3.7, and 5.6 km (1, 2 and 3 nautical miles) offshore of the 1 fathom line indicated on the National Ocean Survey chart no. 1109 (Figs. 1 and 2). These transects were spaced at intervals of 9.3 km (5 nautical miles) from just below Cape Henlopen (Rehoboth Beach area), Delaware, to Cape Charles, Virginia. An additional transect of three stations in a north to south direction was sampled inshore near Cape Henry,

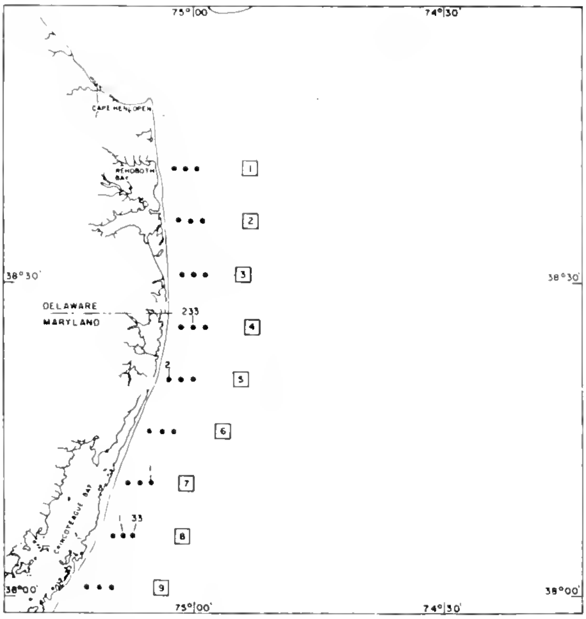

FIG. 1. *Location of sampling stations in the nearshore waters of the upper Delmarva Peninsula. Numbers above the stations indicate the catch of surf clams.*

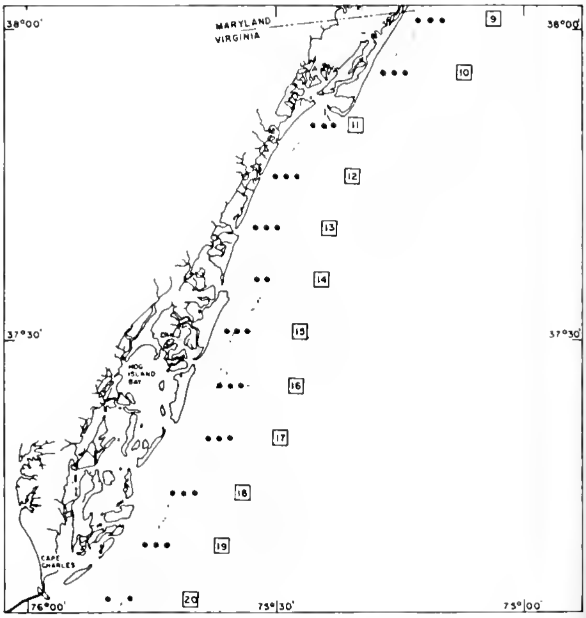

FIG. 2. *Location of sampling stations in the nearshore waters of the lower Delmarva Peninsula. Numbers above the stations indicate the catch of surf clams.*

Virginia (Fig. 3). Offshore of Cape Henry and further south, sampling was conducted along a rectangular grid constructed of six stations on each of 12 transects, in which both stations and transects were at intervals of 4.6 km (2.5 nautical miles). The grid duplicated one sampled by NMFS in August 1974.

Surf clam density was approximated from the product of average catch and area. Sampling did not follow a stratified random sampling procedure or systematic sampling as defined by Cochran (1963) since all station locations were selected. Because there was no underlying probability model, standard errors could not be validly calculated nor interval estimates of densities established.

A constant of 12.6 lbs. of usable meats per bushel was used to estimate standing crop in terms of meat weight. This value, an overall average yield per bushel for 1974 and 1975, was reported by Mr. N. Doughty, owner and operator of C & D Seafood Inc., Oyster, Virginia (Loesch, 1977). The constant of 17 lbs. of meats per bushel used in the U.S. Current Fishery Statistics for converting bushels to meat weight includes the viscera which is not used by the surf clam industry.

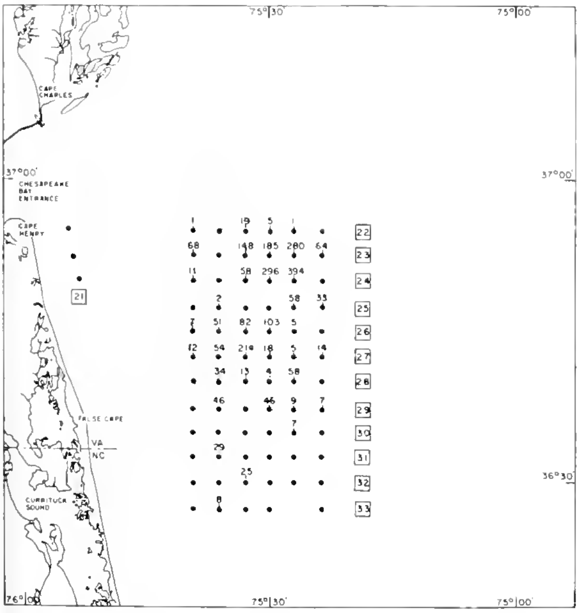

FIG. 3. *Location of sampling stations off the coast of lower Virginia and upper North Carolina. Numbers above stations indicates the catch of surf clams.*

A station is referred to by the transect number followed by its offshore position, e.g., T4(3) is the third station, counting from inshore to offshore, on transect 4 (Fig. 1). Three stations, T14(1), T20(2), and T33(5) were not sampled.

At each station, the catch of surf clams to the nearest 0.1 bushel of clams was measured for length (longest linear dimension).

Two growth curves published by Yancey and Welch (1968) for surf clam stocks of Long Island, New York and off New Jersey were re-evaluated in this report. The age-length relationship for the Long Island clams was ascertained from the growth curve in the unpublished manuscript of Westman and Bidwell (1946); the New Jersey surf clam data were supplied by Welch (personal communication). The Walford analysis (Walford, 1946) was used to transform asymptotic growth functions to the linear form:

$$L_{t+1} = L_\infty(1-k) + kL_t$$

where L_t = length at time t; L_{t+1} = length at the end of a constant time interval (one year in the present cases); $L_\infty(1-k)$ = regression line intercept; k = the regression coefficient; and L_∞ is the asymptotic size, i.e., the average maximum size. The equation is independent of age, but the age-length relationship was estimated by using 0.24 mm (0.01 inch), the midpoint of the general size range of newly settled surf clam spat reported by Loosanoff, *et al.* (1966). At this time, when the larvae leave the planktonic environment and become members of the benthic community, they were established to be age zero. Substitution of the estimated average (0.24 mm) at age zero into the growth function produced an estimate of length at age 1. Growth curves were generated by continuing this process until arbitrarily terminated at age 20.

Average annual recruitment since 1969, the year the area was last surveyed by NMFS, was estimated by assuming a maximum length for age 5 occurred at the mid-point between its average length and the succeeding age group's average length. The short-comings (size overlap by age groups) of this procedure are recognized by the authors, but methods for determining the individual age of surf clams and, thus, stock age structure have not been developed. [Perhaps growth and age estimates from cross-sectioned shells as presently done with several bivalve species (e.g., Kennish and Olsson, 1975) may eventually be shown applicable.]

A Smith-MacIntyre benthic sampler was employed at each station to sample for juvenile clams. A single 0.1 m^2 (1.08 ft^2) grab sample was taken at each station and wet sieved on a 1 mm (0.04 inch) mesh screen. The portion retained was preserved in 5% formalin and returned to the laboratory for examination.

RESULTS AND DISCUSSION

Distribution and Abundance. A commercial density of surf clams was not found in the inshore waters along the Delmarva Peninsula (Figures 1 & 2). Surf clams were obtained at only six of 58 stations sampled. The total catch was 271 and the average catch was 4.7 clams per standard tow. Commercial abundance was indicated at only one site, T4(2) where the catch, 233 clams, was about 87% of the total catch along this Peninsula. This concentration of surf clams was very limited in its distribution since no clams were taken at the adjacent sites T4(1) and T4(3), nor along transect T3, and only two clams were taken along transect T5.

No surf clams were taken at the three inshore stations (T21) off Cape Henry (Fig. 3).

Offshore of Cape Henry and south to upper North Carolina, 71 stations were sampled (Fig. 3). A total of 2,474 surf clams were taken, averaging 34.8 clams per tow. Two areas of heavy surf clam density were apparent. One was along T23 and T24 where 8 of 12 catches ranged from satisfactory ($\geqslant$45 clams) to the highest recorded (394 clams). Another group of five spatially associated high catches occurred along T26 and T27. Only four other stations had catches $\geqslant$ 45 [T24(6); T28(5); and T29(2&4)]. The catch distribution for the NMFS surf clam cruise in August, 1974, exhibited a similar trend (Ropes, 1974). Standing crop estimates, derived from the average catches, are presented in Table 1 for the entire area, transects T22 through T33 (343.75 $miles^2$), and also for the area between T23 and T29 (187.5 $miles^2$), the north-south boundaries of the highest observed densities for both the NMFS and VIMS cruises. Approximately 89% of the estimated standing crop of about 10 million bushels of surf clams occurred within the T23-T29 boundaries.

Estimation of Growth. The surf clam growth curve presented by Westman and Bidwell (not shown) does not appear realistic for Virginia stocks. By the 17th year the curve still does not tend toward an asymptotic size (L_∞) and the Walford analysis indicated that L_∞ would not be attained until about age 38. Thus, one would have to assume the surf clam lived for well over 40 years. Surf clam longevity is not known, but about 17 years has been suggested (Ropes, *et al.*, 1969).

The growth function ascertained from Welch's data by least squares analysis of length at successive check marks which he interpreted as annual marks is:

$$L_{t+1} = 47.05 + 0.6807\, L_t$$

where length is expressed in mm. Substitution of age zero length, i.e., 0.24 mm, the average length of newly settled spat, and the subsequent substitution of each estimated average length at 1 year intervals produced a curve which appears to be a reasonable approximation of surf clam growth in the Virginia fishery area (Fig. 4). This contention is supported by the reported size of juvenile surf clams of known age off Chincoteague, Virginia (Ropes, *et al.*, 1969). A more intense growth study

TABLE 1. *Standing crop estimates for surf clams in the Virginia fishery area south of Cape Henry. VIMS cruise, October, 1974.*

Area	Number Samples	Average Catch	Bushels Per Acre	Total Bushels ($X 10^6$)	Meat Wts. (lbs.) ($X 10^6$)*
T22-T33	71	34.8	34.2	9.96	125.50
T23-T29	42	56.6	55.5	8.84	111.38

*Estimates based on 12.6 lbs of usable meat per bushel.

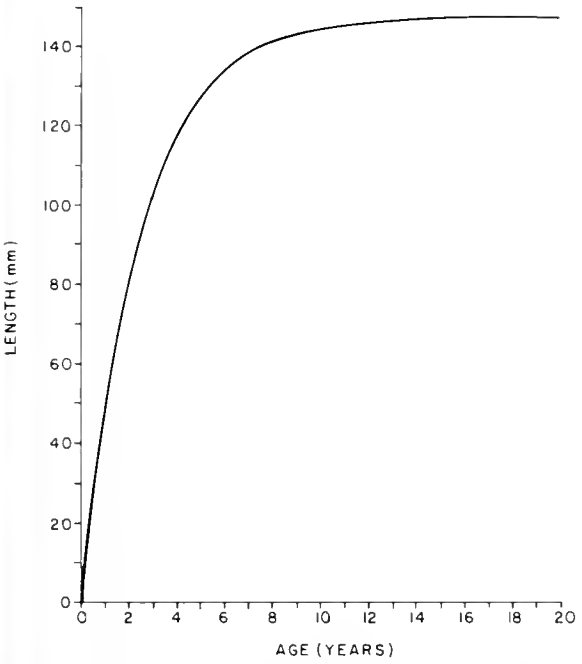

FIG. 4. *The length-age relationship for surf clams derived from the data of Welch.*

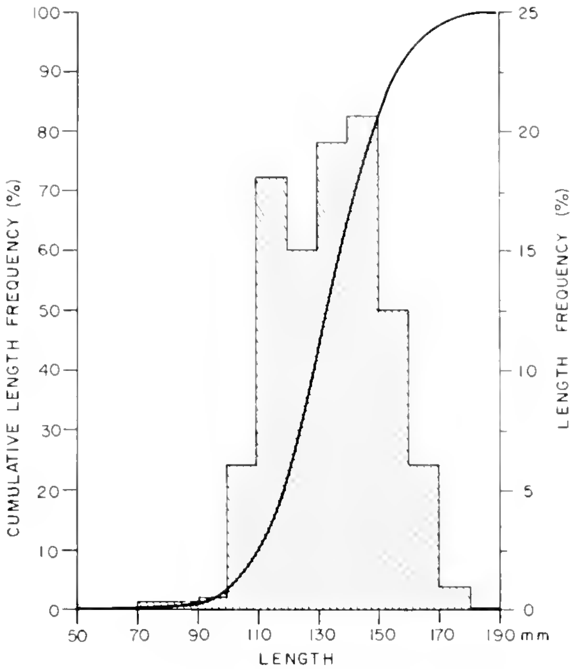

FIG. 5. *The cumulative length frequency percentages of surf clams sampled in the Virginia fishery area south of Cape Henry.*

is needed if long term management of the fishery is considered, since Figure 4 was derived from the data of Welch, who made only 90 check-mark measurements.

The average maximum length (L_∞) was estimated to be 147 mm (5.8 inches) and theoretically reached at about age 14 (Table 2). Of more practical importance are the estimates that 95% of L_∞ occurs at age 8 and 50% by about age 2. The growth curve indicates that recruitment to the Virginia surf clam fishery occurs at age 2, since 76.2 mm (3-inch) rings or cage bars are used in the commercial dredges. Thus, there are not several unexploited year classes which would tend to stabilize a fishery (assuming constant effort) when years of poor setting occur. Potential future recruitment is further reduced by some dredge retention of smaller sizes, and, in addition, a high mortality is suspected for clams which pass through the dredge because the mantle cavity is packed with sand by the hydraulic process.

Length Frequency and Recruitment Estimates. An average length of 133.5 mm (5.25 inches) was estimated from 1,273 surf clam measurements obtained in the Virginia fishery area. The cumulative length frequency curve (Fig. 5) in conjunction with

TABLE 2. *Estimated age-length relationship for surf clams derived from the data of Welch (personal communication).*

Age	Length (mm)	Age	Length (mm)	Age	Length (mm)	Age	Length (mm)
0	0.24	5	125.8	10	144.2	15	146.7
1	47.2	6	132.7	11	145.2	16	146.9
2	79.2	7	137.4	12	145.9	17	147.0
3	101.0	8	140.6	13	146.3	18	147.1
4	115.8	9	142.7	14	146.6	19	147.2

Table 1, indicates that about 40% of surf clams were age 5 or younger. This infers an annual recruitment rate (relative to dredge efficiency) of 8% since 1969 when, prior to 1974, the area was last surveyed by NMFS. Due to the inability to determine stock age structure and the absence of annual surf clam spat set data, it is not known if recruitment is relatively constant or if maintenance of the stocks is dependent upon an occasional strong year class.

If the surf clam harvest is to be managed in order to establish a stable fishery, future annual harvests will have to be reduced relative to those of recent years. An 8% harvest of the estimated standing crop in the total area sampled south of Cape Henry (Table 1) would be about 10 million lbs. of meat, or 9 million lbs. of meat when the smaller area of surf clam concentration (T23-T29) is considered. Virginia landings, based on 12.6 lbs. of usable meat per bushel, were about 32 million and 43 million lbs. of meat in 1973 and 1974, respectively. Mr. N. Doughty estimated that 98% of all Virginia surf clam landings come from an area that is approximately bounded by transects T23 and T27 (personal communication). Therefore, landings far exceed the 8% estimates of standing crop.

Surf Clam Spat. Thirty-two Smith-MacIntyre sediment samples obtained in the Virginia fishery area south of Cape Henry were examined for the presence of surf clam spat. Seven live young-of-the-year clams were present in six of the 32 samples. Size lengths of the young-of-the-year surf clams ranged from 2.2 mm (0.09 inch) to 18 mm (0.71 inch). The duration of surf clam spawning in Virginia waters is not know, but Ropes (1968) reported a major spawning period in summer and a minor period in fall in New Jersey waters. A protracted spawning period would, of course, result in a relatively large size range of the young clams.

The average young-of-the-year catch for the total fishery area (T22-T33) and also for the area of greatest adult density (T23-T29) was about 0.2 clam per grab, i.e., per 0.1 m^2 (1.08 ft^2). By extrapolation it is estimated that the young-of-the-year density was approximately 2.4 billion clams in the former area and about 1.3 billion in the latter. If an 8% survival to age 2 is assumed with an average size of 79.2 mm (3.1 inches), and averaging 170 clams per bushel (Ropes, unpublished data) with a yield of 12.6 lbs. of usable meats per bushel, the estimated recruitment in 1976 will be approximately 14 million lbs. of meat to the total area and about 8 million lbs. to the lesser area. These estimates are based on a few data, but are in reasonable agreement with the previous ones based on 8% of the adult standing crop, and they indicate that recent annual harvests exceed recruitment. This conclusion would still be reasonable even if recruitment was underestimated by 100%.

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MORTALITIES OF OYSTERS AND HARD CLAMS ASSOCIATED WITH HEAVY RUNOFF IN THE SANTEE RIVER SYSTEM, SOUTH CAROLINA IN THE SPRING OF 1975[1]

Victor G. Burrell, Jr.

SOUTH CAROLINA MARINE RESOURCES RESEARCH INSTITUTE
CHARLESTON, SOUTH CAROLINA

ABSTRACT

Mortalities and shell cavity conductivity of hard clams, Mercenaria mercenaria and subtidal and intertidal American oysters, Crassostrea virginica, were recorded during two periods of low salinity in three tributaries of the Santee River, South Carolina in spring of 1975. Hard clam mortality was less than five percent on any date. Deaths of subtidal oysters were: North Santee River, 66%; North Santee Bay, 32%; South Santee River, 32%. Intertidal oyster mortality was 60% in the South Santee River and 47% in the North Santee River. Oyster and clam liquor conductivities were higher than in surrounding waters during periods of low salinity. Lower hard clam mortalities appeared to be related to their ability to remain closed longer than oysters. This may in part result from differences in microhabitats. Low dissolved oxygen concentration and hydrogen sulfide did not appear to be implicated in these shellfish deaths.

INTRODUCTION

The Santee River, South Carolina, is a large system draining approximately 38,000 km^2. In 1942 most of the freshwater discharge in this system was diverted into the Cooper River as a result of the Santee Cooper Hydroelectric Project. The flow back into the Santee River, lying below Wilson Dam, is controlled at a constant 14.2 m^3 sec^{-1} except for excess flood waters which are discharged over the spillway at the dam. Average discharge over a 31 year period has been 63.2 m^3 sec^{-1} (Stallings, 1967; United States Geological Survey, 1976). The mouths of the North and South Santee River estuaries contain dense beds of hard clams (*Mercenaria mercenaria*) and subtidal oysters (*Crassostrea virginica*) providing both seed and market size single oysters. Intertidal oysters also grow along these two tributaries. Recently, both subtidal oysters and clams have been harvested with hydraulic escalator harvesters similar to those described by Manning and Dunnington (1955) and Godcharles (1971). Production in North Santee Bay averaged 20-250 count bags of clams per hour per harvester in the fall-winter fishery of 1975-1976 (R. J. Rhodes, personal communication).

Heavy rains occurred in the Santee watershed during late winter and spring of 1975. As a result, discharge over the Wilson Dam spillway exceeded 32.6 m^3 sec^{-1} and averaged 679.3 m^3 sec^{-1} from 14 March 1975 until 21 April 1975 and exceeded 29.4 m^3 sec^{-1} and averaged 238.5 m^3 sec^{-1} from 17 May 1975 through 23 June 1975 (United States Geological Survey, 1976). This is the greatest spring discharge on record in this system and was responsible for extremely low salinities for extended periods in lower reaches of the two estuaries.

Numerous instances of oyster mortalities associated with low salinities are known

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[1] Contribution No. 70 from the South Carolina Marine Resources Center

(Baughman, 1948; Galtsoff, 1972; Joyce,1972). Lunz (1938) reported a low salinity kill in the same general area in South Carolina. Recorded freshwater-induced mortalities of hard clams are limited. Castagna and Chanley (1973) indicated that this bivalve occurs at minimum salinities of 10-13 o/oo. Following a period of low salinities in Virginia waters, Haven *et al.* (1975) found high mortalities among hard clams which had been transplanted. In contrast, very few deaths were noted among clams which had remained undisturbed in their originial settlement locations.

This study was initiated in the spring of 1975 to assess oyster and clam mortalities in the Santee system resulting from high volumes of freshwater present in the Santee River growing areas.

MATERIALS AND METHODS

To estimate mortality of oysters and hard clams, a series of samples were taken one mile above the mouth of each estuary of the Santee system on seven occasions and in North Santee Bay on nine dates beginning in early April 1975 and extending into July 1975 (Fig. 1). Subtidal oysters and hard clams were sampled with a small box dredge, 0.6 meters across the blade.

Tows were of two minutes duration and were repeated in the case of North Santee Bay (NSB) until a sample of at least 25 clams was accumulated. In the South Santee (SS01) and the main channel of the North Santee (NS01), four or five tows were made to get an oyster sample (at least 2 bushels); it became apparent in intensive sampling at the onset of the study that it would be unlikely that a sample of 25 hard clams could be obtained within a reasonable time. (These beds had been intensively harvested by hydraulic escalator dredges several months earlier, leaving very few hard clams large enough to be collected by the box dredge). Intertidal oysters were sampled by hand at low tide. Mortalities were determined using the criteria described by Haven *et al.* (1975); namely, a live oyster is one whose valves are tightly closed; a dying oyster gapes open but

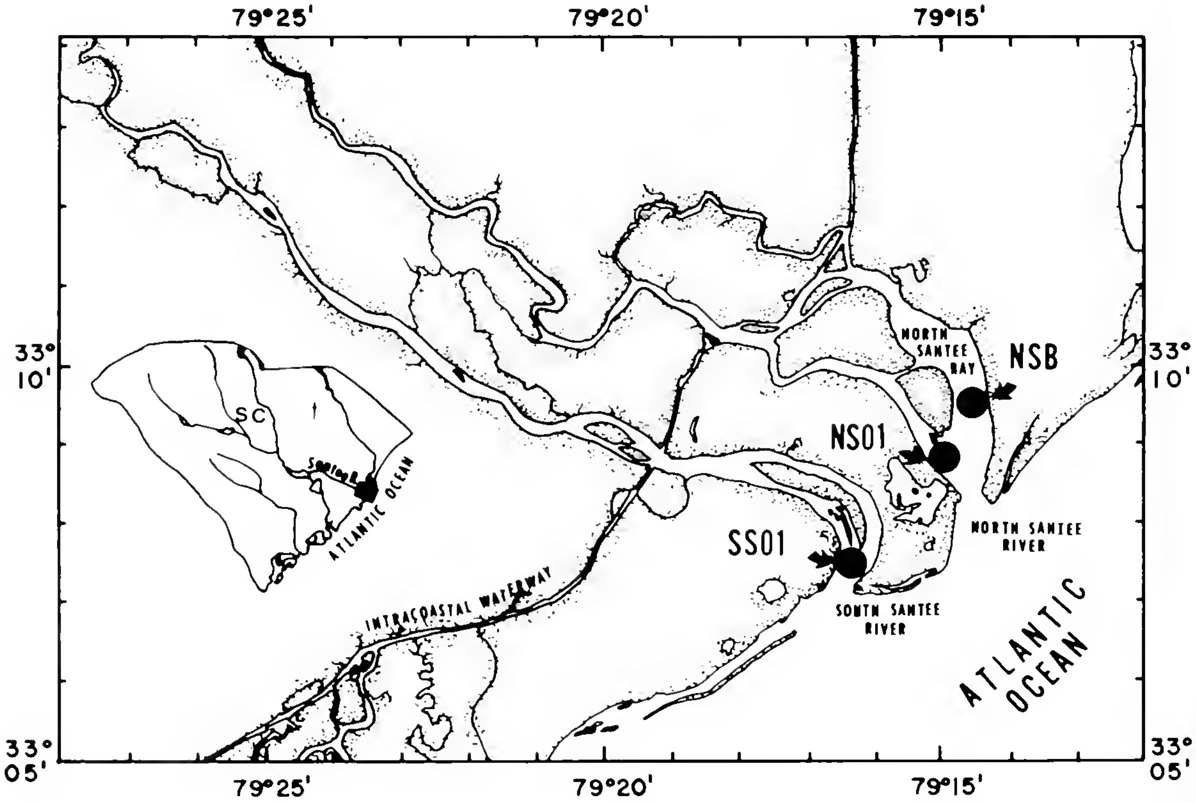

FIG. 1. *Map of the area showing stations sampled.*

still has meat inside; and a recently dead oyster is one whose valves are still attached and the inner surface is white and devoid of fouling organisms.

Percent mortalities were determined as follows:

$$\text{Percent oyster mortality} = \frac{\text{Number of recent boxes} + \text{number dying}}{\text{Number live} + \text{number recent boxes} + \text{number dying}} \times 100$$

$$\text{Percent clam mortality} = \frac{\text{Recent boxes (those still attached at the hinges)}}{\text{Number live clams} + \text{recent boxes}} \times 100$$

Shellfish predators such as starfish, drills, and mud crabs and boring sponges were noted.

To determine ionic concentration changes in oysters and clams in response to low salinity, shell cavity liquor conductivities were measured in each sample. An increase in difference between shellfish liquor conductivity ratio above conductivity ratio/salinity of ambient water was used as an indicator of bivalve shell closure. A conductivity determination was made on each clam by opening and draining all liquor and diluting to five volumes. Oysters were cracked at the bill and the liquor was withdrawn with a syringe. Liquor from five oysters was pooled and diluted to five volumes. Dissolved oxygen, temperature, and surface and bottom salinity were determined for each location from water samples taken with a Kemmerer bottle at the same time dredge samples were taken. All salinity and conductivity determinations were made with a Beckman RS7B induction salinometer. Dissolved oxygen concentrations were determined by the modified Winkler method after fixing in the field. Temperatures were read from a stem thermometer fixed in the Kemmerer bottles. Tide stage was recorded each time water samples were collected.

Subtidal oysters and clams were sampled in North Santee Bay and South Santee River in March 1976 after an extended period of low runoff to determine mortalities and liquor conductivities when high runoff did not affect the beds. Clams were sampled at different stages of the tide to determine if liquor reflected tidal salinity changes. Intertidal oysters sampled in 1976 were taken at two levels above the low tide mark in the South Santee to note mortality and inner shell conductivity differences.

RESULTS

Salinities lower than those conducive to favorable clam or oyster growth and survival (Castagna and Chanley, 1973) were observed in the Santee system twice in the spring of 1975;

TABLE 1. *Bottom temperature, salinity and dissolved oxygen at stations in Santee River oyster and clam beds during spring 1975 and 1976.*

	Temperature °C			Salinity 0/00			Dissolved Oxygen mg-1			
Date	SSO1	NSO1	NSB	SSO1	NSO1	NSB	SSO1	NSO1	NSB	Tide Stage
1975										
3 April			15.9			0.3				late flood
9 April	15.3	14.3	14.4	15.5	8.9	12.0	7.4	7.7	7.7	slack before ebb
	14.8	14.1	14.2	.3	.2	.8	8.2	7.8	7.8	late ebb
17 April	15.4	15.3	15.7	2.7	2.5	3.0	8.1	7.7	7.6	late ebb early flood
24 April	19.2	18.8	19.0	26.7	28.5	27.5	7.3	7.6	7.2	early ebb
1 May	23.2	23.1	23.1	29.0	24.7	21.4	7.4	6.7	6.9	early flood
13 May	24.0	23.4	23.6	17.8	30.4	27.6	6.7	6.2	6.5	late ebb at SSO1, early ebb at NSO1 and NSB
20 May	25.6	25.9	26.0	9.0	4.6	12.9	5.8	6.1		late ebb early flood
6 June	27.1	27.1	27.6	2.4	0.3	1.3	6.7	6.9	6.4	late ebb early flood
2 July			26.9			23.0			5.7	late ebb
1976										
March	18.5		16.8	31.2		32.3	7.7		7.7	slack before ebb
	19.8		20.3	19.7		21.9	7.9		7.6	slack before flood

these exceeded two weeks in one case and three weeks in the other. Bottom salinities at stations in the mouth of the South Santee and North Santee Rivers and North Santee Bay reflected high freshwater runoff during the period between 3 April 1975 - 17 April 1975 and again between 20 May 1975 - 6 June 1975 (Table 1). Samples taken at late flood on 3 and 9 April probably reflect maximum salinities over the shellfish bed during this period of high runoff. Salinities were lower in North Santee River than either North Santee Bay or South Santee River during this time. Bottom salinity throughout a tidal cycle when runoff is minimal is reflected in 1976 samplings at each station (Table 1). Surface salinities indicated that stratification was maximal at high tide (Table 2). The greatest difference recorded (15 $^{0}/_{00}$ at SS01) came during the high runoff period on 9 April 1975.

Bottom water temperatures ranged from a low of 14.3 C in North Santee River on 9 April 1975 to a high of 27.6 C in North Santee Bay in June 1975. Temperatures in March 1976 were 16.8 C and 18.5 C in North Santee Bay and South Santee River respectively. These values are well above minimum temperatures at which clams and oysters cease pumping and are within the range where significant growth takes place in South

TABLE 2. *Surface salinities (0/00) at stations in Santee River oyster and clam beds during Spring 1975.*

Date	SSO1	NSO1	NSB	Tide Stage
3 April			0.3	late flood
9 April	0.4	0.3	0.3	slack before ebb
	0.3	0.3	0.3	late ebb
17 April	2.0	1.1	2.4	late ebb, early flood
24 April	22.3	26.9	27.5	early ebb
1 May	29.7	24.6	21.0	early flood
13 May	13.2	30.3	24.8	late ebb at SSO1, early ebb at NSO1 and NSB
20 May	9.0	——	12.9	late ebb, early flood
6 June	2.4	0.3	1.3	late ebb, early flood
2 July			22.5	late ebb

TABLE 3. *Clam and subtidal and intertidal oyster mortalities observed at stations in the Santee River during 1975 and 1976 expressed as percent fresh boxes to total sample.*

	1975							1976
	9 April	17 April	24 April	1 May	13 May	20 May	6 June	March
Clam Mortalities								
SSO1	0	3.8	0	0	0	0	0	.01
NSO1	0	0	4.5	0	0	0	0	
NSB	0	2.5	0	0	4.8	0	0	.03
Subtidal Oyster Mortalities								
SSO1	27.0	30.0	26.0	23.0	37.0	28.0	18.0	18.2
NSO1	57.0	63.5	66.5	58.2	79.0	69.0	66.0	17.8
NSB	48.0	29.0	27.0	21.0	36.0	26.0	35.0	16.2
Intertidal Oyster Mortalities								
SSO1	57.0	47.0	81.0	28.0	70.0	75.0		17.6[a]-22.4[b]
NSO1	47.0	54.0	60.0	12.0	33.0	74.0		

[a] Low intertidal
[b] High intertidal

Carolina (Eldridge *et al.*, 1976; Galstoff, 1964). Highest dissolved oxygen in 1975 was observed in South Santee RIver (8.2 mg/1) in April and Lowest (5.7 mg/1) in North Santee Bay in July. In march 1976 these values ranged between 7.6 and 7.9 mg/1 in samples taken from South Santee and North Santee Bay.

Hard clams mortalities were less than five percent on any sampling date in each of three beds. The sampling did not reveal any differences between systems. Less than one percent dead clams was found in March 1976 in the South Santee and North Santee Bay (Table 3). Subtidal oyster mortalities were highest in North Santee River on each sampling date, ranging from 57.0 to 79% boxes per trawl. Mortality among subtidal oysters in North Santee Bay and South Santee River appeared about equal in 1975. Box counts in 1976 were similar in all areas and were sufficiently lower than 1975 counts to indicate that a kill had occurred. Mortality was highest among intertidal oysters in the South Santee, but in the North Santee River mortalities of intertidal and subtidal beds were about the same. Deaths appeared to increase with time in intertidal oysters during both periods of low salinities. Counts taken during 1976 indicated that boxes were approximately equal in number between intertidal and subtidal beds; in all cases these were several times less abundant than in 1975.

Shell cavity liquor conductivity of North Santee Bay clams was slightly above ambient water conductivity during periods of low runoff, but several times higher than ambient when external salinities were lowest (Figure 2). These conductivities continued to increase despite lower ambient river water conductivity ratios for periods up to three weeks on two occasions in North Santee Bay, indicating that pumping had essentially ceased. This probably meant anerobic metabolism was taking place. In North Santee River during periods of low salinity, clam shell cavity liquor conductivity was approximately 10 times that of ambient water samples. When bottom water salinity increased, the conductivity differences between shell cavity water and the ambient decreased and on one occasion was lower than ambient. Clams were taken only on three instances in South Santee River, but

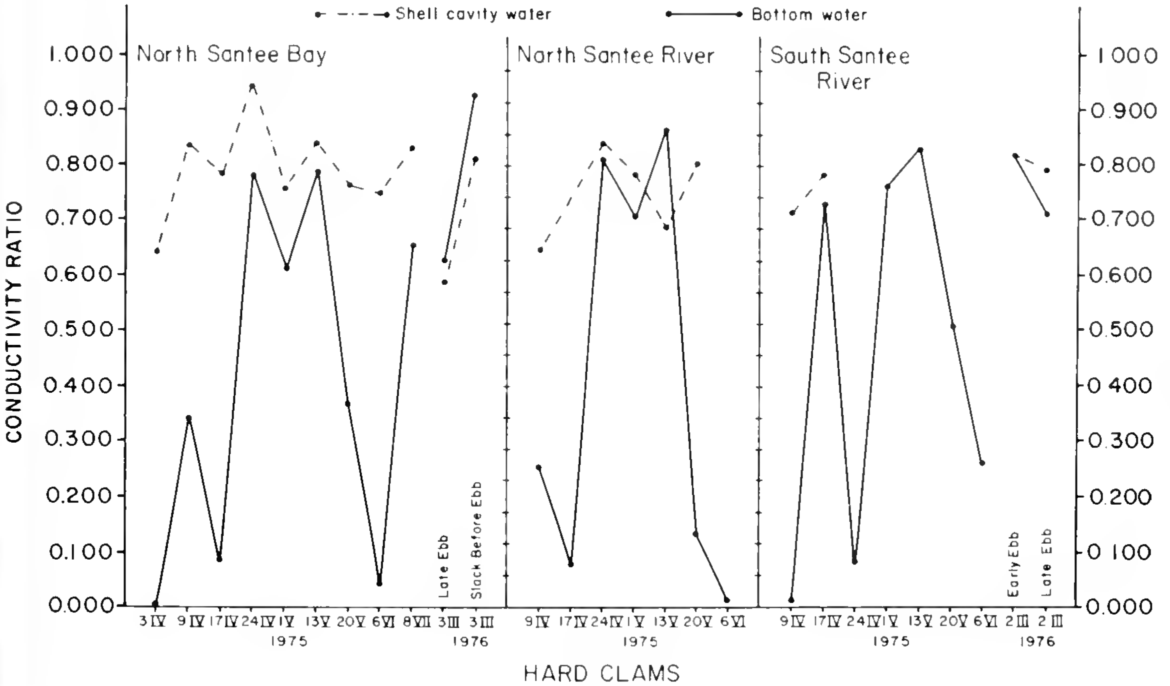

FIG. 2. *Hard clam inner shell cavity conductivities and bottom water conductivities/salinities in Santee River 1975-1976.*

on these dates shell liquor conductivity exceeded surrounding bottom water, following the pattern at the other two sampling sites.

Subtidal oyster conductivity from North Santee Bay exceeded outside water conductivities on each sampling date (Fig. 3). The difference was much greater during periods of high runoff than at times of low runoff. A greater range of conductivity was observed in oysters than hard clams. In North Santee River, liquor conductivity of subtidal oysters was much higher than ambient during periods of high runoff. However, on two sampling dates, when outside salinities were above 28 o/00, oyster liquor conductivity was lower than ambient. Subtidal oysters from the South Santee followed the pattern of the other two systems except in June, when inner shell fluid samples and an extremely high conductivity reading. In both the North and South Santee River, intertidal oysters maintained higher liquor conductivities than the surrounding water during periods of high runoff, but generally had lower inner shell water conductivity ratios than did subtidal oysters (Fig. 4). When external salinities increased, liquor conductivities fell below that of surrounding water.

Liquor conductivities of subtidal oysters and hard clams in North Santee Bay, though much higher than ambient in periods of high runoff, did reflect changes in external ionic concentration throughout the entire sampling period in 1975. During periods of low runoff in 1976, clam liquor conductivity closely reflected outside salinity (Fig. 2). The same was true for subtidal oysters in North Santee Bay and South Santee in 1976 (Fig. 3). Conductivities from intertidal oysters reflected their position above the lower water mark. The lower the position, the lower the conductivity of inner shell water (Fig. 4).

Starfish, oyster drills, whelks, and boring sponges were not observed in any dredge samples taken from subtidal shellfish beds or in intertidal oyster beds in the Santee system in spring of 1975. Starfish (*Asterias forbesi*) and the common oyster drill (*Urosalpinx cinerea*) were present in dredge samples taken over Santee subtidal shellfish beds in 1976.

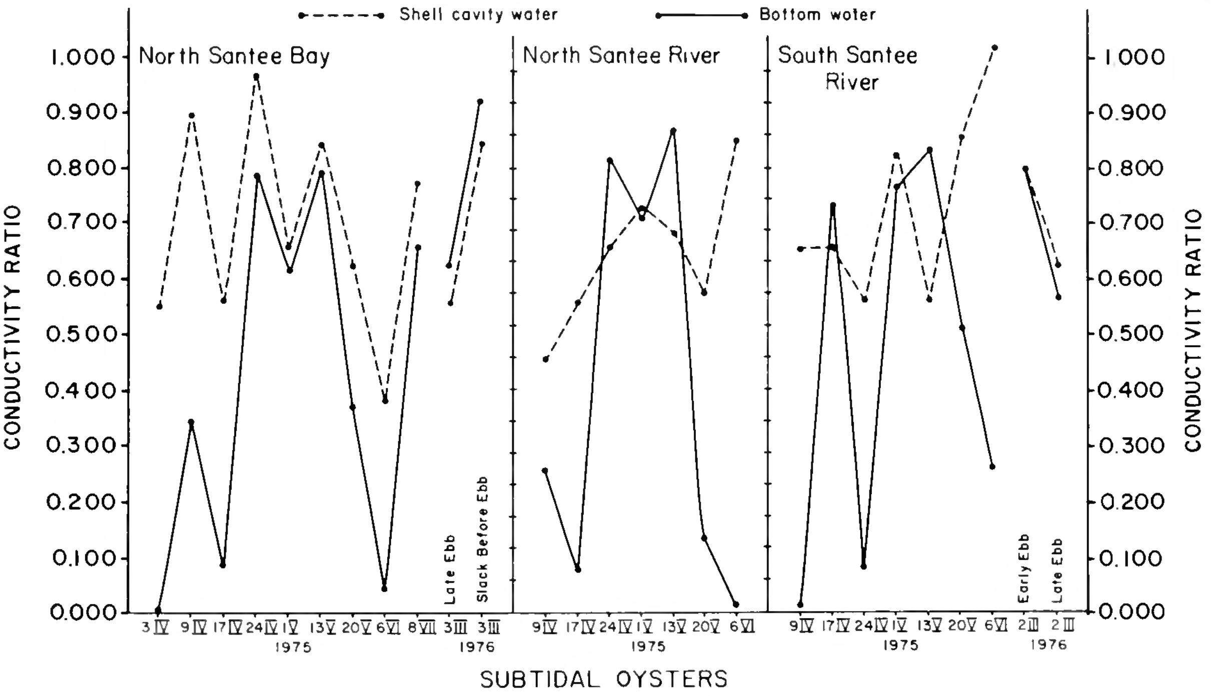

FIG. 3. *Subtidal oyster inner shell cavity conductivities and bottom water conductivities/salinities in Santee River 1975-1976.*

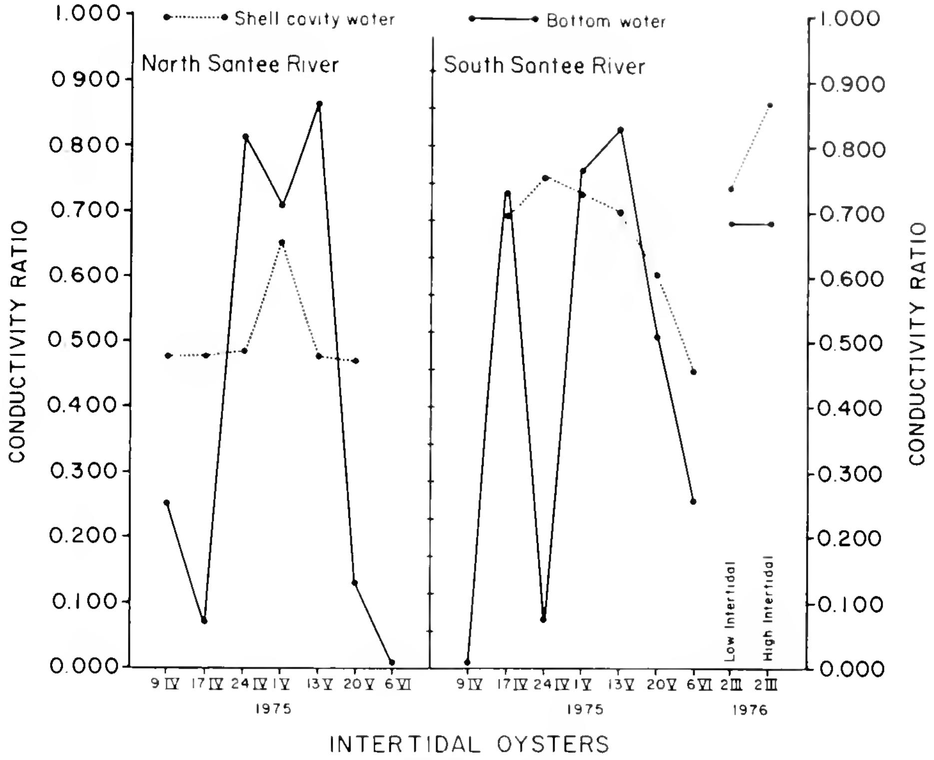

FIG. 4. *Intertidal oyster inner shell cavity conductivities and bottom water conductivities/salinities in Santee River 1975-1976.*

DISCUSSION

The distribution of hard clams indicates that they are more stenohaline than oysters (Wass, 1972). However, short-term tolerance of low salinity appears greater in clams than oysters (Haven *et al.*, 1975). This may be due to the ability of clams to cease or restrict pumping for longer periods than oysters, or that clam microhabitats are more conducive to less metabolic activity than oyster microhabitats. Dugal (1939) indicated that shell calcium buffered the acid products of anaerobic metabolism in both clams and oysters and that the efficiency of this mechanism increased with decreased temperatures. Santee clams were buried and subject to lower ambient temperatures because of buffering effect in sediments to rising spring temperatures (Carriker, 1967). Subtidal oysters, which for the most part lie on a shell bottom or intertidal oysters which may be exposed to as much as 10 hours of highly variable air temperatures daily, are subject to higher ambient temperatures. Clam shell cavity conductivity showed an upward trend while ambient salinities were low, indicating reduced or suspended pumping activities. Observed changes in ionic concentration of South Santee Bay hard clam and subtidal oyster liquor, remaining higher but paralleling external conductivities, indicate that some exchange, however, probably occurs during low salinity periods. Hard clam conductivity fluctuated less with changing salinities than did oysters. This might explain to some degree the higher mortalities found by Haven *et al.* (1975) in relaid clams. If these clams were not as well buried in the bottom, and thereby insulated from higher water temperatures, then ability to reduce pumping might well be affected.

Andrews *et al.* (1959) found oysters conditioned to low salinity at low temperatures were able to withstand low salinities in a state of "narcosis" for long periods. This reaction to low salinity probably did not occur in Santee oysters because low salinity came during a period when oysters were actively pumping (Fig. 3). The higher mortality of subtidal oysters in North Santee may be a result of higher freshwater discharge though this distributary resulting in more pronounced lower salinities. Salinity also might be responsible for higher losses in intertidal than subtidal oysters in South Santee and the equally high losses in intertidal oysters in North Santee. The samples showed a strong surface to bottom salinity gradient was present at times during the high runoff in spring of 1975. This would subject intertidal oysters to lower salinities than subtidal oysters as they come in contact with surface water at some stage of nearly every tide.

Low dissolved oxygen concentrations in the water column often accompany high freshwater run off (McHugh 1967). Such conditions, together with the hydrogen sulfide produced when lower strata of the water column become anaerobic, have been implicated in mortalities of shellfish (Carpenter and Cargo, 1957; Tamura, 1966). No evidence that this may have occurred in the Santee System during 1975 was observed either by low dissolved oxygen values or black shell coloration of dead or dying oysters. In addition, highest mortalities occured in the intertidal zone where oxygenation of the water column would be highest.

Predators often implicated in high shellfish mortalities were not observed in any samples taken in Spring of 1975. Therefore, most if not all mortalities observed during the spring of 1975 can be attributed to low salinity. Starfish and drills were abundant in all subtidal areas during 1976, and were probably responsible for many of the deaths recorded in these samples.

SUMMARY

1. High mortalities occurred in subtidal and intertidal oyster populations in the Santee River during the spring of 1975, concurrent with high freshwater runoff.

2. Deaths among hard clam populations were substantially fewer than in oysters.

3. Liquor conductivity suggested that hard clams remain closed for longer periods than oysters.

4. The ability of an organism to remain closed might be related to microhabitat, with the sediment providing insulation against rising temperature.

5. Common shellfish predators were not present in 1975 during the low salinity period.

6. Low dissolved oxygen did not accompany low salinity in the Santee River in 1975.

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AN EMPIRICAL EVALUATION OF THE LESLIE-DeLURY METHOD APPLIED TO ESTIMATING HARD CLAM, *MERCENARIA MERCENARIA*, ABUNDANCE IN THE SANTEE RIVER ESTUARY, SOUTH CAROLINA[1]

Raymond J. Rhodes, Willis J. Keith,
Peter J. Eldridge, and Victor G. Burrell, Jr.

SOUTH CAROLINA WILDLIFE AND MARINE RESOURCES DEPARTMENT
CHARLESTON, SOUTH CAROLINA

ABSTRACT

This paper estimates the abundance of hard clams, Mercenaria, mercenaria, *in the Santee River estuary based upon catch and effort data generated by hydraulic escalator clam harvesters between 1974 and 1976. Using the Leslie method, catch per unit of standardized effort at each time interval was regressed on the cumulative catch. The resulting regression equations had regression coefficients (estimates of catchability) of .0006, .0014, and .0006 for the South Santee River, North Santee River and North Santee Bay, respectively. There were an estimated 6.4 million, 5.0 million and 10.7 million clams in the legal harvesting areas of the South Santee River, North Santee River, and North Santee Bay respectively. The density of clams in the preferred fishing areas varied between 18/m^2 and 24/m^2.*

In this analysis, the Leslie-DeLury method had two major limitations: first, the lack of effort estimates for specific locations, and second, significant gear competition. It is suggested this method should be considered only for supplementing designed, direct sampling.

INTRODUCTION

In the spring of 1974, the environmental impact and commercial feasibility of using hydraulic escalator clam harvesters was investigated in the Santee River estuary of South Carolina. Based on sampling results and interest by commercial fishermen (Gracy, *et al.*, 1976), the South Santee River was opened for harvesting of clams, *Mercenaria mercenaria*, from September to December in 1974. In subsequent clam seasons, the North Santee river and North Santee Bay were also opened to mechanical harvesting by this equipment. Since 1974, commercial hydraulic escalator harvesting in the Santee Delta has resulted in a significant increase in revenues from the clam fishery (Table 1) and has become a source of seasonal income for commercial fishermen living in McClellanville, South Carolina.

The Maryland hydraulic escalator harvester has been described by others (e.g., Manning, 1957; MacPhail, 1961; Mathieson and DeRocher, 1974). The harvester (Figure 1) is basically a cluster of water jets in front of a scoop (escalator head). Water jets loosen the substrate; clams and other benthos are flushed onto the conveyor belt and carried to the surface for hand sorting. With a normal amount of propeller thrust, the escalator head can be forced through 40 to 45 cm of ". . . solid bottom . . ." (Manning, 1959).

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[1] Contribution No. 68 from the South Carolina Marine Resources Center. References to firms in this paper do not imply endorsement of commercial products by the State of South Carolina.

TABLE 1. *Reported commercial clam,* Mercenaria mercenaria, *landings (U.S. bushels) from 1971 thru 1975 shown by method of harvest.*

	Harvest Method					
	Other		Hydraulic Escalator			
Clam Season	Quantity	Percent[a]	Quantity	Percent	Total	Total Exvessel Value
1971-72	5,296	100%	0	0	5,296	$ 17,370
1972-73	11,292	100%	0	0	11,292	44,273
1973-74	4,594	64%	2,582	36%	7,176	45,339
1974-75	11,302	27%	30,917	73%	42,220	213,382

[a] Percent of total clam harvest for the clam season.

The Leslie (Leslie and Davis, 1939) and DeLury, (DeLury, 1947) methods for estimating population abundance have been employed for many fishery stocks (e.g., Omand 1951; Ketchen, 1953; and Dickie, 1955). Loesch and Haven (1973) employed the Leslie method for estimating clam abundance when using a hydraulic escalator as a molluscan sampling gear. For the South Atlantic states of North Carolina, South Carolina, Georgia and Florida, no published estimates of clam abundance derived from commercial catch and effort data exist.

Consequently, this analysis was performed to evaluate the feasibility of applying the Leslie method to commercial data for estimating clam abundance, and to document the commercial yield from the original populations for future resource management decisions. The second objective seems especially relevant because much of the Cooper River freshwater flow will be rediverted into the Santee River over the next four years. Kjerfve (1976) believes the rediversion will destroy the hard clam and seed oyster beds in the lower Santee River.

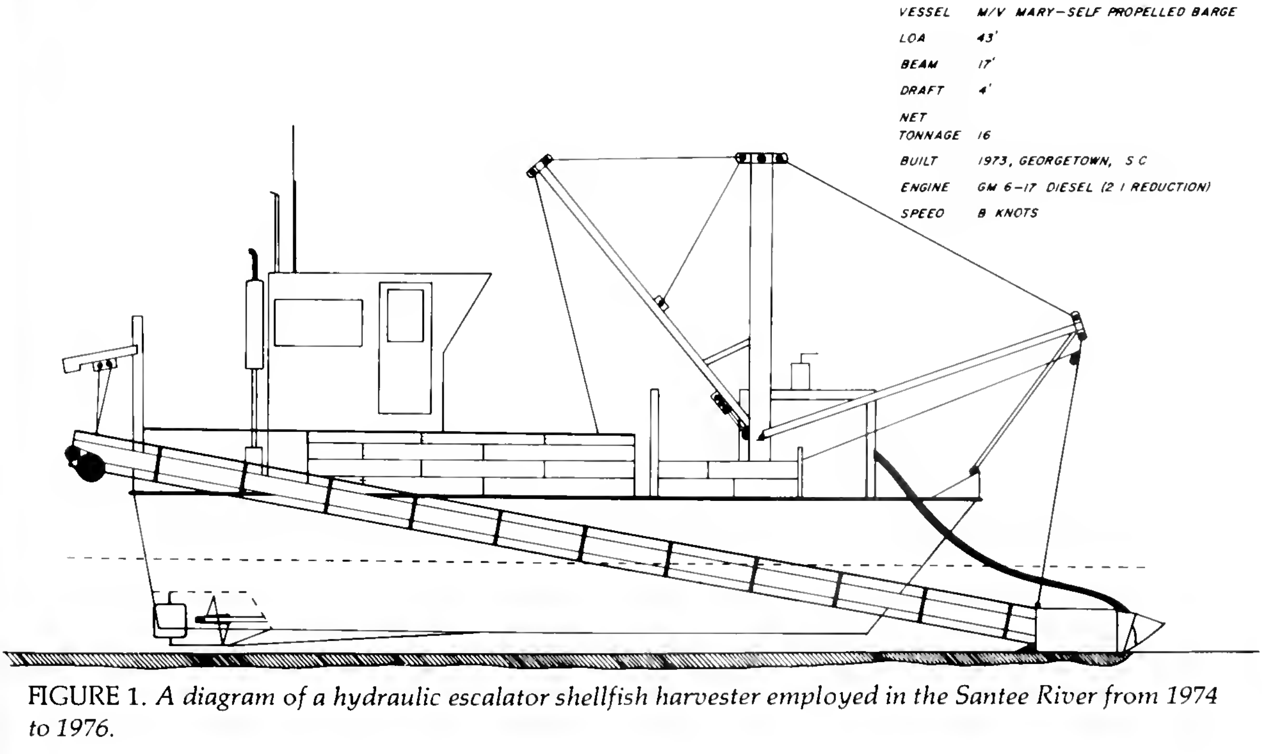

FIGURE 1. *A diagram of a hydraulic escalator shellfish harvester employed in the Santee River from 1974 to 1976.*

METHODS AND MATERIALS

Description of Harvesting Areas. The Santee River flows southeast through South Carolina, draining a river basin of approximately 41,000 km^2 (Anonymous, 1973) before it empties into the Atlantic Ocean 75 km northeast of Charleston, South Carolina (Figure 2). With the completion of the Santee-Cooper Dam in 1942, most of the fresh water discharge in the Santee River was diverted into the Cooper River, thereby decreasing the flow rate of the Santee from 525 m^3/s to 80 m^3/s (Cummings, 1970). At present, approximately 85% of the fresh water reaching the lower Santee Rivery system flows through the North Santee River channels (Cummings, 1970) compared to 15% in the South Santee River channels. Marine processes are eroding the present Santee River delta front, and within the old distributary channels of the North Santee, coarse marine channel sands have accumulated while finer bar sands are being deposited in the shallower water (Stephens, *et. al.*, 1976).

The lower Santee River is a partially mixed estuary, although during flood conditions it approaches the vertically homogeneous type (Kjerfve, 1976). In the North Santee River mouth, bottom salinity ranges from 35 o/oo at flood slack to 32 o/oo at ebb slack (Stephens, *et. al.*, 1976). Bot-

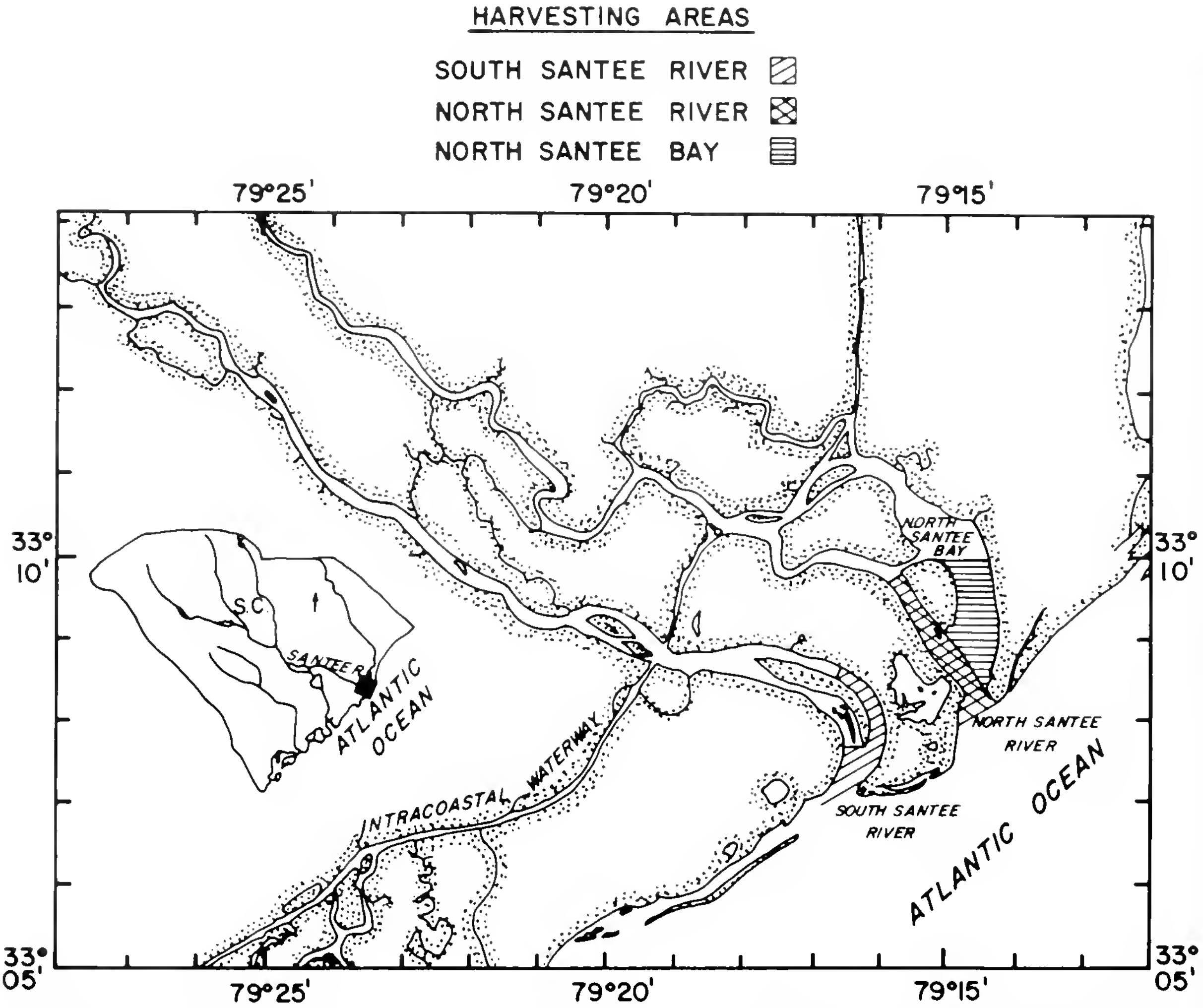

FIGURE 2. *A chart of the Santee River delta, South Carolina, and designated legal harvesting areas from 1974 to 1976.*

tom temperatures range from 8°C in January to 30°C in August (Shealy, 1976). Bottom dissolved oxygen apparently varies between 5.6 ml/l to 4.2 ml/l during the year (Burrell, 1976).

Logbook Catch and Effort Data. Under authorization of Section 28-775, S. C. Code of Laws, permits were issued for hydraulic escalator harvesters during the 1974-75 and 1975-76 South Carolina clam seasons. The legally designated fishing areas for harvesting hard clams will be referred to as the "South Santee River", "North Santee River", and "North Santee Bay" (See Figure 2).

Permit holders were required to maintain a logbook for each harvesting day. The following information was reported: start of fishing time; end of fishing time; an estimate of time spent repairing gear while in the harvesting area; quantity and grades of clams harvested; quantity of oysters harvested; date of harvesting; vessel operator's name and vessel's permit number. In this study, fishing time is defined as an estimate of the hours spent searching for and harvesting clams. Most operators did not indicate time spent for meals or rest periods. The authors observed that during fishing times that exceeded six hours, rest periods and "lunch breaks" usually lasted one hour except when repairs were performed. An hour was subtracted from reported daily fishing time when the total exceeded seven hours. If repairs were indicated in the logbook form, then the one hour adjustment was not subtracted, but the repair time was subtracted because meals and rest periods were usually taken during this time.

After the 1975-76 clam season harvester operators were interviewed to document the spatial distribution of harvesting effort within the legal fishing areas (Figure 2) during previous seasons.

Standardization of Fishing Effort. Fishing effort was standardized by selecting a vessel with a "Maryland type" displacement, vessel No. 5, as a standard, and assigning it a relative fishing power of 1. As Beverton and Holt (1957) indicated, the selection of the vessel for a standard can be arbitrary, and it need not be an "average" vessel for the fishery.

Number of fishing days was considered when selecting the standard vessel to allow the greatest number of direct comparisons. Fishing effort in the South Santee River (nine permits) during 1974 was not standardized due to the changing of vessel operators during the 1974 period and the lack of any previous experience by these new operators.

The standardization method was adapted from Gulland (1956) for the ith vessel, fishing in the time period, t,

$$Y_{it} = c\, P_i \cdot f_{it} \cdot D_t \cdot e_{it} \qquad (1)$$

where

Y_{it} = catch
P_i = relative fishing power of the ith unit
f_{it} = time spent fishing of ith boat in tth interval
D_t = clam density in tth interval
c = proportionality factor
e_{it} = random error term

A catch per unit of effort (Time) logarithmical transformation of (1) as suggested by Gulland (1956) becomes,

$$\log \frac{Y_{it}}{f_{it}} = \log c + \log P_i + \log D_t - \log e_{it} \qquad (2)$$

Two-way analyses of variance tests were performed by utilizing BMDO5V, General Linear Hypothesis (Dixon, 1967), to determine if relative fishing powers of vessels and densities of clams varied significantly during the tenure of the two fisheries. Fishing powers and density of clams for both fisheries did vary significantly (See Table 2). Since catches of every vessel in the fishery were used to calculate relative fishing powers, it was

TABLE 2. *Results of the two-way analysis of variance tests for North Santee River and North Santee Bay fisheries.*

Source of Variation	*d.f.*	F_h[a]
	North Santee River	
Relative Fishing Power	8, 114	9.14**
Density of Clams	20,114	14.21**
Source of Variation	*d.f.*	F_h
	North Santee Bay	
Relative Fishing Power	6, 97	15.68**
Density of Clams	18, 97	11.64**

[a] The method for calculating F_h summarized by Dixon (1967).

not necessary to perform regression analysis relating vessel attributes to relative fishing powers. Calculated relative fishing powers obtained by the use of the BMDO5V program are shown in Table 3. As described previously, vessel No. 5 was assigned a relative fishing power of 1; hence, it was considered the standard vessel.

The Leslie-DeLury Method. The Leslie-DeLury methods are based upon the decline in catch per unit of effort due to the removal of individuals in the exploited population. Since the catch per unit of effort is altered by factors independent of population density (e.g., weather), a series of temporal estimates is usually calculated. According to Ricker (1975), the predictive regression line in the DeLury method will underestimate catchability and consequently overestimate the original population abundance. The Leslie method was selected because it was considered preferable to underestimate resource abundance for the management decision process.

In the original Leslie method, catch per unit effort at each time interval was regressed on the cumulative catch at the start of the time interval. Using a modification by Braaten (1969) and terminology described by Ricker (1975), the equation for the linear regression line is:

$$\frac{C_t}{f_t} = q N_o - K_t \qquad (3)$$

where

N_o = original population abundance

K_t = cumulative catch to start of interval t plus half of that taken during the interval (See Braaten, 1969)

q = catchability, the fraction of the population taken by 1 unit of fishing effort

$\frac{C_t}{f_t}$ = catch per unit of effort during the interval t

The regression equation is estimated by the least squares procedure, and the Y-axis intercept is the absolute value of the regression coefficient (qN_o).

TABLE 3. *Relative fishing power of hydraulic escalator clam harvesters in North Santee River and North Santee Bay, South Carolina.*

Vessel Code	Relative Fishing Power North Santee River	 North Santee Bay
1	.81	1.49
2	.36	.93
3	.62	1.21
4	.73	1.21
5	1.00	1.00
6	.74	1.19
7	.72	.88
8	.88	N[a]
9	.72	N

[a] This vessel did not harvest in the North Santee Bay.

TABLE 4. *The regression equations of the Leslie method for the South Santee and North Santee Rivers and North Santee Bay.*[a]

South Santee River
(t = 7 days)

$$\frac{C_t}{f_t} = 15.4609 - 0.0006K_t$$

North Santee River
(t = 2 days)

$$\frac{C_t}{f_t} = 28.0393 - 0.0014K_t$$

North Santee Bay
(t = 2 days)

$$\frac{C_t}{f_t} = 25.6450 - 0.0006K_t$$

[a] See Gracy, *et al.*, 1976, for legal limitation on harvesting days.

RESULTS AND DISCUSSION

Regression Equation and Correlation Coefficients. The catch per unit effort, C_t/f_t, for each fishing area, was regressed on cumulative catch, k_t, as previously described. The resulting regression equations are shown in Table 4. The analysis of variance results (Table 5) indicate a negative regression coefficient significantly different from zero.

The correlation coefficient (R) was .858, .969 and .965 for the South Santee River, North Santee River and North Santee Bay, respectively. As previously mentioned, South Santee River data variability was probably caused by the entrance of inexperienced harvester operators and the departure of experienced operators during September and October, 1974. It was assumed by December,

TABLE 5. *Analysis of variance results with regression for the South Santee, North Santee Rivers and North Santee Bay.*

Source of Variation	d.f.	Sum of Squares	Mean Square	F
		South Santee River		
Regression	1	115.5955	115.5955	36.3607***
Residual	13	41.3287	3.1791	
Total	14	156.9243		
		North Santee River		
Source of Variation	d.f.	Sum of Squares	Mean Square	F
Regression	1	944.9495	944.9495	310.0777***
Residual	20	60.9492	3.0475	
Total	21	1005.8987		
		North Santee Bay		
Source of Variation	d.f.	Sum of Squares	Mean Square	F
Regression	1	359.0181	359.0181	235.2657***
Residual	17	25.9422	1.5260	
Total	18	384.9603		

TABLE 6. *Catchability (regression coefficient), q, and regression statistics for the Leslie method applied to clam,* Mercenaria mercenaria, *harvesting data from South Carolina.*

	South Santee River	North Santee River	North Santee Bay
Number of observations	15	22	19
d.f.	13	20	17
Catchability	0.0006	0.0014	0.0006
Standard Error	0.0001	.0001	.0001
95% Confidence Limits			
P ⩾	.0004	.0012	.0005
P ⩽	.0009	.0016	.0007

1974, and January, 1975, that their skills had improved significantly.

Catchability. The regression coefficients (estimates of catchability), q, were .0006, .0014 and .0006 for the South Santee River, North Santee and North Santee Bay respectively (Table 6). Confidence limits of catchability for the three harvesting areas are shown in Table 6. A comparison between North Santee River's catchability and North Santee Bay (Table 7) indicates a significant difference.

According to Braaten's (1969) analysis, the constancy of catchability within the fishing season should be a major concern of investigators attempting to estimate the size of a population employing the Leslie-DeLury method. For example, if actual catchability decreases during a fishing season, the Leslie-DeLury method results in an increased (higher) estimate of catchability, which in turn results in a lower initial population size estimate.

Harvesting Areas. Because effort was much greater per area (Table 8) in the North Santee River, one of the major assumptions of the Leslie-DeLury method, i.e, units of fishing effort during the season not being competitive, may have been violated for the North Santee River. Moreover, due to the immobility of hard clams, their spatial

TABLE 7. *The analysis of covariance for catchability (regression coefficients) of the North Santee River and North Santee Bay.*[a]

		Error (Residual)		
Location	d.f.	Sum of Squares	Mean Square	F
North Santee River	20	60.9495	3.0475	1.9970
North Santee Bay	17	25.9422	1.5260	
		Error (Residual)		
Source of Variation	d.f.	Sum of Square		F
Within Locations	37	86.8917	2.3484	
Pooled	39	770.1354	19.7471	
Between Slopes	1	683.2437	683.2437	290.9401***

[a] Table format adapted from Snedecor and Cochran (1967).

TABLE 8. *Estimates of original clam* (Mercenaria mercenaria) *population size,* N_0, *available to hydraulic escalator harvesters in the Santee Delta, South Carolina from 1974 thru 1976.*

	LOCATIONS		
	South Santee River	North Santee River	North Santee Bay
Surface Area	104 ha.	53 ha.	159 ha.
Effort[a]	1517 hr.	1111 hr.	1521 hr.
Effort/Surface Area	14.58 hr.	20.96 hr.	9.57 hr.
Y — Intercept	15.4609	28.0393	25.6450
N_0	6,442,042 clams (25,768 "bags"[c])	5,007,000 clams (20,028 "bags")	10,685,417 clams (42,742 "bags")
95% Confidence Limits[b]			
d.f.	13	20	17
P≥	4,829,020	4,624,000	9,499,750
P≤	7,251,039	5,354,250	14,149,000
Percent of Actual Harvest	59.4%	76.6%	60.7%

[a] Effort not standardized for the South Santee River (See Text).

[b] See DeLury (1951) for formula emplyed in estimating the confidence limits of N_o.

[c] There are approximately 250 ungraded clams per "bag".

distribution in the North Santee River probably increased in heterogeneity (i.e., aggregation) compared to other harvesting sites. This could have increased the probability of a given unit of effort being expended on a substrate nearly "swept clean" by previous effort and may have resulted in a declining catchability coefficient during the season.

Estimate of Density. The y-axis intercept was divided by catchability to obtain an estimate of the original population (N_o) in each harvesting area (Table 8). If these abundance estimates are divided by the total surface area in each legally designated fishing area there would be an overall average of approximately 6.5 clams/m², 9.5 clams/m², and 6.7 clams/m² in the South Santee River, North Santee River and North Santee Bay, respectively. However, unpublished data revealed the presences of two distinct clam density strata in the Santee River estuary; the lowest strata having a density of less than one clam/m². The higher density strata in the three areas varied between 22 and 27 clams/m². Higher density strata was characterized as "sand-shell" substrate and the lower density strata as "sand". Interviews of harvester operators indicated that they had concentrated their effort in the higher clam density strata. As Gullard (1969), has emphasized, fishermen generally expend their effort where they believe the highest stock densities occur. Based upon interview information and the estimate of N_o in each harvesting area, the density of clams in the preferred fishing areas varied between $18/m^2$ and $24/m^2$. These are in good agreement with unpublished data, but due to the subjective nature of interviewing and the difficulty in defining strata precisely, density estimates obtained in conjunction with the Leslie-DeLury method should be considered approximations.

Evaluation. The accuracy of the Leslie-DeLury method when applied to simple commercial fishing catch and effort data has two major limitation compared to designed, direct sampling (e.g., Loesch and Haven, 1973): first, the lack of effort estimates for specific locations, and second, potential of commercial gear interaction. The first limitations might be removed by requiring that vessel operators keep detailed records of their harvesting location. This approach would obviously increase the time (cost) which the operator must devote to record keeping. In contrast, the simple logbook system used in this investigation was generally compatible with the record system of the owners and vessel operators, since most of them maintained daily records of their catches. In areas where harvestable quantities of clams are apparently clustered in a small site (e.g. North Santee River), the second limitation is not avoidable and consequently makes an abundance estimate questionable.

Because of these difficulties, we suggest that this method should be considered only for supplementing direct sampling activities. Such sampling would describe not only the spatial distribution, but also the possible existence of clam density strata so that the influence of distribution on the assumptions required in the Leslie-DeLury method can considered.

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AN ANALYSIS OF TRENDS IN OYSTER SPAT SET IN THE MARYLAND PORTION OF THE CHESAPEAKE BAY

George E. Krantz and Donald W. Meritt

HORN POINT ENVIRONMENTAL LABORATORIES
CAMBRIDGE, MARYLAND 21613

ABSTRACT

Statistics on commercial harvest of oysters and on spat set on natural cultch that occurred from 1939 to 1975 in the Maryland portion of the Chesapeake Bay, were analyzed to explain recent fluctuations in abundance of oysters. Data appear adequate to predict a decline in oyster production in the immediate future. A period of reduced spat set that began in 1968 is the lowest reproductive success recorded for Maryland waters. This condition has occurred in every river system and geographic subunit in the Bay. Spat set has declined significantly in some of Maryland's prime seed oyster production areas. Biological explanation of this phenomena is difficult and Hurricane AGNES which devastated some regions of the Bay cannot be the sole cause of the problem. Other environmental factors and oyster management programs are discussed in reference to the reduction in natural oyster recruitment.

INTRODUCTION

Natural history observations on aquatic animals such as oysters have long been a favorite pastime of biologists studying the Chesapeake Bay (Ferguson *et al.* 1880, Yates 1913). Beginning in the late 1930's biologists at the Chesapeake Biological Laboratory (Natural Resources Institute of Maryland) standardized oyster bar sampling techniques and developed a "field data sheet" where observations on various aspects of the oyster bar communities found in the Chesapeake Bay were systematically recorded. Over the years, oyster bars were inspected annually and the field data sheets have been prepared by a large number of individuals with diverse reasons (management, research, Health Department survey, etc.) for examining the oyster bars.

Personnel at the Chesapeake Biological Laboratory conducted the majority of the surveys until the late 1950's (Beaven 1955) when the field work was assumed by personnel of the State management agency — The Department of Natural Resources.

During the past two years we have assembled, compiled and analyzed various types of data from these sheets. One very interesting phenomena which these field studies document is the change in pattern and density of oyster spat set on natural cultch on the various natural oyster bars in Maryland's portion of the Chesapeake Bay. These data may be found in a recently published document by Meritt (1976). This report is a synopsis of the data which were extracted from over 990 legally defined oyster bars that occupy over 215,000 acres of Chesapeake Bay bottom.

Statistics on the commercial harvest of oysters from the Chesapeake Bay have been collected with various degrees of accuracy since the late 1800's. Data collected by the Fisheries Statistics Branch of National Marine Fisheries Service (Anon, 1973) show a dramatic decline in oyster production from 1890 to 1935, (Figure 1) followed by a more gradual trend toward lower levels of annual harvest. Although Maryland waters have contributed from 55 to 80 percent of the marketable oysters removed from the Chesapeake Bay during

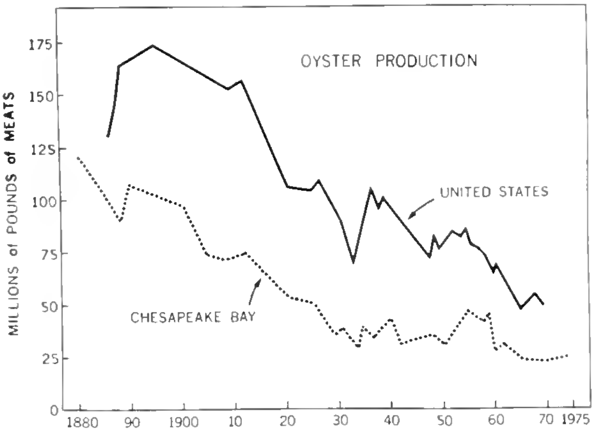

FIG. 1. *Production of oysters* Crassostrea virginica *in Chesapeake Bay and in the United States, 1880 to 1975.*

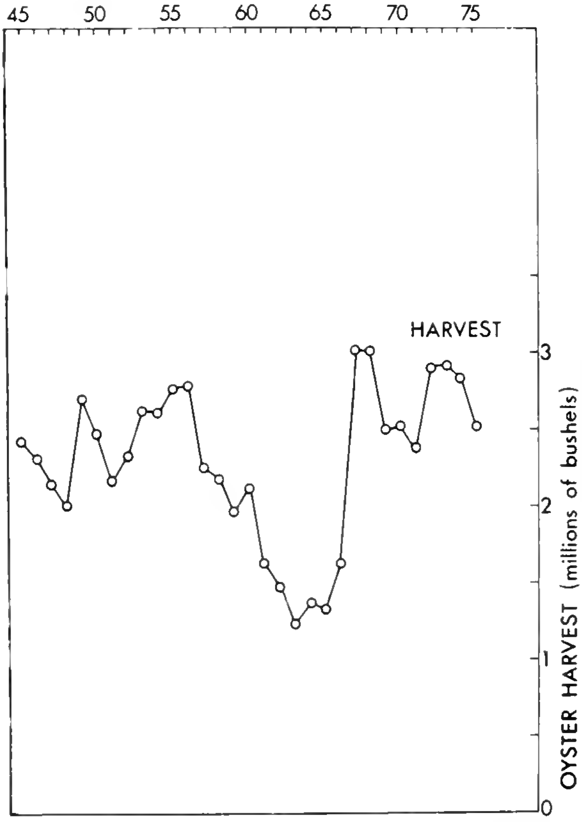

FIG. 2. *Harvest of oysters from the Maryland portion of the Chesapeake Bay in millions of Bushels per year (1945-1974).*

the past 30 years, Maryland oyster harvest statistics (Figure 2) have shown several periods of fluctuation with a marked decline in harvest during the early 1960's. A combination of changes in the social structure of the Maryland population, major shifts in consumer tastes, the rising cost of seafood processing labor, changes in environmental conditions in the Bay, and a decline in the number of oysters available for harvest are collectively responsible for the general decline in landing statistics shown in Figure I. However, several biological factors have also been responsible for the fluctuations in oyster harvest during the past 30 years. Some of these factors have been described through studies of oyster populations in the Chesapeake Bay that were conducted by biologists employed at the University of Maryland, Chesapeake Biological Laboratory; the Oxford Biological Laboratory (NMFS); and the Fisheries Administration of the Maryland Department of Natural Resources. Collectively these studies have produced records of changes in the quality and quantity of adult oysters, mortalities due to diseases and natural phenomena, and the periodicity of successful reproduction, or spat set[1].

OYSTER RECRUITMENT

One Underlying theme found in these studies and in the "field data sheets" which appears to explain the recent and past variations in oyster harvests is the periodicity and geographic distribution of oyster spat-set on natural cultch in the Chesapeake bay. The annual spat set, or natural recruitment, and subsequent growth of the oysters sustains the population of harvestable oysters throughout the Bay. Bay-wide survey techniques that were developed in the late 1930's to determine the number of spat per bushel of shell and/or oysters taken from the natural oyster bars each year, can be used to measure annual variation in recruitment throughout the Bay (Figure 3). Even though recruitment is expressed as a Bay-wide average in this figure (as are harvest statistics found in Fig. 2) two periods of low recruitment are obvious. The first period, 1952 to 1960, is followed by five years of high spat set. The second period of depressed recruitment, 1966 to 1975, is the period of current concern.

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[1] The reader is referred to bibliographies available from these agencies which list published papers as well as unpublished internal reports.

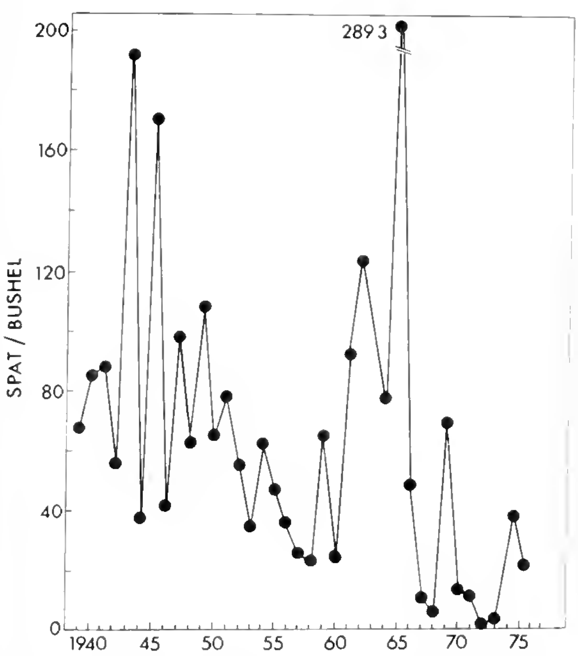

FIG. 3. *Spat Production on natural cultch for Maryland portion of Chesapeake Bay 1939-1975.*

Each geographic area of the Bay (such as Potomac River, Choptank River, Eastern Bay, Tangier Sound, etc.) has experienced different levels of recruitment during the 35 year study period (Fig. 4). Reasons for variation in recruitment in natural populations of oysters are numerous. Environmental disasters during the natural spawning period have obvious effects on the delicate, swimming oyster larvae. Beaven (1946) and Engle (1946, 1955) have shown a relationship between the periodicity of discharge from a given river and the subsequent spat set in that river system.

Hurricane AGNES (which changed the temperature, salinity, and water quality throughout the whole Bay) in June 1972 is an obvious example of an environmental disaster (Anon, 1975). However, most environmental changes are so subtle that the lay public, fishermen and even shellfish biologists do not notice any problems in the oyster populations.

One of these "subtle" disasters was the impact

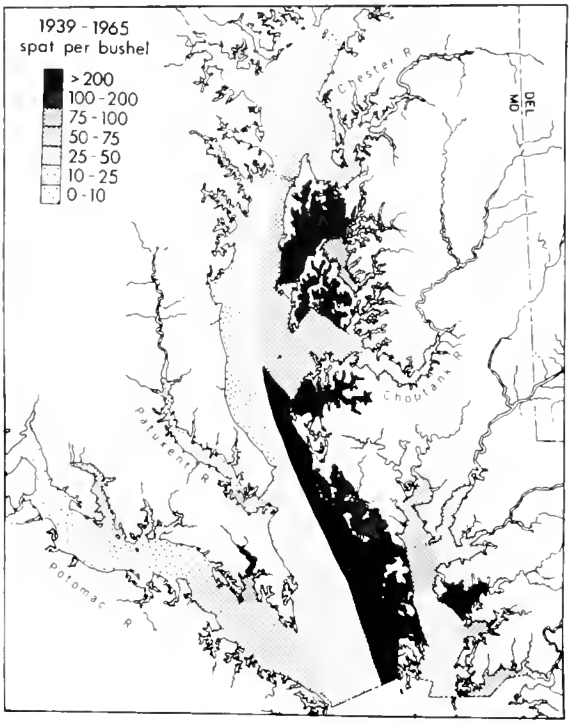

FIG. 4. *Distribution of oyster spat set on natural cultch in the Maryland portion of the Chesapeake Bay 1939-1965.*

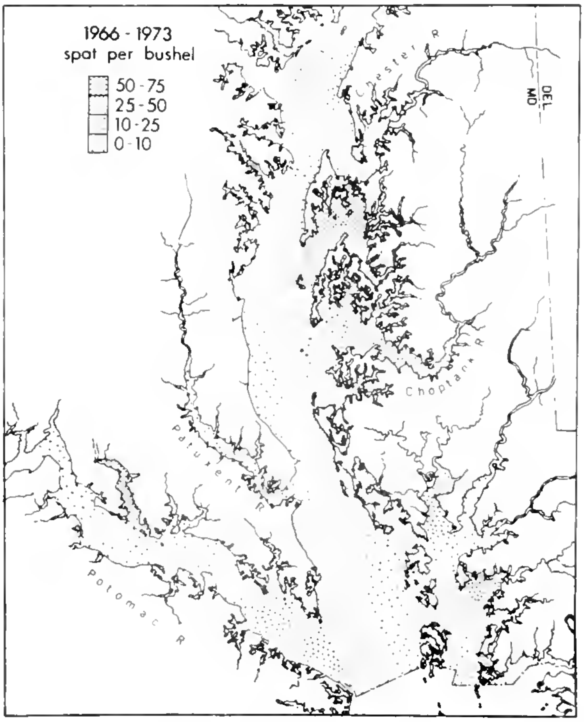

FIG. 5. *Distribution of oyster spat set on natural cultch in the Maryland portion of the Chesapeake Bay 1966-1975.*

of the protozoan disease, *Minchinia nelsoni*, ("MSX") on oysters in the Chesapeake Bay. Effects of this disease are reflected in reduced harvests (Fig. 2) and poor recruitment on specific oyster bars in the Southeastern portion of the Bay (Meritt 1976) during the mid 1960's (Andrews 1960, Sindermann 1968). The impact of "MSX" disease was also severe enough to depress the Bay-wide average spat set for several years even though "disease-free" areas of the Bay had very high recruitment.

Of immediate concern is the period of reduced spat set from 1966 to 1975. Spat set during this period has been lower than ever encountered during biological studies of the Chesapeake Bay and should have an impact on abundance of harvestable oysters during the next 4 to 7 years. Figure 5, which presents geographic distribution of spat set during this period (1966-1975), shows that the problem occurred in all areas of the Bay. Areas with traditionally low levels of spat set (Figure 4) have had virtually no recruitment for 6 years; whereas areas of high annual spat set (Eastern Bay, Broad Creek, Harris Creek, Honga River, St. Mary's River) have experienced 50 to 85 percent reduction in spat recruitment. The reader is referred to Table 1 for actual data from which Figure 5 was prepared. This table indicates the percent decline in spat set during 1966 to 1975 period in specific areas of the Bay. It is noteworthy that a very high percent reduction of spat set occurred Bay-wide and prime areas for spat set in the Bay were the most severely damaged. Many of the highest spat set areas are also used to collect spat on the dredged shell transplantation program.

TABLE 1. *Oyster Spat Set on Natural Cultch in Geographical Regions of the Chesapeake Bay — 1966-1975. Decline is by Comparison to Mean of Data for 1939 to 1965.*

SPAT AREAS 1966-1975	Spat/bu.	% Decline
1. Kedges Straits	71.9	77
2. Wicomico River (Potomac)	63.4	>01
3. Eastern Bay North	60.3	57
4. Dorchester Shore	59.1	76
5. Hooper Straits	58.2	73
6. Upper St. Marys River	57.0	81
7. Honga River	56.1	66
8. Broad Creek	50.9	68
9. Holland Straits	48.6	78
10. Smith Creek	42.0	70
11. Eastern Bay South	39.0	63
12. Lower St. Marys River	37.6	61
13. Harris Creek	37.3	82
14. Talbot Shore	35.0	47
15. Wye River	35.4	37
16. St. Georges Creek	34.7	46
17. St. Marys Shore	33.8	06
18. Lower Potomac River	33.0	54
19. Middle Tangier Sound	31.3	34
20. Little Choptank River	23.7	83
21. Miles River	26.1	73
22. Manokin River	21.1	81
23. Lower Choptank River	20.9	69
24. Poplar Is. Narrows	20.7	46
25. Fishing Bay	18.7	67
26. Lower Patuxent River	18.0	23
27. Middle Choptank River	23.7	83
28. Middle Patuxent River	14.3	14
29. Nanticoke—Wicomico Rivers	13.6	59
30. Lower Tangier Sound	12.6	73
31. Pocomoke Sound	10.8	85
32. Upper Calvert Shore	10.3	16
33. Upper Bay East	9.8	36
34. Lower Calvert Shore	9.0	80
35. Big Annemessex River	9.0	88
36. Upper Tangier Sound	8.3	89
37. South — Rhode Rivers	8.3	58
38. Upper Bay West	7.2	232*
39. Tred Avon River	7.0	83
40. Upper Patuxent River	6.5	64
41. Upper Choptank River	6.0	78
42. Kent Shore	5.6	89
43. Upper Anne Arundel Shore	4.8	02*
44. Little Annemessex River	4.5	87
45. Upper Chester River	4.4	67
46. Tar Bay	4.0	97
47. Severn River	3.7	78
48. Trippes Bay	3.5	93
49. Lower Chester River	3.3	73
50. Middle Potomac River	2.8	80
51. Lower Anne Arundel Shore	2.7	55
52. St. Clements-Breton Bays	2.4	92
53. Upper Potomac River	0.6	93
54. Lower Bay East	0.0	100
55. Magothy River	0.0	No Data

*Denotes % increase

Lack of spat set on the planted shell has nullified the effectiveness of this once successful management technique.

During the recent period of little or no recruitment, oyster harvest has continued at very high levels, and recent harvest statistics have shown a shift of oyster harvest from traditional areas throughout the Bay to the middle Eastern Shore. This increase in fishing pressure and resultant loss of oyster stocks in specific geographic regions of the Maryland portion of the Bay has been noted by local watermen, seafood packers, and management agencies.

Published biological studies (Hidu, 1969; Hidu *et al.*, 1969) and numerous unpublished observations have determined that three to four years are required for an oyster spat to grow to a desirable market size in the Chesapeake Bay. However, oysters usually found in the commercial harvest range from four to seven years old. Therefore, oyster spat set in a given year will begin entering the commercial harvest about four years later and reduced recruitment will be expressed for an additional two to three years. Figure 6 is a combination of data on annual spat recruitment from Figure 3 and on oyster harvest from Figure 2. Figure 2 has been shifted to the left in time to demonstrate the lag of six to eight years in the effect of recruitment on harvest following a period of good spat set (1964-1965) or a period of poor spat set (1950-1954). Correlation coefficients calculated for various lengths of time between spat set and harvest using the data available in this study were as follows: two years, 0; three years, 0.7; four years, 1.55; five years, 2.1; six years, 3.35; seven years 3.9; eight years, 3.85 and nine years 2.6. These calculations further sustain the theory that a period of successive years of low spat set will require between 6 to 8 years before the period of poor recruitment is reflected in commercial harvest.

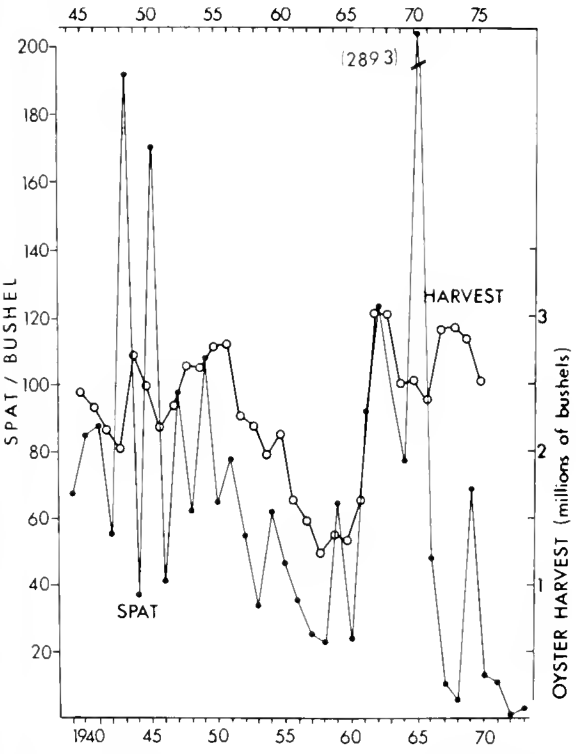

FIG. 6. *Comparison of spat set on natural cultch (Bottom scale) to harvest statistics (top scale) which have been adjusted 5 years in time.*

The 1975-1976 oyster season is nearing the end of the influence of high recruitment during 1964-65, followed by a boost in 1969 in some areas of the middle Eastern Shore. However, the Baywide reduction in spat set during the past eight years should begin to seriously affect harvest levels by late 1976. By inspection of the data in Figure 6 one could predict harvests of less than one million bushels of oysters for the next three to five years. However, any prediction of oyster harvest in Maryland can be invalidated by any changes in the length of season, in existing catch limits, in type of gear used, and by opening any areas previously closed to the fishery, or by annual changes in market demand for oysters. However, available oyster stocks are presently at the lowest level in recorded natural history for the Maryland portion of the Chesapeake Bay. Perhaps for the first time the supply of oysters will solely limit harvest regardless of social or economic changes. Therefore the expected harvest after 1976, should be significantly lower than the previous recorded low levels during the early 1960's (Figure 2).

OYSTER MANAGEMENT STRATEGIES

Several management practices are being employed by the Maryland Department of Natural Resources to sustain levels of oyster harvest thereby stabilizing the industry and social structure supported by the Maryland seafood industry. Transport of oysters from waters polluted by domestic wastes to clean waters for natural depuration provides several hundred thousand bushels of harvestable oysters annually. However, oyster populations in polluted waters have not received spat set for several years and numbers of oysters are being reduced. The planting of dredged oyster shell in seed areas (areas of traditionally high spat set) and subsequent transplantation of spat that attached to this substrate to growing areas, has maintained the harvestable populations of oysters in some locations. This technique was very successful during years of high spat set (1964-1965), but during the recent period of low spat set, a minimum number of harvestable oysters has been produced by the shell planting program. Because of the growth of algae and other estuarine fouling organisms and sedimentation of water born silt on planted shells, dredged shell must be planted annually to provide a suitable surface on which oyster spat may set. This necessitates removing shells planted in the previous year regardless of the number of spat collected on the shell. A recent attempt to cultivate the planted oyster shells (bagless dredging) to produce clean surfaces has shown some success in years of good spat set. However, this technique is expensive in manpower and boat rental. The effectiveness of the bagless dredging procedure is still controlled by natural spat set in the Chesapeake Bay.

Many of the subtle biological reasons for failure of oyster larvae to set in the Chesapeake Bay are currently unknown. Throughout the Bay, biologists have noted an overall increase in turbidity in the water. This turbidity may be related to increased sediment loads in the Bay river systems and to an overall disappearance of rooted aquatic plants which trapped the silt in shallow waters. These rooted aquatic plants also bound energy from the sun, died, and decayed thereby releasing detritus and other plant materials that contributed to the nutrition of adult oysters and to the growth of algae used as food by oyster larvae.

The decline in rooted aquatic plants may be linked subjectively to increased use of herbicides in "minimum-till-farming" as well as other industrial practices that pollute the estuarine environment with persistent chemicals. Levels of several pesticides and PCB's have increased in rivers throughout the United States and in Maryland reached the highest levels in the summer of 1968 (Butler, 1973; Butler, 1976). Since that time these specific residues have declined but are still present in Chesapeake Bay biota. The impact created by these man-made "insults" upon the reproductive capacity of the oyster and other estuarine fauna is not known nor are the subtle natural chemical and physical changes found in the ever-changing Chesapeake Bay.

Another technique that is being used to increase recruitment of natural oyster bars is to spawn and set young oysters in oyster hatcheries, then plant the spat in the natural environment to grow to market-size. Biological and engineering technology have advanced in the past 30 years to a state-of-the-art where oyster hatcheries can control spawning, increase growth of early stage spat and grow marketable oysters more rapidly in special systems than ever observed in nature. The cost of these procedures currently restricts use of the technology to growing oysters only in protected waters where survival of hatchery-reared spat is very high. Conditions on natural oyster bars, (open to public exploitation) are known to produce high levels of mortality in spat and makes the use of hatchery-reared spat to sustain recruitment in natural waters of the Chesapeake Bay questionable on an economic basis.

Research and development studies in the University of Maryland Center for Environmental and Estuarine Studies experimental oyster hatchery at Horn Point are directed toward increasing survival of spat on natural oyster bars, decreasing oyster spat production costs, improving management practices for oyster bars, and producing enough oyster spat so that farming, not just fishing, for oysters in the Chesapeake Bay can become a practicality in the future.

Presently the shellfish research hatchery at Horn point has a design capacity of 100 to 200 million oyster spat per year. This level of output is about 10 percent of the adult oysters harvested annually and would not be adequate to indefinitely sustain the existing Maryland oyster fishery. However, contributions of spat from this oyster hatchery can be of significant value in rehabilitating over-harvested oyster bars during years when natural spat set did not occur. Oyster spat produced by this hatchery may be even more valuable if used to develop new biological and engineering technology, improve and demonstrate the oyster farming techniques for the Chesapeake and educate the public to potential impact of this "new" technology on the traditional oyster fishery.

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ESTIMATION OF LOBSTER POPULATION SIZE AT MILLSTONE POINT, CONNECTICUT, BY MARK-RECAPTURE TECHNIQUES, 1975-1976

Gary H. Cole, Ronald L. Copp, and David C. Cooper

BATTELLE COLUMBUS LABORATORIES
WILLIAM F. CLAPP LABORATORIES
DUXBURY, MASSACHUSETTS

ABSTRACT

Population estimations of the American lobster, Homarus americanus, *in the Millstone point area of Long Island Sound were derived using the Jolly (1965) multiple recapture analysis method. Results to date indicate a population which ranges between 3,800 and 21,000 in an available habitat within the study area of approximately five square miles. Fishing pressure is slight and does not appear to exert a significant effect on size or distribution of the population, but is related to molting periodicity.*

INTRODUCTION

In New England waters the American lobster, *Homarus americanus,* is the subject of an intensive commercial fishery and a less intensive recreational fishery which are of major significance to many local economies. As in the case of pelagic fisheries, various studies have been conducted to determine stock density and the effects of fishing pressure on lobster populations in several localized areas (Wilder, 1947; Templeman, 1935; and Paloheimo, 1963). The approaches have varied, but mark-recapture techniques seem to provide the most reliable results since individual lobsters can be monitored over extended time periods and fairly large areas.

Population estimation relying on mark-recapture techniques involves affixing a unique mark or tag to each member of a subset of a population, releasing the subset into the original population, and recapturing these marked subset individuals along with other organisms within the population. The population size is then a function of the ratio of unmarked to marked individuals within the population, and maximum likelihood estimations can be derived provided that several assumptions regarding longevity, emigration, and immigration are reasonable for the area and organism in question. Paloheimo (1965) discusses mark-recapture methods which are specifically relevant to lobster populations, allow for the varying catchability of tagged and untagged organisms, and allow for motility as related to temperature.

At a more advanced level, Jolly (1965) developed methods of analysis of mark-recapture data which provide estimates of instantaneous population size and allow for multiple recaptures of tagged organisms, thus allowing the monitoring of individuals over longer time periods than less sophisticated population estimation techniques. Likewise, confidence limits can readily be computed from the analyzed data which, in turn, portray a more realistic picture of population estimation in localized areas. These features render the Jolly method an ideal approach for the estimation of lobster populations within defined areas.

The objective of this investigation has been to develop a statistically reliable estimate of lobster crops in a study area at Millstone Point, Connecticut, on the northern shoreline of Long Island Sound. Additionally, the design of the investigation has allowed inferences regarding temporal and spatial variations in standing crops and lobster movements inside and out of the study area to be made.

Although the Millstone Point area is not generally considered to be of primary importance for commercial or recreational lobstering, it was important to assess lobster stocks in the area in order to provide a basis for determining the significance of a nearby bulk power facility. Assessment of lobster population densities is complex, especially with regard to immigration and emigration of lobsters within a study area. The extent and degree of lobster movements have not been clearly defined but appear to be functions of location, depth and temperature. Stewart (Personal communication) has indicated that some lobsters from the Long Island Sound area marked with sonic tags moved as much as 700 yards in one hour while other similarly marked lobsters moved little at all. Morrissey (1971) monitored tagged female lobsters and recorded movements along Cape Cod that averaged 26.1 km during about 39 days. Wilder (1963) and Scarratt (1970) evidenced little movement of tagged lobsters released near Prince Edward Island. Cooper *et al* (1975) showed no discernible seasonal inshore-offshore movements of shallow (less than 75 feet) water lobster populations, indicating to some degree that nearshore lobster populations may be nonmigratory; however, there is no evidence indicating long term residency.

METHODS AND MATERIALS

Study Area. The study area is located about 10 kilometers southwest of New London, Connecticut, adjacent to Northeast Utilities' Millstone Point nuclear generating station. Extensive surveys of bottom types in this area have been conducted in conjunction with the preparation of environmental reports for steam electric stations at Millstone Point and have indicated only a few areas which are suitable for lobster habitation — rocky outcrops interspersed with patches of hard sand. These areas cover about two and a half square miles or about sixteen hundred acres. These locations as depicted in Figure 1 are generally south and east of Millstone Point. Most of the remainder of the study area has bottom types which are comprised of alluvial sediments derived from the Niantic River which enter Niantic Bay from the north.

Lobster Acquisition. Several methods for capturing lobsters for tagging were attempted. Early attempts at setting out artificial burrow habitats and monitoring them regularly by SCUBA proved unproductive, as did removing them by hand from their natural burrows. The use of baited commercial pots set in trawls of five proved to be the most productive means of lobster acquisition. At the onset of this investigation pot trawls were set at several areas in Niantic Bay and around Millstone Point. No lobsters were taken in the pots in Niantic Bay and these pots were moved to more productive areas. No further attempts were made to fish unproductive areas north and west of Millstone Point because maximum catch per unit-effort was necessary to provide statistically reliable estimates.

Beginning in September, 1975, pot trawls were set at each of the four areas near Millstone Point which were suitable for lobster habitation, baited with locally caught fish, and checked three times each week, every Monday, Wednesday, and Friday.

Lobster Tagging. After restraining chelipeds with rubber bands, all lobsters were brought to a

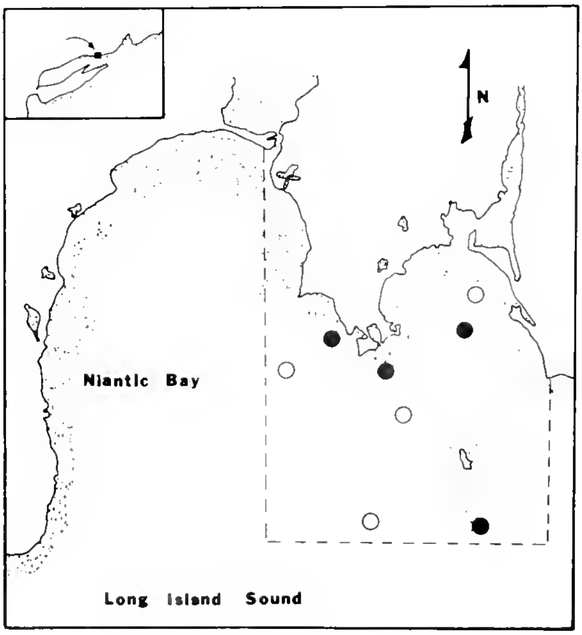

FIG. 1. *The Study Area. Pot Trawl Locations Marked by Closed Circles. Lobster Release Points Marked by Open Circles*

nearby field laboratory with a running seawater system and holding tanks for tagging. Lobsters with carapace lengths greater than 55 millimeters were marked with a sphyrion tag with a stainless steel anchor and No. 20 vinyl tubing. An identification number and our organization's name were stamped on the tubing. Tagging procedures followed those outlined by Scarratt (1970) and allowed for continual security of the tag in spite of periodic molts.

Tagged lobsters were retained in the holding tanks for several days in order to safeguard against any aftereffects of tagging, and released in the study area at points depicted in Figure 1.

Although tag loss after release is an important consideration, no direct attempts were made to assess tag loss rates. Scarratt (1970) suggests a 56% survival rate, and an actual recapture rate of 46.7% for subcarapace sphyrion tags. These calculated limits were acceptable in the present study, and any unusual tag loss or mortality as a result of tagging could be indirectly measured from this data.

Lobster Recapture. Tagging studies usually involve the tagging of legal size lobsters obtained from local lobster fishermen, recapturing of tagged lobsters by same, and tags being returned to the principal investigator. This approach gives estimates of only one segment of the population — legal sized lobsters — and it relys on and assumes accurate reporting by local lobster fishermen. This approach thus presents problems of inaccurate total catch reports and delayed tag returns which can bias population estimates. These factors were recognized at the time that the problem of lobster recapture was considered. Accordingly, only tagged lobsters which were recaptured in our own pot trawls were used in deriving population size estimates. These, in turn, were released immediately and returned to the population. However, tag returns from local (and in some cases, nonlocal) lobster fishermen were useful in determining lobster movements within and outside the study area.

To promote returns from local and nonlocal fishermen, letters were sent to many Connecticut, eastern Long Island, and Fishers Island lobstermen. The tagging program was explained, and returns of tags from legal sized lobsters were requested. Tag identification numbers and point of capture was also requested from tagged sub-legal size lobsters. However, as explained in the letters, it was preferred that tagged sub-legal sized lobsters be returned to the water with the tag intact as this would enhance monitoring over a longer time period. A $2.00 reward was offered for each tag or tag number returned.

Population Estimation. Population estimates were derived according to Jolly (1965). The Jolly model provides for an estimation of instantaneous population within any time interval specified, allows for a flexible sampling schedule, and provides for death, emigration, and immigration. All were considered desirable for this investigation. The Jolly model, like most statistical methods, requires that certain assumptions regarding the population be made. Namely, the population must be single, that is, comprised of individuals that are free to move randomly through a defined area. All marked individuals released into the population must have equal likelihood of capture as unmarked individuals. The population may, however, consist of several classes of animals behaving in different ways. A key feature of this approach to population estimation is that the underlying assumptions of the Jolly model can and have been evaluated from the results of the tagging program itself.

RESULTS AND DISCUSSION

Validation of Jolly Model Assumptions. During the twelve-month period from September, 1975, through August, 1976, 3,811 lobsters were tagged and released. Figure 2 indicates the size frequency

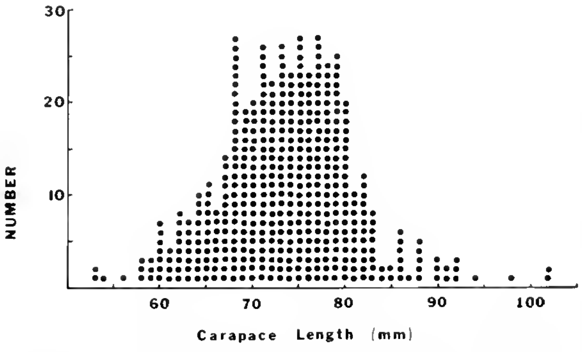

FIG. 2. *Size Frequency Distribution of Lobsters Caught During the Investigation*

distribution of all lobsters captured during this investigation and suggests that a balanced subset of the population was acquired by our sampling protocol. The average monthly rate of recapture of tagged to untagged lobsters was approximately nine percent (see Table 1), but varied somewhat between months. Nonetheless, all monthly recapture rates of lobsters tagged in the *i*'th sample and subsequently recaptured remained fairly constant throughout the investigation (see Table 2).

TABLE 1. *Total Number of Lobsters Tagged, and Total Number of Recaptures Per Month*

Month	Total Tagged & Released	Recaptures	Percent
Oct. 1975	582	37	6.35
Nov. 1975	307	30	9.77
Dec. 1975	612	30	4.90
Jan. 1976	193	18	9.32
Feb. 1976	203	18	8.86
Mar. 1976	328	37	11.28
Apr. 1976	320	40	12.50
May 1976	214	37	17.28
Jun. 1976	373	49	13.13
Jul. 1976	268	25	9.32
Aug. 1976	227	25	11.01
Total	3,811	346	

Catch per unit-effort, expressed as numbers of lobsters, tagged or untagged, (per 100-pot hauls) were calculated on a monthly basis and are listed in Table 3. A two-factor analysis of variance was conducted to assess differences between stations and between months. Since there was only one observation per cell, Tukey's test for additivity was used to determine if any interactions between stations and time occurred. These results are expressed in Table 4. There were no significant differences between stations. However, there were differences in catch per unit-effort between months. Monthly differences in catch per unit-effort probably reflect varying degrees of catchability rather than changes in stock density, as population estimates do not show increases in population size coinciding with increases in catch per unit-effort.

Tag returns from lobster fishermen indicate that there was little emigration from the Millstone study area during the investigation. There were 475 tags returned to us; 27 (5.7%) were taken from lobsters captured outside the study area. Using the Jolly model, which provides for both emigration and immigration, movement was not seen as a major problem.

These results do not suggest varying degrees of catchability for tagged or untagged lobsters, nor is there a suggestion of segregation of tagged or untagged lobsters. Therefore, it is assumed tagged

TABLE 2. *Lobsters Tagged in the i'th Sample and Subsequently Recaptured*

	Month Tagged and Released										
Month	1975							1976			
Recaptured	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Sep 1975											
Oct	11										
Nov	5	20									
Dec	1	10	12								
Jan 1976	0	1	5	9							
Feb	0	2	4	6	3						
Mar	1	5	3	8	7	10					
Apr	0	1	4	6	14	3	6				
May	1	0	5	8	4	1	5	11			
Jun	1	3	4	6	1	4	4	9	16		
Jul	1	0	2	3	2	0	0	2	0	11	
Aug	1	2	0	2	0	2	0	2	1	3	6

TABLE 3. *Lobster Catch Per 100-Pots Hauls at all Stations by Month*

			Stations		
Month	Jordan Cove	Intake	Effluent	Twotree	Total
Jan	142	34	100	102	378
Feb	34	38	26	40	138
Mar	48	69	40	52	209
Apr	99	73	58	49	279
May	52	62	30	32	176
Jun	58	114	64	43	279
Jul	42	64	70	35	211
Aug	52	74	—	40	166
Totals	527	528	388	393	1,836

— = No data, pulled pots.

TABLE 4. *Analysis of Variance of Catch Per Unit-Effort (Two Factors, No Interaction)**

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	P
Station Effect	3	1611.125	537.042	0.809	0.999
Month Effect	5	9371.708	1874.342	2.822	0.054
Residual Error	15	9963.125	664.208		
Totals	23	20945.958			

* Since there is only one observation per cell, we cannot test for interaction with Tukey's test for additivity. Using this model with no interaction means that if interactions are present, then the actual level of significance for testing mean effects is below the specified one. Tukey's test has F much less than 1, so conclude no interactions present so model fits. Now we can say that there are no differences between months or stations at $x = 0.05$; however, there is a difference between months at $x = 0.055$.

TABLE 5. *Monthly Population Estimates (Jolly) Method for October, 1975, through July 1976.*

I	Proportion Marked ALPHA	Total Marked M	Total Number N	Survival Probability PHI	Number Joining B	95% Level ±
Sep 1975		0.00		.9008		
Oct	.0178	165.75	9327.20	.3644	401.87	7656.15
Nov	.0742	281.92	3800.32	1.0801	13714.05	2069.13
Dec	.0358	638.25	17815.50	.4396	—57.23	9690.65
Jan 1976	.0711	552.71	7774.78	1.4221	4630.69	4736.04
Feb	.0679	1064.75	15687.32	1.5778	—3227.32	10417.60
Mar	.0932	2005.00	21524.26	.4127	1466.38	13303.05
Apr	.0932	964.00	10348.82	.7935	—808.55	5591.17
May	.1383	1023.62	7399.28	.5214	2346.48	4793.81
Jun	.1043	646.86	6203.95	.6399	5274.06	4230.25
Jul	.0709	655.83	9244.13			
Aug	.0742					

lobsters mixed randomly with untagged lobsters had equal likelihood of capture as untagged lobsters. If this were not the case, capture ratios of tagged to untagged lobsters would be significantly different over time and recaptures of any one group of tagged lobsters would be higher or more erratic.

Population Estimation. Since the results do not suggest a violation of the Jolly model assumptions, it was utilized in determining the size of the lobster population in the study area. Population estimates by month for the study period ranged from 3,800 in November, 1975, to 21,524 in March, 1976. Table 5 lists monthly estimates, and Figure 3 depicts monthly mean estimates plotted with corresponding 95 percent confidence limits (two standard deviations about the mean).

Considering the available lobster habitat in the study area is approximately two square miles, the approximate population density of legal and near legal size lobsters within the study area ranges from 1,500 to 10,000 lobsters per square mile; the mean population estimate for the study area computed from the entire data base is 10,912 or about 5,000 lobsters per square mile on an annual basis; the stock density ranges are comparable to those calculated by Paloheimo (1963) and Squires *et al.* (1975) for lobster grounds along Canada's Atlantic Coast and off the northwest coast of Newfoundland.

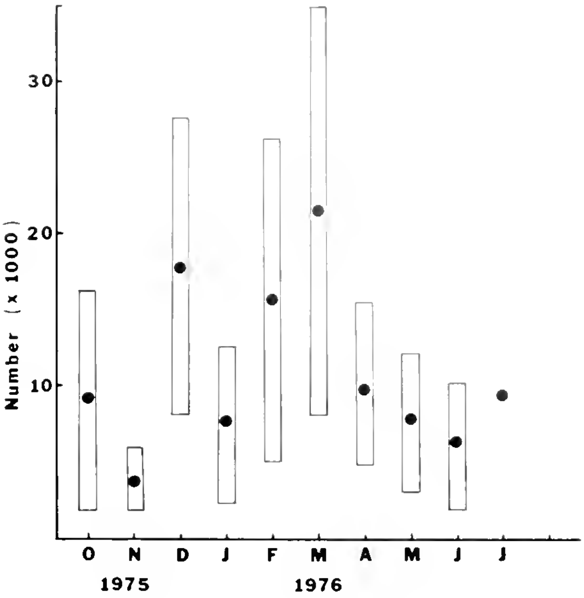

Fig. 3. *Jolly Model Lobster Population Estimates for Study Area, by Month. Closed Circles Designate Means. Brackets Designate Two Standard Deviations About the Mean.*

Several parameters related to population characteristics and fishing pressure are listed in Table 6. Mean carapace length of all lobsters captured in this investigation is 76.3 millimeters, about 5 millimeters less than the legal size in Connecticut. May and August mean carapace lengths are

TABLE 6. *Parameters Related to Population Characteristics and Fishing Pressure*

Month	Growth Via Imminent Molt	Local Lobster Tag Returns	Legal Size Lobsters From Our Pots	Mean Carapace Length
Sep 1975		5	4	—
Oct	4	15	3	—
Nov	—	28	20	—
Dec	—	48	43	—
Jan 1976	—	31	16	77.6
Feb	—	20	16	79.5
Mar	—	16	22	78.0
Apr	13	56	34	—
May	54	54	33	71.6
Jun	102	86	69	79.0
Jul	66	103	55	76.9
Aug	56	40	38	71.5

— = No data.

TABLE 7. *Correlation of Tag Returns with Carapace Length and Imminent Molt*

Factor	vs.	Spearman Coefficient	P Value
Tag Returns	Mean Carapace Length	—.2796	.21
Tag Returns	No. of Imminent Molts	.7143	.06
Tag Returns	No. of Imminent Molts in Previous Months	.7857	.02

significantly ($p = 0.05$) lower than those for all other months. The number of tag returns from commercial lobster fishermen, an indication of fishing pressure, was highest during the summer months.

In an effort to determine the relationships between these parameters, Spearman rank correlation coefficients were computed for the variables. These are listed in Table 7 and indicate that fishing pressure is significantly tied to molting but is not related to the size distribution or the size of the population in a significant way. However, it is assumed that fishing pressure does contribute to fluctuations in lobster population density around Millstone Point. Emigration and immigration of lobsters may also have influenced population size estimates, but are not seen as major influences since the data does not suggest large scale movements of lobsters into or out of the study area during the investigation period. Factors such as available habitat, food, and intraspecific competition are probably more important influences on the size and size distribution of the population in the study area.

ACKNOWLEDGEMENTS

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DETERMINATION OF SHELL CONDITION IN LOBSTERS *(HOMARUS AMERICANUS)* BY MEANS OF EXTERNAL MACROSCOPIC EXAMINATION

G. P. Ennis

DEPARTMENT OF FISHERIES AND ENVIRONMENT
FISHERIES AND MARINE SERVICE
NEWFOUNDLAND BIOLOGICAL STATION
3 WATER STREET
ST. JOHN'S, NEWFOUNDLAND
A1C 1A1

ABSTRACT

Shell condition determination by means of external, macroscopic examination of lobsters (Homarus americanus) is evaluated. The accuracy of the method is determined by comparing carapace length of tagged lobsters at release and recapture and by serum protein concentration of individual lobsters. Over 97% accuracy was achieved for those observations that could be confirmed. It is suggested that shell condition determination by external examination can be used to estimate the proportion of the population molting.

INTRODUCTION

Determination of annual growth rates in lobsters requires data on molt increment and proportion molting at least for those sizes that molt no more than once annually. Using the "sphyrion" tag (Scarratt and Elson, 1965) molt increment data are relatively easy to acquire (Scarratt, 1970; Cooper, 1970; Ennis, 1972) but there are problems associated with obtaining reliable data on the proportion molting. Hepper (1965) discussed various methods of determining whether a lobster has molted and their inadequacies in estimating the proportion molting; he presented an alternate method based on histological examination of the integument of pre-molt lobsters. Aiken (1973) described proecdysis and a method of molt prediction in lobsters. The integument of a recently molted (new-shelled) lobster can be distinguished from that of a non-molted (old-shelled) lobster by histological means (personal communication with Dr. Frank Fifield). However, the difference does not persist long enough for early molters (equivalent to intermolt stages C_2 — C_3 of Drach and Tchernigovtzeff, 1967) in a population to be distinguished from non-molters (stage C_4) near the end or shortly after the molting period. Tag recapture data one year after release can be used to determine the proportion molting by comparing sizes of animals at release and recapture (Hancock and Edwards, 1967). There is concern, however, that tagging might adversely affect the proportion molting. In lobster field studies, however, a much less time consuming, direct method of shell condition determination would be more useful and convenient than any of the above.

Weber and Miyahara (1962) determined proportion molting in king crabs, *Paralithodes camtschatica*, by means of external, macroscopic examination of the shell. This method is subjective and depends on observer experience with the particular species. If the accuracy of such observations could be demonstrated by comparison with other types of evidence, it might be an acceptable method of determining proportion molting annually in lobsters.

This paper describes the accuracy of using macroscopic observations to determine shell condition of lobsters from a Newfoundland population and discusses the application of this method in estimating the proportion molting annually in a lobster population.

MATERIALS AND METHODS

Fishing was carried out during July 1-9 immediately following the 1975 commercial lobster fishing season in the Arnold's Cove, Placentia Bay area and 387 lobsters were tagged with sphyrion tags in a procedure described by Ennis (1972). No evidence of molting was seen while SCUBA diving on July 18 but it was observed on July 23. All tagged lobsters were thus old-shelled at the time of tagging. Further fishing was carried out between September 17-23 by which time molting in the population had all but ceased and some tagged lobsters were recaptured. Shell condition of all lobsters caught was determined by external examination and recorded as new (definite), which is equivalent to intermolt stages A_2 — C_1; old (definite), which is equivalent to stage C_4; new (uncertain) or old (uncertain), neither of which can be assigned an intermolt stage classification with certainty but most are probably stage C_2 or C_3.

All evaluations of shell condition were made by the same individual and were based on several criteria: (1) *shell firmness* — slight pressure applied with the thumb and fingers to each side of the carapace will result in buckling in new-shelled lobsters, in old-shelled lobsters the carapace is considerably more rigid and resistant to such pressure; (2) *scratches* — on the ventral surface generally, but particularly on the claws, of old-shelled lobsters darkly stained scratches are present and the color is usually more faded than dorsally; the outside edges of the claws are particularly darkened; (3) *color* — in new-shelled lobsters the color is bright whereas in old-shelled lobsters the color is usually noticeably faded; (4) *epizoa* — various encrusting organisms are often found on the shells of lobsters, usually more abundantly on old-shelled lobsters.

Comparison of carapace length measurements at times of release and recapture was used to confirm the accuracy of shell condition classifications in tagged-recaptured lobsters. Serum protein concentration in lobsters changes dramatically during the molting cycle (Ennis 1973) and this was investigated as another means of confirming observations on shell condition. Blood samples were taken for spectrophotometric analysis from 153 lobsters caught during the September 17-23 fishing period. Means were calculated for the serum protein absorbance values of lobsters that had been classified old-shelled (definite) and those that had been classified new-shelled (definite). These were significantly different ($P<.01$). Absorbance values above the mean for the old-shelled group were considered proof that the lobster was old-shelled and values below the mean for the new-shelled group were considered proof that the lobster was new-shelled.

RESULTS

Only 19 of the 387 lobsters tagged just prior to the molting season were recaptured during the short (September 17-23) fishing period near the end of the season. All classifications of shell condition by external examination made at the time of recapture were proven correct by comparing the carapace length at recapture with that at the time of tagging (Table 1). Of the 153 blood samples taken, 13 were from these recaptured lobsters. The absorbance values in this group of 13 indicated a fairly wide gap between old- and new-shelled lobsters. The lowest value for old-shelled lobsters was .219 and the highest for new-shelled lobsters was .132 (Table 1). This is a good indication that absorbance values above .284 (mean value for all blood samples from lobsters classified as old-shelled [definite]) and below .149 (mean value for all blood samples from lobsters classified as new-shelled [definite]) can be taken as proof of old- and new-shelled lobsters respectively.

Of the 153 blood samples analyzed, 67 absorbance values were above the old-shelled (definite) mean or below the new-shelled (definite) mean and only these are used to confirm the observations on shell condition for the lobsters from which these blood samples were taken. Absorbance values for the remaining 86 blood samples are not used here. Of the 67 used all shell

TABLE 1. *Comparison of carapace length of "sphyrion" tagged lobsters at tagging and at recapture and validation of shell condition determinations.*

Carapace length (mm) At tagging	 At recapture	Molted	Shell condition classification at recapture	Serum protein absorbance value
83	83	No	Old (definite)	.269
84	84	No	Old (definite)	.226
97	97	No	Old (definite)	.219
92	92	No	Old (definite)	.292
95	95	No	Old (definite)	.330
107	107	No	Old (definite)	.241
94	94	No	Old (definite)	.372
79	79	No	Old (definite)	.260
95	95	No	Old (definite)	.292
85	85	No	Old (definite)	
97	97	No	Old (definite)	
88	88	No	Old (definite)	
77	77	No	Old (definite)	
82	97	Yes	New (definite)	.132
80	92	Yes	New (definite)	.084
83	92	Yes	New (definite)	.097
90	106	Yes	New (definite)	.087
78	89	Yes	New (definite)	
71	82	Yes	New (uncertain)	

TABLE 2. *Numbers of serum protein absorbance values less than .149 (mean of all new-shelled [definite]) lobsters and greater than .284 (means of all old-shelled [definite]) lobsters for each shell condition classification.*

Shell Condition	No.	No. of absorbance values < .149	No. of Absorbance values > .284	Results
Old (definite)	29	0	29	29 out of 29 correct
Old (uncertain)	1	1	0	1 our of 1 incorrect
New (definite)	27	27	0	27 our of 27 correct
New (uncertain)	10	7	3	7 out of 10 correct
	67			

condition observations recorded as new (definite) and old (definite) were correct but mistakes were made in some recorded as new (uncertain) and old (uncertain) (Table 2).

Comparison of absorbance values below .149 for the new (uncertain) group with those below .149 for the new (definite) group showed no significant difference (P>.9). This indicates that shell condition determinations for the new (definite) group can be made with the same confidence no matter on which side of the mean (.149) for the group the absorbance value falls. A similar comparison is not available for old-shelled lobsters but it is felt that the same is true for the old (definite) group.

A total of 935 lobsters was caught during the September 17-23 fishing period; new (definite) and old (definite) shell classifications comprised 94.3% of the observations, new (uncertain) and old (uncertain) 5.7%. Mistakes were made only in the new (uncertain) and old (uncertain) groups. Since mistakes in one group are balanced somewhat by mistakes in the other, the overall effect on the accuracy of estimates of proportion molting would be slight.

DISCUSSION

In the field the most practical and convenient method of determining shell condition in the lobster, *Homarus americanus,*is by means of external, macroscopic examination. The accuracy of such observations, however, needs to be demonstrated.

For populations of lobsters that have a well-defined and relatively short annual molting period, shell condition determination by this method can be very accurate if sampling is carried out near the end of the molting period. In the present study, for those observations that could be confirmed, 97.2% accuracy was achieved. This is a clear indication that such observations can be used reliably for lobsters in the determination of proportion molting annually.

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AN EFFECT OF CHLORINATION ON THE HATCHING OF COON STRIPE SHRIMP EGGS: SO WHAT?

T. O. Thatcher

BATTELLE
PACIFIC-NORTHWEST LABORATORIES
MARINE RESEARCH LABORATORY
SEQUIM, WASHINGTON

ABSTRACT

Groups of ten coon stripe eggs were subjected to chlorinated sea water in continuous-flow-through experiments. A 96-hr exposure to total residual oxidant levels as low as 0.16 mg/1 resulted in delayed hatching of the eggs for 2 to 7 days compared to controls and lower toxicant concentrations. The observed delayed hatching of eggs exposed to chlorinated sea water occurred only after returning the eggs to clean water, in all cases except one. The possibility of both beneficial and detrimental effects of this delay are hypothesized, but the significance of this effect to individuals, populations, and ecosystems is yet to be determined.

INTRODUCTION

The increasing introduction of chlorine into marine environments is causing marine chemists and biologists a plethora of problems. The chemists face an enormous task of defining not only the "simple" forms of the halogens (various species of chlorine, bromine and iodine, which together constitute what has come to be referred to as "free-and combined-available oxidant"), but also, at present, an innumerable quantity of intermediate and end-product compounds that will form as a result of reactions involving potentially thousands of organic components (Vallentyne, 1957; Reuter, 1976). These reactions will occur under a variety of water quality parameters, which are suspected of influencing them. On the other hand, the biologist ultimately has the most important task of determining the answer to the big question that eventually must be applied to all such investigation of the synthesis and effects of chemical compounds in the marine environment, that is, SO WHAT? Part of the evaluation deals with observing whether the compounds of interest actually produce any effects in marine organisms. Another step is the determination of whether the observed effects are consequential or not at the individual, population, species, or ultimately, the ecosystem level. The Ecosystems Department of Battelle-Northwest is investigating this complex problem of the chemistry and biology (i.e., the synthesis, effects and fate) of seawater chlorination through a comprehensive program being coordinated at our Marine Research Laboratory at Sequim Bay, Washington. The study reported on here describes a sublethal effect of chlorination upon the hatching of coon stripe shrimp (*Pandalus danae*) eggs. Moreover, this report serves to illustrate the complexity of the biologist's problem of predicting whether an obvious effect is really of any consequence.

MATERIALS AND METHODS

One of the simplest methods of containing small organisms while performing aquatic flow-through toxicity tests has been in a 12.5 cm long cylindrical section of 3.8 cm diameter, white PVC plastic pipe, having one end covered with nytex netting of appropriate mesh size. These tubes are fastened in positions around the periphery of a glass 45-ℓ aquarium. An automatic siphon, consisting of an inverted "U" tube on the effluent standpipe causes a continual 4 cm fluctuation in the solution surface level in the aquarium, and consequently within the tube containers, thereby insuring an exchange of solution within the cylinders. The flow rate through the aquarium is 0.5 ℓ per minute.

Eggs of coon stripe shrimp were used because it is an important food web and commercial species in the Pacific Northwest (Browning, 1974); it is likely to inhabit areas that will receive chlorinated effluents; and it has proven to be a good experimental species in our previous laboratory studies. The shrimp were captured by otter trawl in Sequim Bay at depths generally between 15 and 40 meters. The water quality parameters at this site are essentially the same as at the laboratory. The egg- bearing females were segregated promptly and held under laboratory conditions for a minimum of 2 weeks. The water temperature was 12.5°C ± 1.5°C; pH was 8.0 ± 0.2; salinity was at 30 0/00 ± 2.0, and dissolved oxygen was above 7.0 mg/1. Individuals with eggs nearing the hatching stage were then removed to 19-ℓ glass aquaria in the experimental area where they were maintained in continuous-flowing conditions. Two or three of these shrimp were kept in each of several aquaria. All shrimp were fed daily on freshly-thawed Oregon Moist Pellet and minced clam at a rate of approximately 5% of their weight while kept at the laboratory.

When the eggs on a shrimp were within several days of hatching (based on previous observations), clusters of 75 - 100 were removed with fine-tipped forceps. These were then gently teased apart with dissecting needles, and 10 apparently healthy (with no visible defects) individual eggs were selected randomly and placed in each white plastic container. The eggs remained in the chlorinated sea water for 96 hours and were then transferred to clean water. These were observed daily for mortality, hatching, or abnormal development for approximately three weeks, including the 4-day exposure to the chlorinated sea water. Ten experiments were conducted from May through July, using eggs removed from several female shrimp.

The two principal means of chlorinating water at industrial and municipal sites are by adding a solution of sodium hypochlorite (NaOCl) or by injecting chlorine gas. In the latter method, better than 99% converts to hypochlorite almost instantaneously, so the reactions would be expected to be the same, regardless of the chlorine source (Dove, 1970; Morris, 1975). For these experiments, the chlorine source was a diluted NaOCl solution readily available as "Clorox." This solution was considered to be equivalent (but merely more diluted) to those currently in use by several west coast power plants. "Clorox" contains 90% water, 5.25% sodium hypochlorite, 4% sodium chloride, plus 0.75% pH buffers consisting of sodium hydroxide and sodium carbonate. It contains no other additives often referred to as "whiteners" or brighteners."[1]

A series of five chlorine exposure levels and one control was maintained by a proportional diluter (Mount and Brungs, 1967) that delivered toxicant solution to each 45-liter experimental aquarium at a rate of about 0.5 liter per minute. During the experiments, water quality parameters were identical to those described previously for the 2-week holding period. Total residual oxidant levels, which are considered to be the most practical units currently available for analyzing the toxicant level (Brungs, 1973; Mattice and Zittel, 1976), were measured daily by an amperometric titration system employing 2 platinum electrodes (1 stationary, 1 revolving) and using a polarograph for endpoint detection. Although such sensitivity was not necessary for these experiments, this system can detect total residual oxidant levels down to 1 ppb in sea water.

Three different concentration intervals were employed during these experiments; the range of measured concentrations extended from 0.03 to 0.85 mg/l. These exposure levels represented approximately 50% of the chlorine (Cl) added to the diluter, and the fate of the other 50% has yet to be determined.

RESULTS

The 96-hr LC50 values were found to be approximately 0.5 mg/l (ppm) for these near- hatch-

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[1] As per personal communication with the Clorox Company, Oakland, California, and the USEPA Pesticide Registration Office, Seattle, Washington, May and June, 1975.

ing eggs.[2] However, early in the series of experiments, it was observed that some of the chambers, with sublethal concentrations of residual oxidant, contained eggs which hatched several days later than the eggs in the control and the lowest concentrations (Figure 1). The delayed hatching which occurred 2 to 7 days later than the control eggs or those exposed to low concentrations was observed at total residual oxidant levels as low as 0.16 ± .01 mg/1. In all cases except one (3-day delay at 0.17 mg/l), the reported delayed hatching occurred only after the eggs were removed from the chlorinated solutions and returned to clean water.

It is obvious from the data scatter (Figure 1) that there was no relationship between the concentration of toxicant and the number of days of shrimp egg hatching delay. This may have been due to the inability to predict the exact date of hatching of the eggs when removed from the female. As a result, the age of the eggs used in one experiment could easily be several days older or younger than those in another experiment; however, the data from any one experiment were assumed not to be affected by variable age, due to the random selection process. No additional effects were observed during the one to two week period following their hatching.

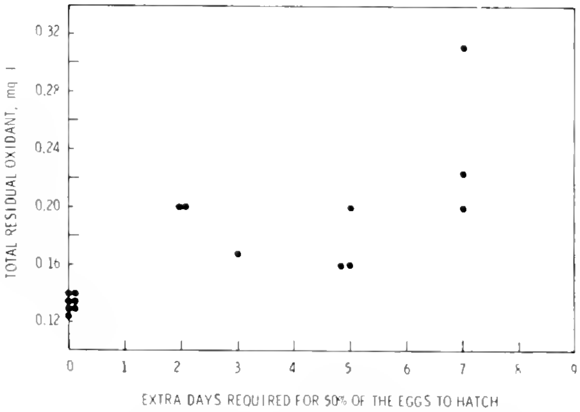

FIG. 1. *Relationship Between Coon Stripe Egg Hatching Delay and Total Residual Oxidant Concentration in Chlorinated Sea Water.*

DISCUSSION

So what? What difference does it mean to the survival of coon stripe shrimp that some eggs hatch later than others? That question has not been answered by these preliminary experiments; however, several hypotheses are suggested: (a) the effect on the hatching process could be of significance to the survival of a population of shrimp that was continuously exposed to chlorinated sea water; (b) experiments have shown that newly hatched shrimp are more susceptible to chlorinated sea water than the egg stage and the delay in hatching could actually be of survival value; (c) if optimal larval releasing sites were avoided due to the presence of a toxicant, the selection of suboptimal sites could be detrimental to the population; and, (d) extending the early developmental period could result in greater predation losses.

There are situations in which shrimp populations may be continuously exposed to chlorinated water, e.g., mariculture systems employing power plant effluent cooling water, power plant effluent embayments or canals, embayments fed by sewage treatment plant effluents. Since it is not yet known whether the causative agent of the egg hatching delay is actually one of the components of the total residual oxidant fraction of the chlorinated sea water or a longer-lived by- product, the true potential of this effect can not presently be assessed. Further studies need to be conducted to determine whether the same effect is observed under intermittent chlorination schemes, and at what other stages during the reproductive cycle, if any, chlorinated water causes problems.

If the egg-bearing females were stimulated to leave an area (exhibit avoidance) containing hatch-inhibiting levels of chlorinated sea water, it would appear to be beneficial to survival of the population for hatching not to occur until a "clean" water area was reached, since the newly hatched shrimp are more sensitive than the eggs. This, of course, makes the untested assumption that no latent or other deleterious effects result from the initial exposure. Also, if the hatching- inhibitory chlorination levels were rather infrequent, as a result of variable or intermittent chlorination, it would again appear to be of survival value to the impacted populations to avoid

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[2] These data and their derivation by probit analysis are discussed in detail in a manuscript presently in preparation.

hatching during periods of potentially lethal (to the newly hatched) conditions.

If chlorinated sea water were to be released in an area which otherwise was the preferred site for female shrimp to release their young, such areas might be avoided by the females. Releasing the young in suboptimal areas could be detrimental to the shrimp populations.

Another possible consequence of this delay would be that free-swimming forms would be available to predators for a longer period, if this delay in development carries on through the molting of the immature stages.

Previous work relating to delayed egg hatching due to chlorination is not readily apparent. Alderson (1973) observed a delay in hatching of flatfish eggs exposed to chlorinated sea water but did not specify the concentrations at which the effect was observed. Neff, *et al.* (1976) have also reported delays in the development of immature stages of crabs exposed to chlorinated compounds.

In summary, another sublethal effect to shrimp has been identified which results from the chlorination of sea water. The significance of this effect to individuals, populations and the ecosystems has yet to be determined. Both negative and positive ramifications have been hypothesized.

ACKNOWLEDGMENT

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MORPHOLOGICAL VARIABILITY IN SEA SCALLOPS, *PLACOPECTEN MAGELLANICUS* (GMELIN) RELATED TO MEAT YIELD[1, 2]

Herbert Hidu, Mark S. Richmond, Alison H. Price, II

IRA C. DARLING CENTER
UNIVERSITY OF MAINE AT ORONO
WALPOLE, MAINE 04573
and
MAINE COAST OYSTER CORP.
BLUE HILL, MAINE

ABSTRACT

Morphological parameters were defined for the sea scallop, Placopecten magellanicus, which may contribute to large observed differences in muscle meat weight of uniform height classes. Relatively large variability in muscle width, as governed by variability in shell width, and muscle area (muscle scar) were major contributing factors. Age was a complicating factor with slight positive correlations between slow growth rate and relative size of muscle width and muscle area.

INTRODUCTION

This paper is an attempt to determine the importance of morphological differences in producing large observed muscle weight variability in harvested populations of sea scallops, *Placopecten magellanicus*. It may provide information necessary for selecting superior animals for brood stock in projected mariculture operations of several species of scallops, perhaps allowing production of improved strains in controlled culture efforts.

The relationship of shell height to meat yield has received considerable attention because it is used to set minimum size limits in the harvest of natural populations (Haynes, 1966; Medcof, 1949; Baird, 1954). The minimum size limit of sea scallop drag mesh has generally been set at 4 in. or 10 cm because scallops are observed to increase muscle weight at accelerated rates at sizes over 4 in. The relationship of shell height to meat yield is obvious; however, data, especially those of Haynes (1966), reveal that other factors may be important as well, including geographical area and season of harvest related to gonad maturation.

However, an analysis of shell height vs. muscle meat weight data taken at single locations during a single season reveals differences in meat yield from uniform sized scallops that require another explanation. For example, an inspection of Haynes' (1966) data, shows that scallops from Penobscot Bay, Maine, when divided into ½ cm shell height groups may vary by a factor as much as 3.1 (averaging over 2.3) with respect to meat (muscle) weight. These meat weight differences are not explained by differences in shucking

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[1] This work is a result of research sponsored in part by NOAA Office of Sea Grant, Department of Commerce, under Grant Nos. NG-40-72, 04-3-158-63, and 04-5-158-39. The U. S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

[2] Ira C. Darling Center Contribution No. 101

method since Haynes estimated only a 3% loss in shucking. Seasonal variability does not appear to have great importance, because scallops taken at Georges' Bank at distinct seasons and again divided into ½ cm size classes reveal similar and greater (up to 7.2) variability in individual meat yield. The density of the muscle probably is not greatly variable. Thus, it would seem reasonable that meat weight differences in scallops of a given shell height might be governed by variability in "muscle area" at the base of attachment, and "muscle width" governed by the variability in overall width of the paired shells (Figure 1) and age as it might affect these factors. The muscle area and width components, of course, would be the determining factors in muscle volume and thus weight.

Presented here are data from a Maine population of scallops relating shell height to variability in shell length, muscle width (shell width less shell thickness), muscle area, muscle volume, and age. From these data it is possible to determine the relative importance of these parameters in explaining observed differences in scallop meat yield.

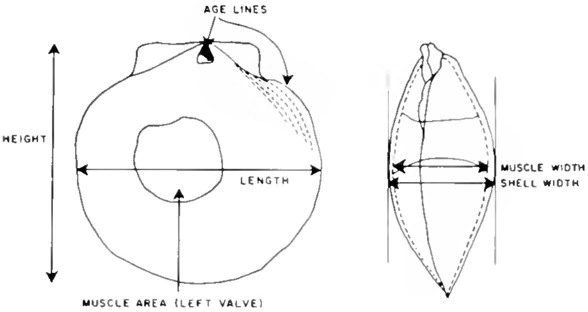

FIG. 1. *Sea scallop, P. magellanicus, measured shell parameters.*

MATERIALS AND METHODS

A collection of 151 randomly selected paired scallop shells was procured in February, 1971, from a commercial scallop boat working the inshore commercial beds near Stonington, Maine. The following shell parameters were measured in the laboratory: *Shell height* is the maximum distance from shell margin to shell margin measured perpendicular to the external hinge line. *Shell width* is the maximum distance of the closed paired shells measured perpendicular to the commissure plane. *Muscle width* is the shell width minus the thickness of each of the paired shells. Mean *muscle area* is the average of the area in cm^2 of the muscle scars of the left and right valves measured by a planimeter. *Muscle volume* was calculated by multiplying mean muscle area by muscle width, assuming that the muscle of the closed scallop roughly approximated a cylinder.

Age was figured by the method of Merrill *et al.* (1965) using banding patterns on the resilium and shell. To determine the reliability of our use of the technique, two technicians aged the shells independently and a correlation coefficient, r, was calculated on the separate results. This value was 0.83, indicating considerable lack of confidence in our application of the aging technique of Merrill *et al.* However, since the determinations were unbiased, it is thought that some valid estimates of the effect of age on other parameters could be drawn.

Regression analysis and correlation coefficients (r) were calculated using an IBM 370 computer. Shell height was regressed on shell length, muscle width, muscle area, age, and calculated muscle volume. Muscle width was also regressed on mean muscle area. To determine the relationship of age to muscle area and muscle width, and muscle area to muscle width, while minimizing the complicating effect of shell height, correlation coefficients (r) were calculated within 1 cm height classes for each of the three paired factors.

RESULTS

The regression of calculated muscle volume on shell height (Figure 2) depicts variability similar to the reported data (Haynes, 1966) on meat weight vs. shell height. Therefore, we can assume that meat weight differences are largely the result of variability in parameters contributing to muscle volume, i.e., muscle area and muscle width. An inspection of the muscle width and area parameters regressed on shell height (Figures 3 and 4) reveals that variability in both can contribute to significant differences in meat weight in scallops of a uniform shell height. These differences are greater than one would expect when examining the almost absolute uniformity of shell height vs. length (Figure 5). Confidence limits of the regression lines in the muscle width component are especially wide (Figure 3), indicating that this may be the major component contributing to meat weight differences.

Given the relatively great variability in the muscle width and muscle area components, an important question is: "Are the scallops with the relatively large muscle width the ones also with the large muscle area, regardless of the shell height of the scallop?" The spread in data points on the regression of muscle width vs. muscle area would suggest that this is not true (Fig. 6). The very high correlation coefficient here (0.89) obviously results from the effect of a third parameter (shell height) on muscle area and muscle width. Further, the correlation coefficients of muscle area vs. muscle width, calculated within 1 cm height classifications for all scallops in the sample, ranged between —.30 and .30 averaging .12 (Table 1). These data are slightly suggestive that a positive correlation exists, although a large sample of scallops of an absolutely uniform height would be needed to learn of the true relationship.

Similarly, it would be important to know what effect age has on the shell parameters. There appears to be a wide variation in age of especially the larger sized scallops (Fig. 7), although our lack of confidence in the aging technique certainly contributes to this variability. One wonders whether a slow growing scallop would have a relatively large muscle area and muscle width. Correlation coefficients of age vs. muscle width and muscle area for given size classes, averaging between .33 and .34 respectively (Table 1), would indicate that this might be the case to some degree although, again, a large sample of uniform height scallops would be necessary to substantiate these observations.

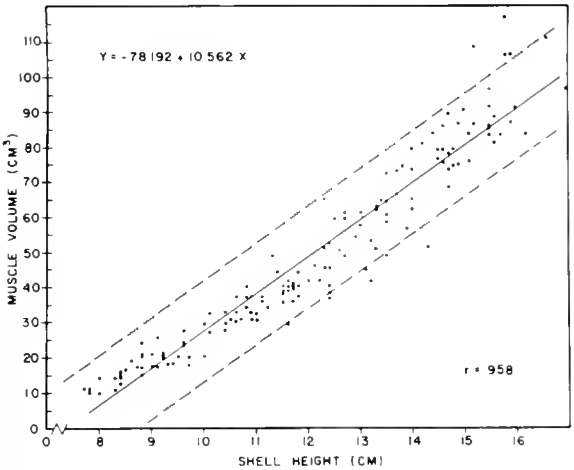

FIG. 2. *Relationship between calculated muscle volume and measured shell height, and regression line with confidence limits at the .05 level.*

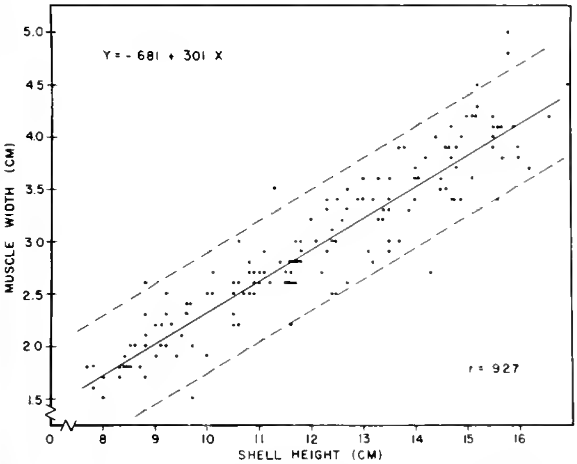

FIG. 3. *Relationship between calculated muscle width and measured shell height, and regression line with confidence limits at the .05 level.*

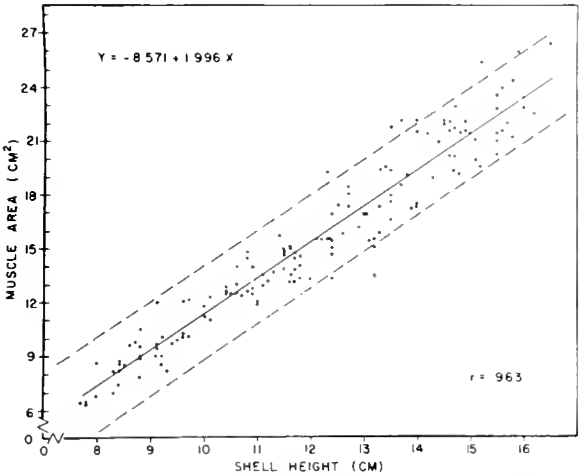

FIG. 4. *Relationship between calculated muscle area and measured shell height, and regression line with confidence limits at the .05 level.*

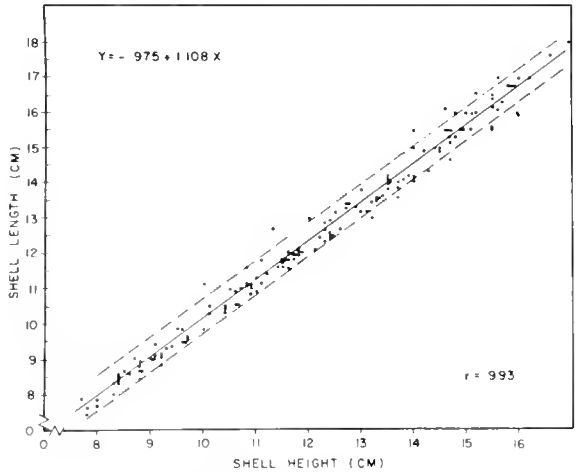

FIG. 5. *Relationship between measured shell length and measured shell height, and regression line with confidence limits at the .05 level.*

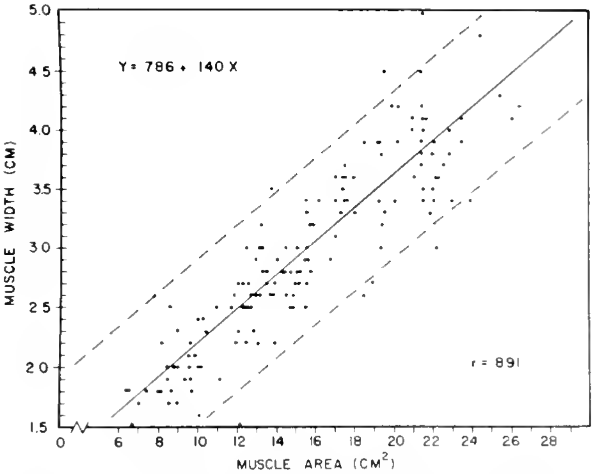

FIG. 6. *Relationship between calculated muscle width and calculated muscle area, and regression line with confidence limits at the .05 level.*

DISCUSSION

An improved scallop for mariculture no doubt should be fast growing, with a relatively large shell width (muscle width), and muscle area. This study suggests ways that such scallops might be found and the pitfalls to be avoided along the way.

First, to select for improved growth form in scallops, it would be desirable to select several very distinct height classes within the population and then establish natural ranges in variability in shell width and muscle area and determine the effect of age on these parameters.

However, with *P. magellanicus*, at least, there would appear to be some difficulty in aging live scallops since the technique of Merrill involves counting of striations on the resilium of the hinge, in addition to lines on the shell surfaces. Our two technicians, working separately, using the cirteria of Merrill, frequently disagreed on the age of individual scallops. Thus, aging live scallops using just the markings on the external shell surface would be even more difficult.

To find potentially valuable specimens of *P. magellanicus* it would be desirable to measure separately for both shell width and muscle area, since there appears to be a very low correlation between "thick" scallops and the ones with large muscle scars within given height classes. And, again, since there appears to be some correlation between age and the parameters producing muscle volume, it would be valuable to select for the shell parameters, together with a relatively young age for the particular height class.

Finally, the question of the role of environment vs. heredity in scallop growth form should be considered. There is some thought that the relatively thick-bodied scallop might be free living and not fast in the bottom as others might be. We have made no observations on this, although it is ob-

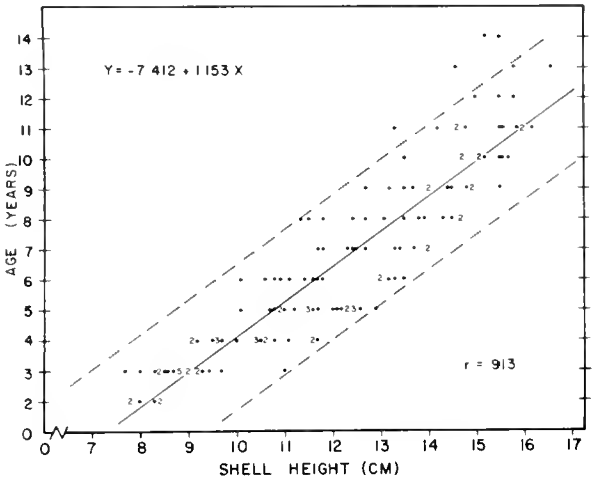

FIG. 7. *Relationship between estimated age and measured shell height, and regression line with confidence limits at the .05 level.*

TABLE 1. *The relationship of scallop age to muscle area; age to muscle width, and muscle area to muscle width expressed as correlation coefficient r for 1 cm height groups of a single population of 142 sea scallops.*

Size Classes (height cm)	No. Scallops	Age vs. muscle area	Age vs. muscle width	Muscle area vs. muscle width
8.0 - 8.9	16	.71	.46	.38
9.0 - 9.9	15	.45	.21	—.30
10.0 - 10.9	18	.06	.26	.26
11.0 - 11.9	22	.43	.57	.10
12.0 - 12.9	17	.53	.05	.30
13.0 - 13.9	18	.30	.26	.15
14.0 - 14.9	20	.59	.32	.10
15.0 - 15.9	16	—.45	.50	—.07
	142T	$\bar{x}$ .33	.34	.12

viously an important point in selection. Heritability trials with selected animals and specimen collection by SCUBA would determine whether or not this is true.

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THE RELUCTANCE OF THE OYSTER DRILL *(UROSALPINX CINEREA)* TO CROSS METALLIC COPPER[1]

John E. Huguenin[2]

UNIVERSITY OF MASSACHUSETTS
WAREHAM, MASSACHUSETTS

ABSTRACT

It was demonstrated statistically (highly significant) that oyster drills are extremely reluctant to cross metallic copper. This reluctance was shown to be due to some characteristic of the metal rather than to the effects of physical obstruction (statistically highly significant). It was also shown that the width of copper strip is an important parameter in preventing crossings (statistically highly significant). Copper barriers at least as wide as the largest animals are recommended for maximum effectiveness. In addition, suggestions are presented for exploiting this phenomenon in practical applications.

INTRODUCTION

The steady decline in oyster meat production in the U.S. from 231 million pounds (105,000 metric tons) in 1910 to 77 million pounds (35,000 metric tons) in 1951 (and presently somewhat less) has been blamed, at least in part, on ineffective control of predation by oyster drills (Glancey, 1953). The oyster drill *Urosalpinx cinerea* (Say) is a small, predatory marine snail which is widely distributed in the coastal waters of North America and the British Isles. It is particularly destructive of young shellfish with their thin shells and greater vulnerability. A great deal of effort has been expended in studying this predator and in trying to control its predation on shellfish stocks (Galtsoff, *et al.*, 1937; Carriker, 1955).

It is a common belief among some shellfish culturists in the Middle Atlantic and New England States that oyster drills avoid metallic copper and will not cross a barrier of copper. Past research clearly indicates that this phenomenon exists both in the laboratory and in the field (Glude, 1956). Based on this effect, considerably efforts in the 1950's were expended trying to develop bottom mounted copper barriers to inhibit the movement of oyster drills and other gastropod predators onto shellfish flats (Glude, 1956; Castagna, personal communication).

The experiment described in this paper was designed to further explore the inhibiting effects of metallic copper on the movement of oyster drills. The intent was to carry out experimentation preliminary to a reevaluation of the practical problems of trying to exploit this interesting phenomenon in commercial shellfish culturing.

MATERIALS AND METHODS

Fifty *U. cinerea,* ranging in length from 2 cm to 3 cm with a mean of 2.4 cm, were placed in a 60 cm x 30 cm x 30 cm deep glass aquarium with a useable volume of 50 L and a steady through flow of about 1.5 L/min of raw estuarine seawater. All the test animals were collected at low tide along the shore and within 30 m of the laboratory's seawater intakes in Wareham, Massachusetts. The bottom of the tank was covered with coarse sand

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[2] Current address: Groton BioIndustries, P.O. Box #133, Woods Hole, MA 02543.

and three sides were covered on the outside with black contact paper to reduce the possibilities of inadvertent exterior stimuli. All drills were placed in the tank environment for at least three weeks prior to starting experimentation. Water temperatures were always in the range of 22-28°C and salinities were 15-30 0/00 during the experiments. Both parameters varied as a function of the tide and weather conditions.

Two identical pedestals were made from standard PVC (polyvinyl chloride) fittings. Each pedestal had a base consisting of a 1½ inch (nominal) socket coupling (4 cm long by 5.7 cm in diameter) joined to a length of 1½ inch (nominal) plastic pipe (4.7 cm in diameter) forming a pedestal 13 cm high. The outside surfaces were roughened with coarse sand paper. Each pedestal had a 1½ inch (nominal) plug which formed a solid platform recessed 0.8 cm on the inside of the plastic pipe at the top. The pedestals each had four 1/16 inch diameter (0.16 cm) holes, to be used for securing experimental filaments, drilled at 0.6 cm intervals along their length and centered on the midpoint of the plastic pipe sections. The intent was to provide a section of constant diameter both before and after the "barrier" position. The overall dimensions of the pedestals were constrained by the depth of the water column.

In order to stimulate drills to climb the pedestals, mussels, including both the blue mussel, *Mytilus edulis* and the ribbed mussel, *Modiolus demissus*, were used as "bait". Mussels were chosen over oysters, due to the apparent preference of drills for mussels when presented with prey animals of equal size (Carriker, 1955). In addition, both these mussel species were present in the area where the drills were collected. However, it should be noted that size is probably an even more important parameter than species in the food preference of drills, younger faster growing bivalves being preferred (Haskin, 1950). Mussels were periodically placed on the platform at the top of the pedestals to accustom the drills to feeding from the pedestals during the early conditioning period. Drills did not appear to hesitate climbing up the pedestals or feeding in this manner. However, they were starved for about 3 weeks prior to the start of experimentation.

Three experiments were conducted with the two pedestals. In experiment #1 (July 29 — Aug. **4**, 1975), pedestal No. 1 was wrapped around the midpoint with a 2.3 m length of 20 gage copper wire (diameter of 0.8 mm). This produced a copper band 1.75 — 2 cm wide including about a dozen evenly spaced wraps around the plastic pipe. The copper wire was leached in running seawater for more than a month before it was placed on the pedestal at which time it was greenish in color. The second pedestal was bare. Based on the exposed copper surface area-flow rate relationships and the range of corrosion rates for pure copper, it is clear that the stabilized copper concentrations in the water during these experiments, under the worst conditions, could not have been more than a doubling of the existing background level (6-8 PPB) (Huguenin & Ansuini, 1975). In experiment #2 (Aug. 5-15, 1975), pedestal No. 1 was unchanged but pedestal No. 2 was wrapped around the middle with nylon monofilament fishing leader material, also previously leached and of equivalent length and diameter to the copper wire of pedestal No. 1. The intent was to provide two pedestals of equal physical obstruction to the climbing drills, one of copper and the other of an "inert" material. In experiment #3 (Aug. 18-23, 1975), pedestal No. 1 continued unchanged while pedestal No. 2 had a single winding of the same copper wire producing a copper strip with a width equal to the diameter of the wire.

The following procedures, involving frequent switching of bait and pedestal positions, were developed to cancel out any biases between the pedestals that might be present in the tank due to water circulation patterns, different lighting conditions, extraneous external stimuli or other positional factors. Procedures also compensated for any learning on the part of the drills. Small live mussels of equal size (2-3 cm long), one of each species, were placed on top of the pedestals in the morning of each day of experimentation. Mussels on the pedestals were switched each day.

On days data was collected, the tank was checked periodically to see if drills had climbed up either pedestal. These checks occured irregularly but usually at approximately 0.5 hr. intervals. If no drills were present on the pedestals, no record was made nor was any other action taken.

However, if drills were on either or both pedestals a positive observation was recorded. The number of drills above and below the midpoint of each pedestal were noted. If no drills had proceeded past the midpoints, they were simply removed from the pedestals and placed to the sides of the tank. In contrast, if some had progressed past the midpoint, on either pedestal, not only were they removed but the pedestal positions were switched. All data were acquired during daylight hours.

RESULTS

Table 1 gives the numbers of drills noted per positive observation in each condition by experiment and a summary of the data. Utilizing an F test, the observed differences in oyster drill behavior between both pedestals in each of the three experiments were statistically analyzed using a one-way classification with equal numbers. Differences between pedestals in experiment #1, experiment #2, and experiment #3 were all statistically highly significant at the 1% level.

DISCUSSION

I observed during experiments #1 and #2 that drills tended to pile up directly under the copper pedestal No. 1 while not doing so on the other pedestal. However, activity levels of drills during the experiments varied considerably. They commonly extended their proboscis over the copper strip to distances approaching the heights of their shells before backing off or letting go and falling off. This led to the idea that the dimension of the copper strip might be important, and resulted in experiment #3. In this experiment the single strand of wire, though stopping many drills, was clearly not as effective as the wider band of copper. Thus, in order to be most effective, the copper strip must be at least as wide as the height of the snails' shells.

It was clear in experiment #1 that drills would

TABLE 1. *Number of Drills Observed During Experiments and a Summary of the Data*

		# Drills Below Pedestal Midpoint	# Drills Above Pedestal Midpoint	Remarks
EXPERIMENT 1 July 29 - August 4, 1975	Pedestal #1 (Band of Copper Wire)	23 (1.00)*	0 (0)	— 4 days of data taking, 23 positive observations over a six day period
	Pedestal #2 (Bare)	6 (.26)	30 (1.30)	
EXPERIMENT 2 August 5, - August 15, 1975	Pedestal #1 (Band of Copper Wire)	62 (1.05)	9 (.15)	— 9 days of data taking, 59 positive observations over an eleven day period.
	Pedestal #2 (Leader Material)	18 (.31)	79 (1.34)	
EXPERIMENT 3 August 18,- August 23, 1975	Pedestal #1 (Band of Copper Wire)	43 (1.79)	0 (0)	— 4 days of data taking, 24 positive observations over a six day period.
	Pedestal #2 (Single Strand of Copper Wire)	17 (.71)	16 (.67)	

* Average number of drills per positive observation.

not cross the copper wire. However, during the early phases of experiment #2 a few did cross. This might be explained by the fact that, while the copper wire had been leached for over a month prior to being installed on pedestal No. 1 for experiment #1, when the wire was being wrapped around the pipe the green oxide cracked in numerous places showing hairline cracks of golden copper coloration. During the 8 days between the start of experiment #1 and the start of experiment #2, these cracks had disappeared. The exact chemical condition of the copper surface could be expected to influence the degree of reluctance of oyster drills to cross copper. However, it isn't clear from the data whether or not this was the case in these experiments. The effects of copper can be better understood by examining the corrosion product films which form after exposure to seawater. The initial film is cuprous oxide which adheres tightly to the metal substrate but this film in time hydrolizes to form cuprous hydroxychloride which appears to be neither as toxic nor as tightly adherent (Efird, 1975). This second film is easily removed, such as by the continued slow action of abrasive particles carried by water currents.

A higher corrosion rate to further increase the barrier effectiveness of the copper could be achieved by coupling electrically to materials more noble than copper in the galvanic table. Unfortunately, copper tends to be more noble than most of the common metals and coupling to these materials would of course completely destroy the effectiveness of copper as an oyster drill barrier since the copper would no longer corrode at all. Materials that would be acceptable for this application include graphite, titanium and some of the high alloy specialty steels. It should be noted that the barrier effectiveness of copper is not due to the electropotential. This is substantiated by previous experiments (Castagna, unpublished) where comparable voltages were induced on carbon with no response from the snails.

There are interesting implications for large areas along the coast where traditional bottom culturing of shellfish can no longer be accomplished, or is carried out only with difficulty, because of serious predation by oyster drills. The work reported here, as well as previous related efforts (Glude, 1956; Castagna, unpublished), clearly show that copper is an effective barrier. The question revolves around how to exploit this phenomenon in practical applications. Previous efforts have concentrated on small bottom mounted barriers to protect traditional shellfish beds. These barriers were all very effective but cost and maintenance difficulties made them impractical (personal communication, Michael Castagna). However, since the basic repellent principle works well, there is a good chance that reevaluation, redesign and further efforts can overcome the problems. It should be possible to incorporate copper into bottom-mounted fences which are also designed to be effective against other shellfish predators.

Another alternative to achieving practical applications is to consider a different approach, such as bottom-mounted frames which support off-bottom culturing of shellfish on strings or in trays. Oyster drills could easily be kept from climbing up the vertical supports by making these risers either wholly of a copper material or by using only small copper strips around the bases. As an example, a 4 inch (10.2 cm) diameter by 6 inch (15.2 cm) wide band of copper roof flashing 0.002 inch (0.55 mm) thick, when placed around each of the four legs of an off-bottom culture frame, would have a retail materials cost of only about four dollars and a useful lifetime in seawater of at least four years.

Copper barriers may in time prove to be valuable, but alone they do not offer a long term complete solution. While drills do not have a pelagic stage, the young are noted for their ability to travel long distances by tacking on to floating and drifting objects (Carriker, 1957). Thus some movement of drills into the system, by drifting in on objects and by a few crossing the barriers, must be assumed. Other measures will be necessary to periodically remove these drills before they can build up to unacceptable levels. Therefore, a copper barrier may well form the core of an anti-drill system but will probably have to be supplemented by other techniques for it to fully realize its potential. Considerable increases in yields of shellfish and new productive acreage could result if practical systems can be developed. Under most likely circumstances involving estuarine applications, copper would not pose a threat to the quality or survival of the culture organisms, or their food organisms, although there are some potential pitfalls (Huguenin & Ansuini, 1975). These pitfalls include being aware of acceptable copper surface area-flow rate relationships and avoiding inadvertent galvanic cells by coupling to other metals or by burying part of the copper material in the bottom. With care, copper additions to the water can usually be easily kept to concentrations several orders of magnitude below existing background levels.

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A STUDY OF THE LITTLENECK CLAM (*PROTOTHACA STAMINEA* CONRAD) AND THE BUTTER CLAM (*SAXIDOMUS GIGANTEUS* DESHAYES) IN A HABITAT PERMITTING COEXISTENCE, PRINCE WILLIAM SOUND, ALASKA.

Richard B. Nickerson

ALASKA DEPARTMENT OF FISH AND GAME
F. R. E. D. DIVISION
CORDOVA, ALASKA

ABSTRACT

Frequency of occurrence is stratified by tide level and some individuals survived a 5.5 feet (2m) landmass upheaval following the 1964 Good Friday earthquake having endured 8 years in abnormally high zones on the low tide terrace. Growth and age were determined from mark and recovery studies which subsequently yielded age- length-weight relationships and determination of critical size.

Histological studies yielded spawning information. Population estimates were obtained by stratified random sampling and probability density function parameters. Harvesting with high pressure water jets appears practical and huge man-made pads of suitable substrate at optimum tide levels seem feasible on a crop rotation basis.

INTRODUCTION

Alaska possesses 33,904 miles of tidal shore line and extensive clam populations that have scarcely been touched commercially for human consumption. Fresh and frozen razor clams (*Siliqua patula* Dixon) from approved growing areas achieved interstate shipping status during 1975. Attention is now focusing on butter clams (*Saxidomus giganteus* Deshayes) and littleneck clams (*Protothaca staminea* Conrad) for the same purpose.

This study was conducted to obtain background data on the biology and yield of *S. giganteus* and *P. staminea* for management application and shellfish industry use when large-scale exploitation is initiated.

Although *S. giganteus* and *P. staminea* are often found together on the same beach in various ratios (Bourne, 1967, Fraser and Smith, 1928) they are also found in the absence of the other (Fraser and Smith, 1928). I have recovered *S. giganteus* from marginal razor clam bearing substrate near Cordova, Alaska, but not *P. staminea*. Similarly, H. M. Feder (personal communication) found *P. staminea* at sites in Galena Bay and Landlocked Bay, Prince William Sound, but not *S. giganteus*; he observed the reverse situation at a site at the head of Port Fidalgo, Prince William Sound. Quayle (1974) describes *P. staminea* habitat as protected gravel-mud beaches and *S. giganteus* habitat as sand-gravel beaches.

The habitat of the site examined in this study and its close proximity to Cordova, Alaska provided a convenient location to study adequate densities (for statistical purposes) of *P. staminea* and *S. giganteus* simultaneously.

MATERIALS AND METHODS

Habitat. The study site was located near the head of the west side of the east arm of Simpson Bay, Prince William Sound, Alaska, i.e., 60° 38′ 22′ No. Lat.; 145° 51′ 52″ W. Long. Distance from Cordova, Alaska to the site was 7.5 miles (12.07 km) straight line distance and 12.2 miles (19.63 km) by skiff.

Prior to the 1964 Good Friday earthquake the study site formed the northwest shore of an island. The earthquake raised the landmass in the Cordova area 5.5 feet (2 m) (Reimnitz, 1966) which caused the island to become part of the mainland and created a small, very protected cove of the former northwest shore (Fig. 1).

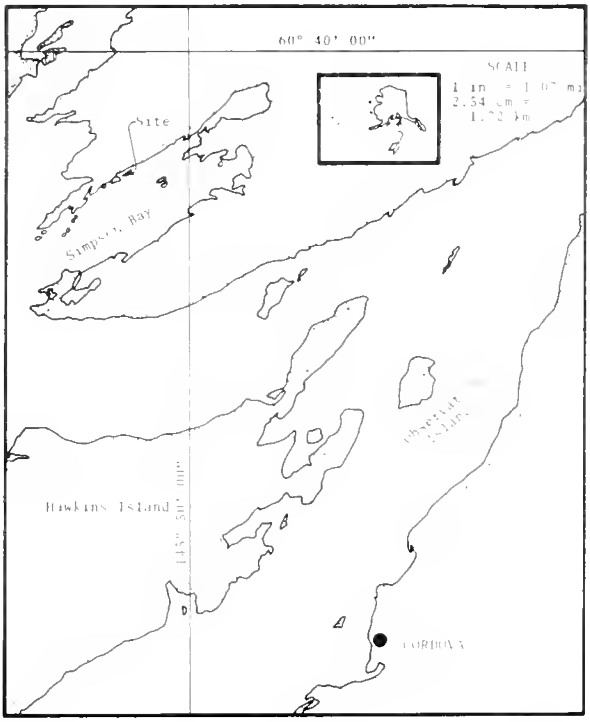

FIG. 1. *Location of P. staminea and S. giganteus study site near Cordova, Alaska.*

The site was shaped somewhat like an amphitheatre. Width of the beach at the —3 foot (—0.91 m) tide level was 37 feet (11.28 m) and became progressively wider at higher elevations; width at the +6 foot (+1.83 m) tide level was 111.5 feet (33.99 m). Slope distance from the +6 foot to the —3 foot tide level ranged from 62.25 feet (18.97 m) to 122.50 feet (37.34 m) averaging 89.58 feet (27.30 m).

The upper limit of the beach merged with a rocky cliff. Large rocks 18 by 9 inches (46 × 23 cm) heavily capped the upper portion of the beach from the +15 (4.57 m) to the +9 foot (2.74 m) tide level. Size and density of rock capping diminished at lower beach levels. Cobbles 5 by 10 inches (13 × 25 cm) were common at the +6 foot tide level and were rare at the +2 foot (0.61 m) tide level. Small stones ½ to 3″ (1.27 to 7.62 cm) capped the beach densely at the +4 foot (10.16 m) tide level and meagerly at the —1 foot (—0.3048 m) tide level. The substrate became softer and muddier from the +1.5 to the —2.5 foot (+0.46 to —0.76 m) tide level, being completely mud at the latter level. The subsurface substrate, a damp mud-gravel, was very firm from upper tide levels down to the +2 foot level. Below the +1.5 foot tide level, consistency went from soft and yielding to a thick liquid, being entirely the latter at the —2.5 foot tide level.

At a depth of 1 foot (0.3048 m), a layer of organic matter resembling peat was occasionally encountered. Both *S. giganteus* and *P. staminea* were found down to this depth residing on or just above, but not within or beneath, the organic layer.

Frequency of occurrence by tide level. On July 11, 1972 eighteen tide levels were located by hand level and leveling rod in conjunction with local tide tables from +6.0 to —2.5 feet (+1.83 to —0.76 m) relative to mean lower low water in 0.5 foot (0.15 m) increments. Each tide level was marked with two or more steel stakes, depending upon the contour. The stakes were appropriately labeled.

Each tide level, therefore, represented a transect stratum. Strata were sampled by randomly placing a square sampling frame enclosing an area of 1.0 ft.^{2} (0.0929 m^2) along the beach n times. Initially a 5 ft.^{2} (0.46 m^2) frame was used, but was found to be too difficult to work with. All substrate was excavated to a depth of 1 foot (0.3048 m) which coincided with the maximum depth of the species involved at this site. Excavation was facilitated by use of small garden trowels and cultivator claws.

Sampling from the —1 foot (—0.3048 m) to the —2.5 foot (—0.76 m) tide level required the sampler to sit on a 2-foot by 3-foot (0.61 × 0.91

m) sheet of plywood after walking along boards placed on the beach to prevent sinking into the mud. Propane lanterns were used during night sampling.

Large clams were removed as excavation proceeded and placed in labeled containers. Clams smaller than 20 mm in total valve length were not as easily discerned, hence were recovered by washing the substrate through a screen containing 16 meshes per inch (2.54 cm) with water supplied by a Homelite Model XL pump. All clams from each 1 $ft.^2$ sample were placed in labeled containers and separated later at the laboratory.

The average number of *P. staminea* and *S. giganteus* per 1 $ft.^2$ (0.0929 m^2) by respective tide level was calculated. The frequency distribution of *P. staminea* by tide level was extremely leptokurtic, that of *S. giganteus* less so. P. staminea data was smoothed by employing the gamma function:

$$\Gamma(X) = \int_0^\infty t^{x-1} e^{-7} dt$$

whereas a function of the form: $LnY = a + b\ln x + c(\ln x)^2 + d(\ln x)^3$ sufficied for fitting *S. giganteus* data. The above equations were employed to obtain estimates of proportions by tide level to serve as probability density function parameters in population estimates for clams residing in this particular tidal regime.

Growth and Age. Assistance in determining growth and age of *P. staminea* and *S. giganteus*, collected during the "frequency of occurrence by tide level study" phase, was provided by a mark and recovery program.

On January 18, 1973 67 *S. giganteus* and 200 *P. staminea* were captured at the Simpson Bay site and returned to the laboratory where they were kept in refrigerated buckets of sea water. On January 22, the clams were placed in a 20 p.p.m. solution of alizarin red and remained in the refrigerated solution (i.e. 33.5° F) (0.83° C) which was changed every few days, until February 9, 1973. The clams were a medium purple color when released from the solution. The same day they were returned to the Simpson Bay site. Prior to planting them in a marked, previously unexcavated location between the previously excavated +1 and +1.5 foot (+0.3048 and +0.4572 m) tide level, each clam was marked by filing a narrow "V" at the ventral edge of the valves using a double extra slim taper file. The purpose of the file mark was to insure a permanent mark on the annulus that was being or had just formed lest the alizarin became too faded in time. The clams were recovered on April 11, 1974, 13 months later.

From the aforementioned program, specific annuli which facilitated age and growth analysis of the stored valves of the "frequency of occurrence by tide level" specimens were easily identified. Early annuli on small specimens were determined with the aid of a dissecting microscope (10 x to 60 x).

Length-age relationships were constructed for both species which, when subjected to the von Bertalanffy growth equation, $\ell t = \ell\infty(1-e^{-K(t-t0)}$ (Ricker, 1958), the Walford expression, $\ell t+1 = \ell\infty(1-k) + k\ell$, (Ricker, 1958), Taylor's equations for maximum rate of natural mortality $M = 2.996/A_{.95}$ and life span to achieve 95 percent of the asymptotic length $A_{.95} = t_o + 2.996/K$, (Taylor 1958) and linear and curvilinear functions yielded the following: estimated growth rates; asymptotic length, $\ell\infty$; asymptotic weight, $w\infty$; maximum rate of natural mortality, M; the $A_{.95}$ value; the first differentials of absolute growth and biomass; and critical size. These statistics are of value in setting minimum legal size limits and for determining optimum sustained yield.

Length-weight relationship. Collections of *P. staminea* and *S. giganteus* were made biweekly to monthly, except for February, during 1972 and 1973. Greatest valve length was recorded to the nearest millimeter; total weight, shucked weight and trimmed weight (mantle muscles, adductor muscles and lower section of body — see Quayle, 1969, pp 52, 53) were recorded to the nearest hundredth of a gram. Prior to weighing, the whole clams were rinsed and brushed of adhering substrate, then dried with paper toweling. Shucked clams were blotted momentarily on paper toweling to remove excess liquids.

Linear functions yielded length-weight relationships depicting change in weight by time. Age-length-weight relationships were obtained using data from the previous section.

Spawning. Along with weight-length data, additional information obtained from the clams included: sex; gonad appearance; relative degree of sexual maturity and ripeness based on gross observation and microscopic inspection of living tissues; pH of the gonad using "pHydrion" paper; and representative diameters of ova. Blocks of gonad tissue were fixed in 10 percent buffered formalin. The paraffin method of tissue preparation was followed. Hematoxylin staining procedures (progressive method) were employed using Delafield's Hematoxylin and eosin Y counterstain. Tissues were placed in a dilute solution (about 0.5 percent) of parlodion in ether-absolute alcohol (50:50) for 2 minutes following the first absolute alcohol bath to prevent yolky tissues from loosening from slides. Sections were cut 10 to 20 μ thick, with *S. giganteus* sections averaging 15 μ and *P. staminea* sections averaging 10 μ.

During 1973 a 45-day Peabody-Ryan recording thermograph with sensory probe was placed 1 fathom (2 m) below mean lower low water at the study site. Seawater temperatures were related to gonad pH, and manifest changes in gonad appearance with the passage of time were analyzed.

Population estimation. Estimates of the standing crop of *P. staminea* and *S. giganteus* for the entire beach at the site were made utilizing the stratified random sampling method (Cochran, 1963). In addition, employment of proportions by tide level yielding probability density function parameters (Nickerson, 1975) were used in conjunction with an index tide level for *P. staminea* for comparison with the stratified method.

Methods of harvest. A hydraulic clam digger (Fig. 2) similar to that described by Bourne (1967) was tested at the Simpson Bay study site and at Observation Island, Orca Inlet, 3 miles (4.83 km) north of Cordova where a dense mat of blue mussels (*M. edulis*) covered a mud-cobble beach containing *P. staminea* and *S. giganteus*. The digger had a primary manifold composed of 2½ inch (6.35 cm) i.d. copper tubing. Three secondary manifolds composed of 1 inch (2.54 cm) i.d. copper tubing extended from the primary manifold. Each secondary manifold was fitted with four ¼ inch (6.4 mm) i.d. nozzles on 3 inch (7.62 cm) centers. The odd shape of the digger permitted the handle to be reversed for digging razor clams to a depth of 18" (45.72 cm). A Homelite 2¼ inch (6.35 cm) high pressure pump delivering up to 105 pounds (47.63 kg) per square inch (6.4 cm²) and up to 12,500 gallons (47,318*ℓ*) per hour was floated from a skiff. The screened intake was secured about 1 foot (0.3048 m) off the bottom. An in-depth study of the digger was not conducted; such a study was carried out by Bourne (1967) with butter clams. A pilot experiment by Feder and Paul (1973) wherein littleneck clams were excavated by hosing a jet of water over the substrate indicated that the method was productive.

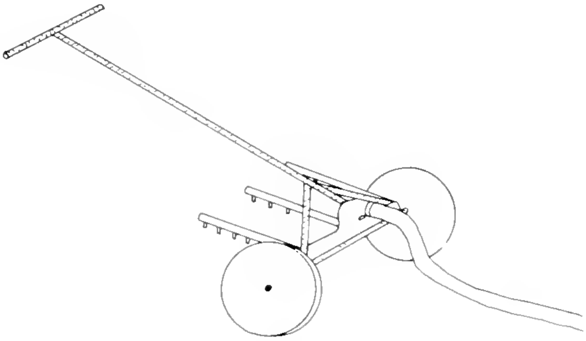

FIG. 2. *Hydraulic clam digger.*

The digger used at Simpson Bay and at Observation Island was tested for apparent efficiency at various pressures parallel, perpendicular, and angular to the water's edge.

RESULTS

Frequency of occurance by tide level. P. staminea was distributed from the +5.0 to the —2.5 foot (+1.52 to —0.76 m) tide level, the mode occuring at the +1 foot (+0.3048 m) tide level (Fig. 3). *S. giganteus* was distributed from the +3.5 foot to the —2.5 foot (+1.07 to —0.76 m) tide level, the mode occuring between the —0.5 and the +0.5 foot (—0.15 to +0.15 m) tide levels (Fig. 4). The "estimated" curves shown in these figures have predictive value and will be used in a later section dealing with population estimation. Noteworthy are the two dips in the "observed" curves of both species located at the —0.5 and —1.5 foot (—0.15 and —0.46 m) tide levels. The dips reflected the presence of two large, subsurface rocks occupying the area under respective sampling frame locations.

P. staminea obtained at the study site using a 5 ft.² (0.46 m²) sampling frame at the +5 foot (1.52

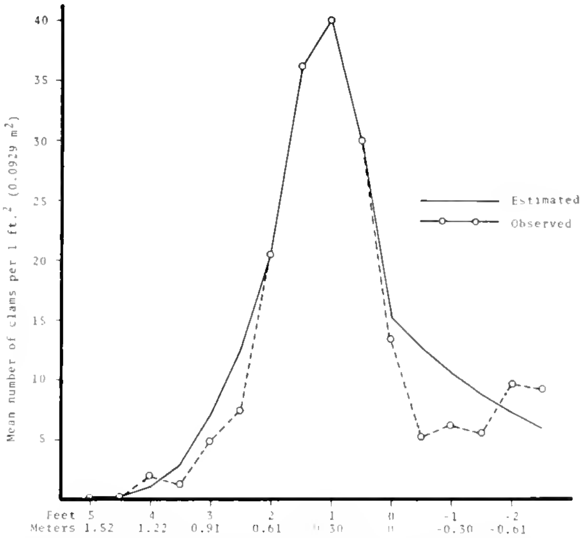

FIG. 3. *Frequency of occurrence of P. Staminea by tide level, Simpson Bay, Prince William Sound, Alaska.*

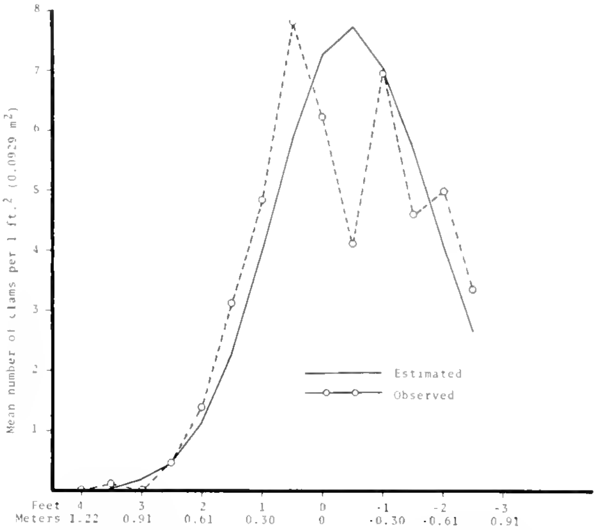

FIG. 4. *Frequency of occurrence of S. giganteus by tide level, Simpson Bay, Prince William Sound, Alaska.*

m) tide level (n = 4) ranged in approximate age from 13 to 15 years. Extreme disruption of growth occurred after achieving age 5 to 7 years. Maximum valve length of the largest specimen was 30.70 mm. Growth disruption was attributed to land-mass uplift. Growth disruption of *P. staminea* was less noticable at the +4 foot tide level where the youngest specimen was approximately 10 ±1 years of age. At the +3.5 foot tide level 1 specimen of *S. giganteus* was collected; its age was approximately 16 ± 2 years and maximum valve length was 34.75 mm.

Post-earthquake recruitment of *P. staminea* was found at the +2.5 foot tide level and lower tidal zones. Post-earthquake recruitment of *S. giganteus* was found at the +2 foot tide level and lower tide zones.

Growth and age. Age was determined by counting annuli of the "frequency of occurrence by tide level" specimens which were identified following the mark and recovery program. Age and growth rates for *P. staminea* and *S. giganteus* are presented in Tables 1 and 2, respectively. Walford lines, first differentials of absolute growth and biomass, asymptotic length and weight, critical size, $A_{.95}$ value and maximum natural mortality rate for the above species are presented in Figures 5 and 6 respectively.

Comparisons of growth rates between two tide levels each for *P. staminea* and *S. giganteus* reveal that growth rates are significantly greater at tide levels where modes of frequency of occurrence are located than at higher tide levels. *P. staminea* achieves a significantly greater rate of annual increment in valve length at the +1 foot (+0.3048 m) tide level than at the +2 foot (+0.61 m) tide level. Similarly, *S. giganteus*'s rate of annual increment in total valve length is significantly greater at the 0 (MLLW) tide level than at the +1.5 foot (+0.46 m) tide level. Tables 3 and 4 present these data.

Slower growth rates for *P. staminea* observed by Paul and Feder (1973) at Galena Bay are attributed to more severe winter conditions than observed at Simpson Bay. Inner Galena Bay, where Eater Beach and Indian Creek Flats (designated by Paul and Feder, 1973) are located, occasionally freezes and sea ice in excess of 1 foot (0.3048 m) thick is documented (Capt. H. Curran, M/V Montague, ADF&G, pers. comm.).

Size of *P. staminea* and *S. giganteus* increases with depth of location within the substrate. That is, smallest clams were found near the surface; largest clams were found at the lower limit of capture.

TABLE 1. *Average greatest valve length and average whole weight of* Protothaca *from Simpson Bay Prince William Sound, Alaska with corresponding relationship to age, and data for fitting a Walford line to length.*

Annulus	t Age (Years)	Number of Clams	Observed X Length[a] (mm)	Std. Dev. Sx (mm)	Std. error of Mean Sx (mm)	Calculated Length (mm)[b]	Calculated Weight (g) 9-25-72[c]	Calculated Weight (g) 7-17-73[d]
1	0.5	35	1.36	0.50	0.08			
2	1.5	49	4.53	1.12	0.16			
3	2.5	49	10.26	2.72	0.39	10.64	0.37	0.32
4	3.5	49	18.56	4.09	0.58	19.28	1.94	1.96
5	4.5	49	26.63	3.96	0.57	26.09	4.49	4.88
6	5.5	49	32.13	4.08	0.58	31.46	7.56	8.59
7	6.5	49	35.85	4.40	0.63	35.70	10.74	12.59
8	7.5	42	38.52	4.83	0.75	39.04	13.78	16.50
9	8.5	28	41.74	4.56	0.86	41.67	16.52	20.10
10	9.5	8	45.97	2.48	0.88	43.75	18.92	23.29
11	10.5					45.39	20.96	26.03
12	11.5					46.68	22.66	28.33
13	12.5					47.70	24.06	30.25
14	13.5					48.50	25.21	31.81
15	14.5					49.14	26.14	33.09

[a] Obtained from the +1 foot (+0.348 m) tide level.

[b] Calculated from the von Bertalanffy growth equation using final trail $\ell\infty = 51.5$ mm, $r = 0.9987$.

[c] Calculated from $\text{Log } Y = -3.2888 + 2.7823 \text{ Log } X$, $r = 0.9984$. The standard error of estimated Y, Sy', is given by the following equation

$Sy' = \text{antilog} \sqrt{0.00005929 + (0.0226 \log X)^2}$ where X = departure from mean, Mx.

$Mx = 1.3822$[e]

$N = 50$

[d] Calculated from $\text{Log } Y -3.5940 + 3.0233 \text{ Log } X$; $r = 0.9941$.

$Sy' = \text{antilog} \sqrt{0.0001123б + (0.0712 \text{ Log } X)^2}$ where X = departure from mean, Mx

$Mx = 1.5276$[e]

$N = 37$

[e] From Ezekiel and Fox (1959) pp 287-288

Length-weight relationships. Significant changes (P<.05) in total body weight occur for *P. staminea* and *S. giganteus* throughout the year. Tables 1 and 2 present the greatest observed range in weight for *P. staminea* and *S. giganteus*, respectively, and also show correspondence with age and length. Table 5 presents total weight-shucked weight relationships for *P. staminea*. Tables 6 and 7 present total weight — shucked weight — trimmed weight for *S. giganteus*.

The largest specimen of *P. staminea* collected at the Simpson Bay site measured 62 mm in total valve length and weighed 64.47 grams. The largest specimen of *S. giganteus* collected at the same site measured 98 mm in total valve length and weighed 258.94 grams.

Spawning. Histological studies indicate that spawning is initiated by *P. staminea* between late May and mid-June with an accumulation of approximately 1050 temperature units (i.e., the cumulative degrees fahrenheit of the maximum daily deviation of seawater temperature ±32°F. (0° C) observed from January 1 to the onset of spawning). Spawning of *S. giganteus* appears to begin between mid-June and early July when approximately 1282 temperature units have ac-

TABLE 2. *Average greatest valve length and average whole weight of* Saxidomus *from Simpson Bay, Prince William Sound, Alaska with corresponding relationship to age, and data for fitting a Walford line to length.*

(1) Annulus	(2) t Age (Years)	(3) Number of Clams	(4) Observed X Length[a] (mm)	(5) Std. Dev. Sx (mm)	(6) Std. error of Mean Sx (mm)	(7) Calculated Length (mm)[b]	(8) Calculated Weight (g) 1-18-73[c]	(9) Calculated Weight (g) 7-2-73[d]
1	0.5	22	1.65	0.67	0.14		0.0009	0.0012
2	1.5	50	6.37	1.67	0.24		0.05	0.07
3	2.5	50	14.82	2.16	0.31		0.68	0.85
4	3.5	47	23.32	4.15	0.61		2.66	3.27
5	4.5	40	30.62	5.45	0.86		6.05	7.36
6	5.5	33	38.74	6.29	1.09		12.30	14.82
7	6.5	26	45.41	6.63	1.30		19.85	23.78
8	7.5	16	48.95	6.77	1.69	44.28	24.90	29.74
9	8.5	8	51.26	5.79	2.05	49.78	28.61	34.12
10	9.5					54.72	34.84	41.44
11	10.5					59.15	44.05	52.26
12	11.5					63.13	53.61	63.44
13	12.5					66.70	63.28	74.73
14	13.5					69.90	72.88	85.92
15	14.5					72.78	82.31	96.90
16	15.5					75.36	91.43	107.49
17	16.5					77.68	100.18	117.65
18	17.5					79.76	108.49	127.28
19	18.5					81.62	116.30	136.33
20	19.5					83.30	123.66	144.85
21	20.5					84.81	130.55	152.81
22	21.5					86.16	136.91	160.17
23	22.5					87.37	142.79	166.96
24	23.5					88.46	148.23	173.24
25	24.5					89.43	153.18	178.96
26	25.5					90.31	157.77	184.26
27	26.5					91.10	161.97	189.10
28	27.5					91.80	165.75	193.46
29	28.5					92.44	169.26	197.50
30	29.5					93.01	172.43	201.15

[a] Obtained from the 0 foot (0.0 m) tide level, M.L.L.W.

[b] Calculated from the von Bertalanffy growth equation using final trial $\ell\infty = 98$ mm. r = 0.9984

[c] Calculated from Log Y = −3.6982 + 3.0149 Log X; r = 0.9978. Values for ages 0.5 to 8.5 obtained from Column (4). The standard error of estimated Y (Sy) is given by the following equation

$Sy' = \text{antilog}\sqrt{0.0000256 1 + (0.02788 \log x)^2}$, where x = departure from mean Mx

Mx = 1.6685[e]

N = 51

[d] Calculated from Log Y = −3.5585 + 2.9779 Log X; r = 0.9960. Values for ages 0.5 to 8.5 obtained from Column (4)

$Sy' = \text{antilog}\sqrt{0.00002682 + (0.04464 \log x)^2}$, where x = departure from mean Mx

Mx = 1.7165[e]

N = 37

[e] From Ezekiel and Foz (1959) pp 287-288

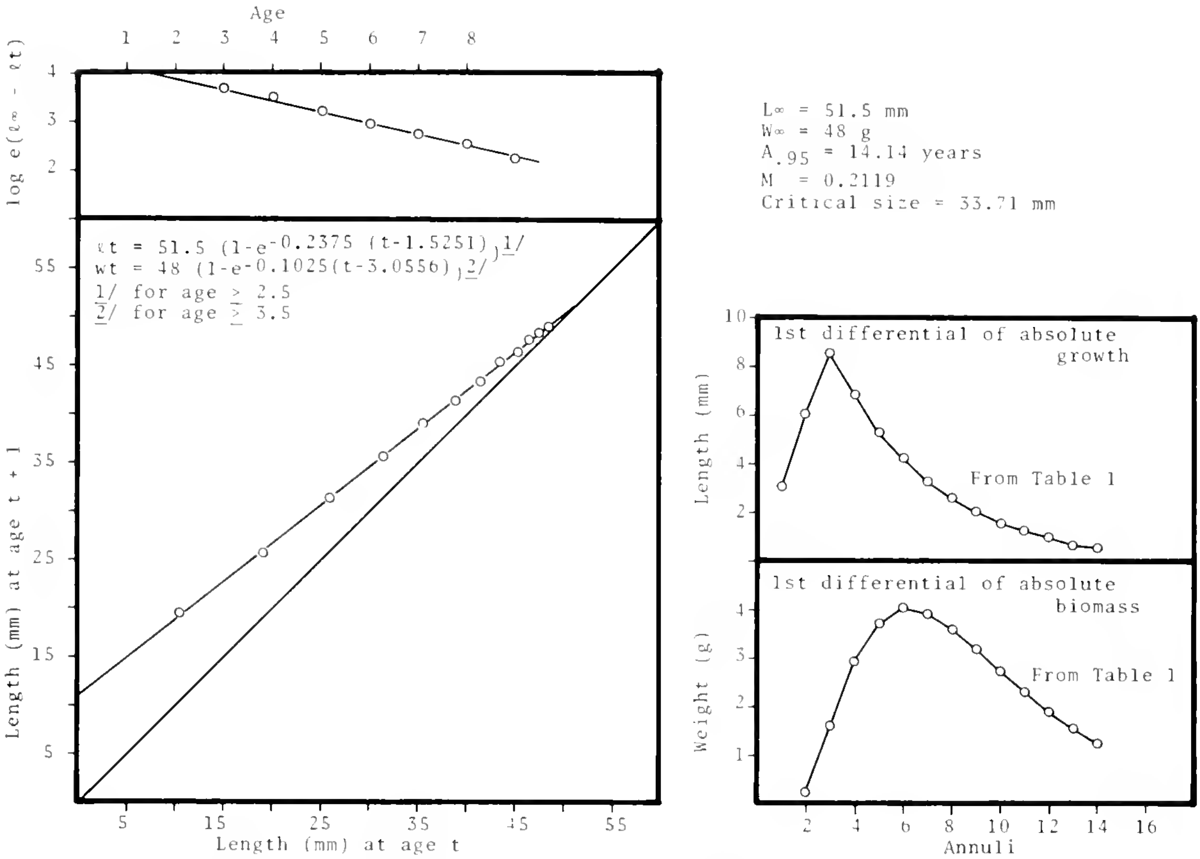

FIG. 5.*Growth of P. staminea from Simpson Bay, Prince William Sound, Alaska.*

cumulated. Spawning continues into September, and by early October heavy proliferation of follicle cells is evidenced in ovaries of some females to the extent that lumina of the ovaries are completely filled and the germinal epithelium is studded with ovogonia. Both developing ovocytes and residue ova are observed through winter months, and by late May ovaries of *P. staminea* and *S. giganteus* are filled with ripening ova 40 to 60μ in diameter. Proliferation of spermatogonia is initiated by mid-March with layers of gonia to four deep; by mid-April primary and secondary spermatogonia are layered 10 to 15 cells deep and dense columns of developing sex cells are filling the lumina of the spermaries.

The data suggest that spawning follows the attainment of extreme low gonad pH (acid) levels (i.e., 6.1) as with *Siliqua patula* Dixon (Nickerson, 1975). Seawater temperatures were significantly warmer ($P<.01$) during 1974 than in 1973 for the months April through September except for July ($P>.05$). Similarly extreme low gonad pH levels were attained at an earlier date in 1974 than evidenced for 1973 samples. This, in turn, may be reflective of nutrition and abundance of food. Both highly significant ($P<.01$) and non- significant ($P>.05$) differences were observed for gonad pH levels between *S. giganteus* and *P. staminea* for the same sampling periods during spring and summer months of 1973 and 1974. Interpretation of these similarities and differences is difficult without additional data. Speculation on these phenomena may lead to the hypothesis that *P. staminea* and *S. giganteus* achieve two or more peaks of spawning activity (Quayle, 1942) during average warm years with fluctuating seawater temperatures, but achieve only one peak of spawning activity during warmer than average years with less fluctuating seawater temperatures.

Based on the sectioned samples the smallest sexually mature *P. staminea* was a female (ova to 50

μ in diameter), 13 mm in total valve length. The smallest mature *S. giganteus* was a female (ova to 45 μ in diameter), 31 mm in total valve length. Generally, these sizes correspond to 3 years of age for *P. staminea* and 5 years of age for *S. giganteus*. Both individuals contained very few ripe ova.

Within the major period of tissue collection (1973 and 1974) maximum seawater temperatures at the Simpson Bay site did not exceed 53.6° F. (12° C) (on-site thermograph) during 1973 (August 24), and probably did not exceed 56.53 ± 1.79° F. (13.63 ± 0.99 ° C) (based on a correlation between 1973 seawater temperatures at the Cordova tide station and those at Simpson Bay, i.e., $Y = -154.4176 + 121.4868 \log_{10} X$; $r = 0.9990$; $Sy.x = 0.2518$) during 1974 (August 30). The following average seawater temperatures obtained from on-site thermograph data are presented below:

April = 40.84 ± 0.93° F. (4.91 ± 0.52° C) n = 19
May = 42.15 ± 1.08° F. (5.64 ± 0.60° C) n = 26
June = 47.09 ± 2.67° F. (8.38 ± 1.49° C) n = 29
July = 51.12 ± 1.22° F. (10.62 ± 0.68° C) n = 31
August = 52.74 ± 0.84° F. (11.52 ± 0.47° C) n = 22
Sept. = 51.30 ± 0.48° F. (10.72 ± 0.27° C) n = 27

Population estimation. Tables 8 and 9 show population estimates for *P. staminea* obtained by the stratified random sampling method (stratifying on beach surface area) and by using probabilities and an index tide level. Probabilities were obtained from Table 10. As shown, confidence intervals are much narrower using the former method, but sampling by the latter method takes much less time. Table 11 shows population estimates for *S. giganteus* by employing the stratified random sampling method. Table 12 provides proportion of *S. giganteus* by tide level for persons interested in using the probability-index tide level(s) method.

Methods of harvest. Hand-dug clams lead to a comparatively more expensive food product which cannot compete favorably with clam products derived by reliable mechanized equipment (Nickerson, 1975). Use of the hydraulic clam harvester showed that littleneck and butter clams

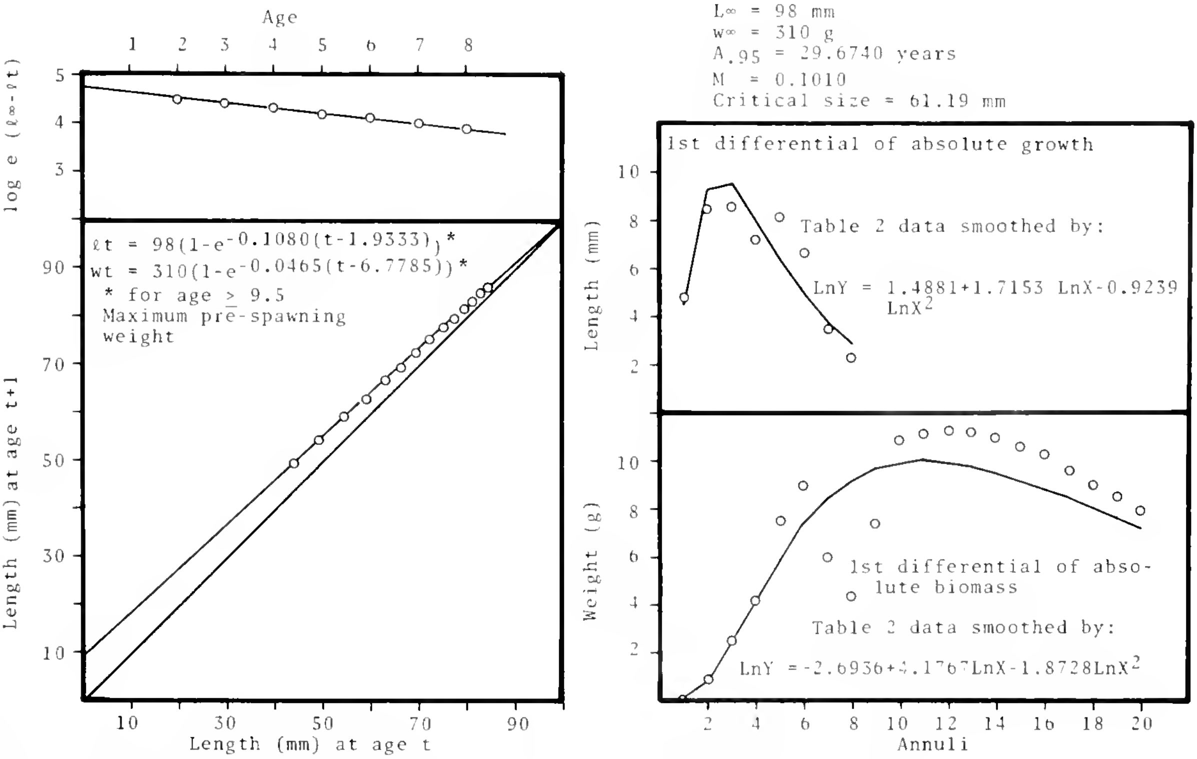

FIG. 6. *Growth of S. giganteus from Simpson Bay, Prince William Sound, Alaska.*

TABLE 3. *Comparison of growth rates of* P. staminea *from the +1 foot (+0.3048 m) and the +2 foot (+0.61 m) tide levels, Simpson Bay, Prince William Sound, Alaska, 1972.*

	+1 foot tide level			+2 foot tide level			
Annulus	Mean Greatest Valve Length	Variance	n	Mean Greatest Valve Length	Variance	n	"t" Value
2	4.5306	1.2656	49	3.8000	1.2089	35	2.96
3	10.2643	7.3772	49	8.6286	7.1225	35	2.74
4	18.5622	16.7085	49	14.9000	11.1442	35	4.36
5	26.6292	15.7125	49	21.5857	11.9191	35	6.06
6	32.1316	16.6578	49	27.0857	15.1687	35	5.69
7	35.8510	19.3169	49	31.5278	19.2703	36	4.48
8	38.5250	23.3492	42	35.4143	19.0952	35	2.93
9	41.7429	20.4829	28	38.7069	18.5804	29	2.54
10	45.9688	6.1271	8	42.2778	18.9182	18	2.15

Conclusion: growth rate is significantly greater ($P < .05$) at the +1 foot tide level than at the +2 foot tide level for above age classes tested.

can be harvested more rapidly and with less effort than hand digging with standard clam fork. Tests revealed that approximately 2500 clams per hour could be harvested by one person with the hydraulic device at zones of maximum density i.e., +1 foot (+0.30 m) tide level. However, only 400 clams per hour could be harvested at the +3 foot (+0.91 m) tide level.

Due to drainage of the trench excavated by the nozzles, transects at a shallow angle from one tide level to a lower one gave better results than transects maintained on one contour. Transects perpendicular to the waters' edge drained rapidly, but yielded less than those at a shallow angle at optimum density tide levels due to the narrow width of this optimum density zone. In areas where beach slope would permit a wider optimum density zone, transects perpendicular to the waters edge would probably be most favorable. The trench averaged about 4 inches (10 cm) deep and 20 inches (51 cm) wide. Water pressure ranged from 30 to 60 psi (14 to 27 kg/6.4 cm^2) depending upon density of clams; breakage was negligable. Clams left behind fell prey to sea stars, *Evasterias troschelii* and *Pycnopodia helianthoides*. Areas that were disturbed by the hydraulic harvester were clearly visible one year following its use, but

TABLE 4. *Comparison of growth rates of* S. giganteus *from the 0 foot (0.0 m) and the +1.5 foot (+0.46 m) tide levels, Simpson Bay, Prince William Sound, Alaska, 1972.*

	0 foot tide level			+1.5 foot tide level			
Annulus	Mean Greatest Valve Length	Variance	n	Mean Greatest Valve Length	Variance	n	"t" Value
2	6.3690	2.8023	50	5.4575	1.9685	20	2.12
3	14.8150	4.6598	50	11.2375	4.9226	20	6.12
4	23.3223	17.2604	47	19.2425	7.8235	20	3.96
5	30.6225	29.6626	40	26.9450	7.7379	20	2.79
6	38.7424	39.5372	33	33.5175	10.4695	20	3.38
7	45.4077	43.9699	26	39.3650	19.2745	20	3.44
8	48.9469	45.7968	16	43.5350	26.4837	20	2.64
9	51.2563	33.5246	8	46.5528	30.4472	18	1.89

Conclusion: Growth rate is significantly greater ($P < .05$) at mean lower low water than at the +1.5 foot tide level for age classes 2 to 8.

nearly undetectable after two years.

Maximum pump pressure (105 psi) (48kg/6cm^2) at Observation Island cut through a dense mat of mussels in a few minutes. Underlying substrate was a mud-cobble, and continued high pressure caused *P. staminea* and *S. giganteus* to bounce off the cobbles causing heavy damage to valves. When pressure was reduced to about 30 psi (14 kg/6 cm^2) damage was minimal.

DISCUSSION

Earlier I mentioned that a land-mass upheaval of approximately 5.5 feet (2 m) occurred in the Simpson Bay area as a result of the 1964 Good Friday earthquake. Two points of interest occur here in regard to the distribution of *P. staminea* and *S. giganteus* on the low tide terrace, the first being that if the uppermost tide levels mentioned where post-earthquake recruitment were found are considered to be the normal uppermost habitable zones of *P. staminea* and *S. giganteus*, respectively, for this tidal regime their presence at abnormal zones is evidence of remarkable survival capacity in a very hostile environment. The second point is that the uppermost post-earthquake recruitment zone of *P. staminea* coincides with findings of Feder and Paul (1973) at Galena Bay described by Roys (1971) as the "normal zone" where tectonic deformation ranged from —1 to +2 feet (-0.3048 to 0.6096 m).

Approximately 34.39 percent of *P. staminea* collected at the Simpson Bay site were ≥ 33.71

TABLE 5. *Relationship of whole weight (X) to shucked weight (Y) for* Protothaca, *Simpson Bay, Prince William Sound, Alaska*

	Shucked weight (grams) $Y = a_0 + a_1 X$		
	Date		
Whole weight (grams)	7-24-72[a]	8-26-72[b]	1-18-73[c]
1	0.71	0.21	1.10
5	1.58	1.51	1.93
10	2.67	3.12	2.96
15	3.75	4.74	4.00
20	4.84	6.35	5.04
25	5.92	7.97	6.08
30	7.01	9.58	7.12
35	8.10	11.20	8.15
40	9.18	12.82	9.19
45	10.27	14.43	10.23
50	11.35	16.05	11.27

a	b	c
$a_0 = 0.49580311$	$a_0 = 0.10899515$	$a_0 = 0.88784667$
$a_1 = 0.21712986$	$a_1 = 0.32309154$	$a_1 = 0.20759088$
$r = 0.9756$	$r = 0.9903$	$r = 0.8697$
$Sy.x = 0.4171$	$Sy.x = 0.4067$	$Sy.x = 0.9374$
$S_0 = 0.20962217$	$S_0 = 0.10996553$	$S_0 = 0.55066632$
$S_1 = 0.01152195$	$S_1 = 0.00812550$	$S_1 = 0.02355937$
$n = 20$	$n = 33$	$n = 27$

*a_0, a_1 = regression coefficients.

r = Coefficient of correlation.

Sy.x = Standard error of estimate of Y on X.

S_0 = Standard error of the regression coefficient a_0.

S_1 = Standard error of the regression coefficient a_1.

TABLE 6. *Relationship of whole weight (X_2) and shucked weight (X_3) to trimmed weight (X_1) for* Saxidomus, *Simpson Bay, Prince William Sound, Alaska, September 24, 1972.*

Whole weight (g)* X_2	Shucked weight (g)* X_3	Trimmed weight (g)* X_1
10	4.57	1.43
20	8.01	3.11
30	11.44	4.78
40	14.88	6.46
50	18.31	8.13
60	21.75	9.81
70	25.19	11.49
80	28.62	13.16
90	32.06	14.84
100	35.49	16.51
110	38.93	18.19
120	42.36	19.86
130	45.80	21.54
140	49.23	23.22
150	52.67	24.89
200	69.85	33.27
250	87.03	41.65
300	104.20	50.03

$$X_1 = -0.67172 + 0.03911\,X_2 + 0.37399\,X_3$$

$S1.23 = 1.15$g. $R1.23 = 0.9941$

$\underline{n = 23}$

To determine X_3 from X_2 use:

$X_3 = 1.13649 + 0.34356\,X_2$

$r = 0.9938$ $SX_3.X_2 = 2.47$ grams

$S_0 = 0.71843$ $S_1 = 0.00836$

To determine X_1 from X_2 use:

$X_1 = -0.24669 + 0.16759\,X_2$

$r = 0.9934$ $SX_1.X_2 = 1.24$ grams

$S_0 = 0.36171$ $S_1 = 0.00421$

*S1.23 = Standard error of estimate for multiple linear regression
R1.23 = Coefficient of multiple correlation
r = Coefficient of correlation
$SX_3.X_2$, $SX_1.X_2$ = Standard error of estimate.

S_0, S_1 = Standard error of regression coefficients for the regression line $\hat{Y} = a_0 + a_1x$.

TABLE 7. *Relationship of whole weight (X_2) and shucked weight (X_3) to trimmed weight (X_1) for* Saxidomus, *Simpson Bay, Prince William Sound, Alaska, January 18, 1973.*

Whole weight (g)* X_2	Shucked weight (g)* X_3	Trimmed weight (g)* X_1
10	3.74	1.36
20	6.67	2.79
30	9.60	4.22
40	12.53	5.65
50	15.46	7.08
60	18.39	8.51
70	21.32	9.94
80	24.26	11.38
90	27.19	12.81
100	30.12	14.24
110	33.05	15.67
120	35.98	17.10
130	38.91	18.53
140	41.84	19.96
150	44.77	21.39
200	59.43	28.55
250	74.08	35.70
300	88.74	42.86

$$X_1 = -0.5992 - 0.04865\,X_2 + 0.65423\,X_3$$

$S1.23 = 0.67$ grams $\qquad R1.23 = 0.9961$

$n = 32$

To determine X_3 from X_2 use:

$$X_3 = 0.8083 + 0.2931\,X_2;\ r = 0.9937$$

$SX_3.X_2 = 1.70$ grams; $S_0 = 0.4472$; $S_1 = 0.0062$

To determine X_1 from X_2 use:

$$X_1 = -0.0705 + 0.1431\,X_2$$

$R = 0.9849 \qquad SX_1.X_2 = 1.24$ grams

*S1.23 = Standard error of estimate for multiple linear regression
R1.23 = Coefficient of multiple correlation
r = Coefficient of correlation
$SX_3.X_2$, $SX_1.X_2$ = Standard error of estimate
S_0, S_1 = Standard errors of regression coefficient for the regression line $Y = a_0 + a_1x$

mm (my recommendation for minimum legal size). Applying this figure to the population estimate (Table 8) and length-weight data (Tables 1 and 5) reveals that approximately 25,000 littleneck clams were available for harvest. They would have a minimum whole weight of approximately 505 pounds (229 kg) and a minimum drained edible meat weight of 157 pounds (71 kg). Considering that about 19 percent of the *P. staminea* production came from the +1 foot tide level stratum (greatest density) containing an area of 341.6 ft.^{2} (31.73 m^2) an acre of similar tide level habitat would produce approximately 1.9 tons (1725 kg) of edible meat and 4.2 tons (3825 kg) of shell.

Running through the same exercise with *S. giganteus* (Tables 2, 7 and 11) using 61.19 mm as the minimum legal size we find that approximately

TABLE 8. *Population estimate of* Protothaca *(all sizes pooled) at the Simpson Bay site, Prince William Sound, Alaska, by the stratified random sampling method.*

h	Tide Level (ft)	N_h (ft.²)	n_h	y_{hi}	W_h	$\bar{y}_h$	S_h^2	$\frac{W_h^2 S_h^2}{w_h}$	$W_h S_h^2$
1	+5	400.41	9	1	0.07	0.11	0.07	0.0049	0.0049
2	+4.5	441.33	8	1	0.07	0.13	0.12	0.0098	0.0084
3	+4	422.18	9	18	0.07	2.00	2.46	0.1722	0.1722
4	+3.5	450.26	8	10	0.08	1.25	1.93	0.2059	0.1544
5	+3	553.28	9	43	0.09	4.78	14.90	1.7241	1.3410
6	+2.5	549.10	8	59	0.09	7.38	22.56	3.0456	2.0304
7	+2	510.40	9	184	0.09	20.44	179.83	20.8089	16.1847
8	+1.5	441.00	8	290	0.07	36.25	500.86	40.9036	35.0602
9	+1	341.60	9	361	0.06	40.11	473.93	24.3735	28.4358
10	+0.5	285.09	8	240	0.05	30.00	67.40	2.8083	3.3700
11	0.0	320.11	9	121	0.05	13.44	23.23	0.8296	1.1615
12	−0.5	342.44	8	44	0.06	5.50	7.45	0.4470	0.4470
13	−1	294.84	8	51	0.05	6.38	13.99	0.5829	0.6995
14	−1.5	242.50	8	47	0.04	5.88	26.73	0.7128	1.0692
15	−2	196.65	8	79	0.03	9.88	13.25	0.1988	0.3975
16	−2.5	207.50	8	76	0.03	9.50	27.98	0.4197	0.8394
	N = 5998.69	n = 134			1.00			97.2476	91.3761

$\bar{y}_{st}$ = 12.1278 clams per 1 ft.² (0.0929 m²) for entire beach.

$S^2(\bar{y}_{st}) = \frac{1}{134}(97.2476) - \frac{1}{5998.69}(91.3761) = 0.7105$

$S(\bar{y}_{st}) = 0.8429$

Estimated total number of clams = $N\bar{y}_{st}$ = 72,751

Standard error of estimate = $NS(\bar{y}_{st})$ = 5056

NOTATION

h = Stratum number
N_h = Number of units in stratum.
n_h = Number of units in sample.
y_{hi} = Number of clams obtained in the ith unit.
$W_h = \frac{N_h}{N}$ = Stratum weight.
$\bar{y}_h$ = Stratum mean.
S_h^2 = Estimated variance.
$w_h = \frac{n_h}{n}$ = *Sample weight*
$\bar{y}_{st}$ = Mean number of clams for entire beach
$S^2(\bar{y}_{st})$ = Variance of $\bar{y}_{st}$.
$S(\bar{y}_{st})$ = Standard error of $\bar{y}_{st}$.

14.43 percent, or 3043 clams, were available for harvest. These would have had a minimum whole weight of approximately 327 pounds (148 kg) and a minimum trimmed weight of approximately 46 pounds (21 kg). Regression estimates indicate that the −0.5 ft. (−0.15 m) tide level stratum contains the greatest densities, i.e., approximately 16 percent of the *S. giganteus* production. Proportionalizing again we find that an acre of similar tide level habitat would produce a minimum of approximately 0.47 tons (428 kg) of edible meat (trimmed weight), 0.56 tons (508 kg) of waste (gurry) and 2.30 tons (2087 kg) of shell.

This trend of analysis leads to potential clam farming operations in Alaska by private aquaculture groups. By creating huge pads (i.e., acre size) of suitable substrate, the top of which coincides with the optimum productive tide zone,

TABLE 9. *Population estimate of* Protothaca *(all sizes pooled) at the Simpson Bay site, Prince William Sound, Alaska, utilizing probabilities from an index tide level (+1 foot)*[a] *relative to mean lower low water*

Number of Clams	Mean	Standard deviation	Standard error of mean
per 1 ft.^{2}	40.1333	21.7718	7.2573

$P_I = 0.1899$

(1) Strata	(2) Tide Level (ft.)	(3) Area ft.^{2} Ai	(4) Pi	(5) Total Estimate	(6) Standard deviation
1	+5	400.41	0.0004	33.85	18.36
2	+4.5	441.33	0.0007	65.29	35.42
3	+4	422.18	0.0035	312.28	169.41
4	+3.5	450.26	0.0133	1265.60	686.57
5	+3	553.28	0.0333	3893.76	2112.31
6	+2.5	549.10	0.0587	6811.92	3695.38
7	+2	510.40	0.0969	10452.36	5670.27
8	+1.5	441.00	0.1715	15983.90	8671.06
9	+1	341.60	0.1899	13709.54	7437.25
10	+0.5	285.09	0.1419	8549.57	4638.03
11	0	320.11	0.0728	4925.05	2671.78
12	—0.5	342.44	0.0612	4429.10	2402.73
13	—1	294.84	0.0506	3152.95	1710.43
14	—1.5	242.50	0.0417	2137.11	1159.36
15	—2	196.65	0.0346	1437.97	780.08
16	—2.5	207.50	0.0289	1267.35	687.52
		5998.69		78427.59	±14,867.58

(1) = Strata; (2) = Tide level, feet, (3) = Area, Ai, ft.^{2}; (4) = Probability of distribution at the ith tide level, Pi

(5) = Total estimate by strata = $\Sigma \frac{P_i A_i}{P_I} \cdot \bar{y}$, (6) = Standard deviation by strata = $\sqrt{\left(\frac{P_i A_i}{P_I}\right)^2 \cdot V\bar{y}}$

[a] For conversion 1 ft^2 = 0.0929 m^2
1 ft = 0.3048 m

many pads in a small area would reduce time and expense of routine sampling for paralytic shellfish poison and sanitary surveys. Several of these pads would be required for each species and a crop rotation plan would be adopted. Approximately 6 years would be required for *P. staminea* to achieve harvestable size; for *S. giganteus* approximately 11 years would be required to achieve harvestable size (i.e. realize the maximum benefit of body weight increase). Spat culture stations could form a branch of the aquaculture program, providing viable, robust seed stock for the "farms".

ACKNOWLEDGEMENTS

I would like to thank Mr. Robert Bynum, Fishery Technician, for field assistance; Mr. Tim Brown, Fish Culturist, for laboratory assistance; Mrs. Janice Shaw, Clerk Typist, for assisting in preparation of the text, figures and tables, and Mr. John McMullen, Dr. Bernie Kepshire, Dr. Roger Grischkowsky, and Mr. Ivan Frohne, for their editorial comments.

TABLE 10. *Regression estimates of* Protothaca *frequency of occurrence by tide level on the low tide terrace derived from a gamma distribution* ($ {}^{I}xy^{*} = 0.9758$; $Sy.f(x) = 3.84$) *fitted to Simpson Bay data, Prince William Sound, Alaska.*

(1) Tide levels relative to mean lower low water Feet	Meters	(2) Density in clams per ft.^{2} (0.3048 m^2)	(3) Relative clam density expressed in proportion
+5.0	1.52	0.0877	0.0004
+4.5	1.37	0.1441	0.0007
+4.0	1.22	0.7418	0.0035
+3.5	1.07	2.8166	0.0133
+3.0	0.91	7.0287	0.0333
+2.5	0.76	12.4054	0.0587
+2.0	0.61	20.4870	0.0969
+1.5	0.46	36.2482	0.1715
+1.0	0.30	40.1315	0.1899
+0.5	0.15	29.9981	0.1419
0.0	0.00	15.3802	0.0728
—0.5	—0.15	12.9365	0.0612
—1.0	—0.30	10.7042	0.0506
—1.5	—0.46	8.8201	0.0417
—2.0	—0.61	7.3029	0.0346
—2.5	—0.76	6.1166	0.0289
	SUMS	211.3496	1.0000

*From Ezekiel and Fox (1959), p. 128 — index of correlation for curvilinear relations.

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TABLE 11. *Population estimate of* Saxidomus *(all sizes pooled) at the Simpson Bay site, Prince William Sound, Alaska by the stratified random sampling method.*

h	Tide Level (ft.)	N_h	n_h	y_{hi}	W_h	$\bar{y}_h$	S_h^2	$\frac{W_h^2 S_h^2}{w_h}$	$W_h S_h^2$
1	+3.5	450.26	8	1	0.10	0.13	0.12	0.0171	0.0120
2	+3	553.28	9	0	0.12	0.00	0.00	0.0000	0.0000
3	+2.5	549.10	8	4	0.12	0.50	0.86	0.1769	0.1032
4	+2	510.40	9	12	0.11	1.33	2.37	0.3585	0.2607
5	+1.5	441.00	8	25	0.09	3.13	8.41	0.9732	0.7569
6	+1	341.60	9	44	0.07	4.89	23.43	1.4351	1.6401
7	+0.5	285.09	8	63	0.06	7.88	33.87	1.7419	2.0322
8	0	320.11	9	56	0.07	6.22	14.75	0.9034	1.0325
9	−0.5	342.44	8	33	0.07	4.13	1.85	0.1295	0.1295
10	−1	294.84	8	56	0.06	7.00	7.73	0.3975	0.4638
11	−1.5	242.50	8	37	0.05	4.63	9.67	0.3454	0.4835
12	−2	196.65	8	40	0.04	5.00	8.58	0.1961	0.3432
13	−2.5	207.50	8	27	0.04	3.38	4.00	0.0914	0.1600
		$N = 4734.77$	$n = 108$		1.00			6.7660	7.4176

$\bar{y}_{st}$ = 3.6870 clams per 1 ft.^{2} (0.0929 m^2) for entire beach.

$S^2(\bar{y}_{st}) = \frac{1}{108}(6.7660) - \frac{1}{4734.77}(7.4176) = 0.0611.$

$S(\bar{y}_{st}) = 0.2471$

Estimated total number of clams $= N\bar{y}_{st} = 17{,}457.$

Standard error of estimate $= (NS(\bar{y}_{st}) = 1170.$

NOTATION

h = Stratum number

N_h = Number of units in stratum

n_h = Number of units in sample

y_{hi} = Number of clams obtained in the ith unit

$W_h = \frac{N_h}{N}$ = *Stratum weight*

$\bar{y}_h$ = Stratum mean

S_h^2 = Estimated variance

$w_h = \frac{n_h}{n}$ = Sample weight

$\bar{y}_{st}$ = Mean number of clams for entire beach.

$S^2(\bar{y}_{st})$ = Variance of $\bar{y}_{st}$

$S(\bar{y}_{st})$ = Standard error of $\bar{y}_{st}$

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TABLE 12. *Regression estimates of* Saxidomus *frequency of occurrence by tide level on the low tide terrace derived from a cubic function (i.xy* = 0.9765; Sy.f(x) = 1.16) fitted to Simpson Bay data, Prince William Sound, Alaska.*

(1) Tide levels relative to mean lower low water		(2) Density in clams per ft.^{2} (0.3048m^2)	(3) Relative clam density expressed in proportion
Feet	Meters		
+3.5	1.07	0.0946	0.0019
+3.0	0.91	0.1959	0.0040
+2.5	0.76	0.4808	0.0098
+2.0	0.61	1.1266	0.0230
+1.5	0.46	2.3097	0.0471
+1.0	0.30	4.0155	0.0820
+0.5	0.15	5.8841	0.1201
0.0	0.00	7.3069	0.1491
−0.5	−0.15	7.7699	0.1586
−1.0	−0.30	7.1619	0.1462
−1.5	−0.46	5.7940	0.1183
−2.0	−0.61	4.1634	0.0850
−2.5	−0.76	2.6870	0.0548
	SUMS	48.9903	1.0000

*From Ezekiel and Fox (1959)

THE RELATION OF SHELL LENGTH TO TOTAL WEIGHT, TISSUE WEIGHT, EDIBLE-MEAT-WEIGHT, AND REPRODUCTIVE ORGAN WEIGHT OF THE GASTROPODS *NEPTUNEA HEROS, N. LYRATA, N. PRIBILOFFENSIS,* AND *N. VENTRICOSA* OF THE EASTERN BERING SEA

Richard A. MacIntosh and A. J. Paul

NATIONAL MARINE FISHERIES SERVICE
NORTHWEST AND ALASKA FISHERIES CENTER
2725 MONTLAKE BOULEVARD EAST
SEATTLE, WASHINGTON 98112

INSTITUTE OF MARINE SCIENCE
UNIVERSITY OF ALASKA
SEWARD, ALASKA 99664

ABSTRACT

The relations of shell length to total weight, tissue weight, edible-meat-weight, female-gonad-weight and male-penis-weight were determined for 214 Neptunea heros, *179* N. lyrata, *186* N. pribiloffensis, *and 197* N. ventricosa *from the eastern Bering Sea. Equations describing these relationships are presented. Edible-meat-weight was found to average 27.9% for* N. heros, *30.5% for* N. lyrata, *30.6% for* N. pribiloffensis, *and 27.9% for* N. ventricosa. *The plots of shell length vs. female-gonad-weight and male-penis- weight exhibit sudden increases in slope and become near vertical lines thus indicating a generalized size at which maturity is approached. In female* N. heros, N. lyrata, N. pribiloffensis, *and* N. ventricosa *this increase occurs at 110, 110, 105, and 102 mm respectively. Males of these species undergo similar increases at 95, 100, 90, and 87 mm respectively.*

INTRODUCTION

Four species of large *Neptunea* (Gastropoda, Prosobranchia, see Figure 1), *N. heros* (Gray, 1850), *N. lyrata* (Gmelin, 1791), *N. pribiloffensis* (Dall, 1919), and *N. ventricosa* (Gmelin, 1791), are commonly encountered in the eastern Bering Sea (Fig. 2). These gastropods are currently harvested or show considerable potential for harvest in the eastern Bering Sea, and have been described by MacIntosh[1].

Japan has commercially harvested snails, primarily *Neptunea pribiloffensis*, in the eastern Bering Sea since 1971. The fishery occurs east of 175° west longitude along the continental shelf around and northwest of the Pribilof Islands. As many as 28 vessels may be involved in the fishery (Kiyoshi Yoshihara, Dept. of Fisheries, Nihon University, 3-34-1 Shimoua Setagaya, Tokyo, 154 Japan, personal communication). However, National Marine Fisheries Service (NMFS) patrols in the eastern Bering Sea observed only 14, 5, 1, and 6 vessels fishing snails in the years 1971 through 1974, and no vessels in 1975 and 1976 respectively (James Branson, NMFS Law Enforcement Division, Box 1036, Kodiak, AK 99615,

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[1] MacIntosh, Richard A. 1976. A guide to the identification of some common eastern Bering Sea snails. Unpub. manuscr. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, Kodiak, AK 99615.

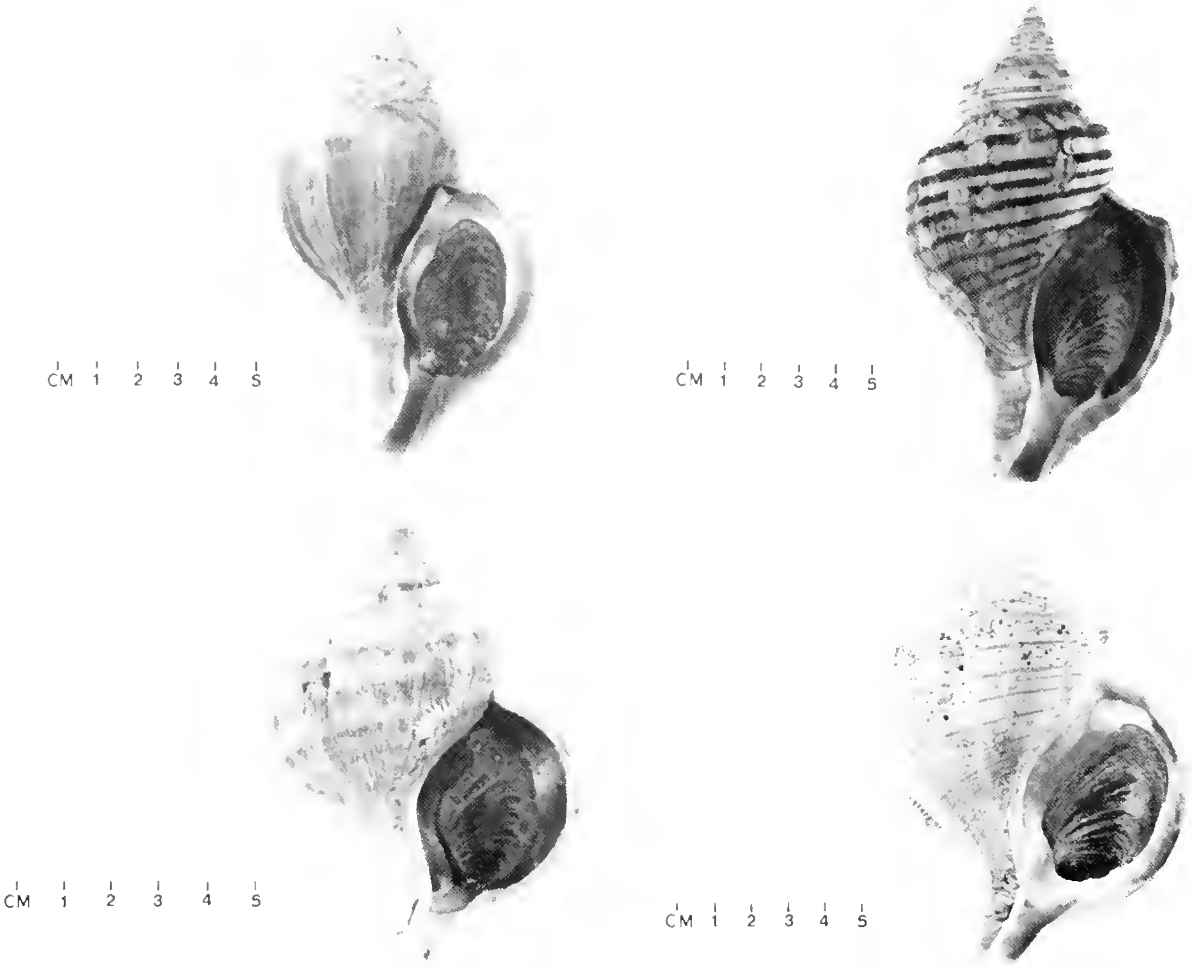

FIG. 1. *The four large* Neptunea *from the eastern Bering Sea, clockwise from upper left,* Neptunea heros, N. lyrata, N. pribiloffensis, *and* N. ventricosa.

personal communication). Catches from 1972 to 1975 have ranged from 3,000 to 3,574 metric tons (average 3,277 mt) of edible meat (data obtained by U.S. Embassy, Tokyo, Japan from the Japan Fishery Agency; provided to authors in June, 1976). Fishing vessels licensed to engage in the Japanese eastern Bering Sea snail fishery range in size from 96 to 490 gross tons, or about 25 to 50 meters in length (U. S. Embassy, Tokyo, Japan). Some vessels in the snail fleet operate independently while others fish for a factoryship. Processing consists of crushing the shells, briefly cooking the meats and removing the soft parts and shell fragments. The meats are graded by size and quality and quick frozen in trays. The small snails may be frozen whole (James Branson, personal communication).

The gear used in the fishery consists of conical pots which are similar in shape to those used in Japan's snow (Tanner) crab, *Chionoecetes bairdi* and *C. opilio*, fishery in the eastern Bering Sea. These pots are about 880 mm in diameter across the bottom, 450 mm across the top, and 363 mm in height. The diameter of the tunnel in the top of the pot varies from 120 to 150 mm. The webbing on the side of the pot changes from 60 mm mesh over the first 170 mm from the base, to 121 mm mesh on the remainder of the side (James Branson, pers. comm.). Some vessels in the fishery utilize 12 sets of pot gear, each set consisting of 500 pots on a common groundline. Four sets of pots, baited with fish, are picked and set every day making the average soak time three days (Nagai, 1975).

Official figures on the total value of the fishery are not available; however, fishermen are reported to receive between one and two U. S. dollars per kg (Kiyoshi Yoshihara, personal communication) depending on product quality. Assuming an average value of $1.50 per kg, the average annual dockside value of the fishery is approximately 4.9 million dollars. No data are available concerning the retail value of the catch; however, the meats are considered an expensive luxury item in Japan.

The most common gastropod in the Japanese fishing area is *Neptunea pribiloffensis*, which in 1973 comprised about 70% of the total harvest by weight (Nagai, 1974). The other three species of *Neptunea* do not occur in the fishing area in large numbers (Nagai, 1974), but occur in dense aggregations in other parts of the Bering Sea (Kaimmer et. al., 1976). *Buccinum angulossum* (Gray, 1839) and *B. tenue* (Gray, 1839) combined, accounted for an additional 20% of the 1973 catch.

Descriptions of the egg capsules of *Neptunea lyrata* and *N. pribiloffensis* are available (Golikov, 1961; Ito, 1957). Similar data for the other two *Neptunea* are not available. No other literature concerning the basic biology of these gastropods has been found by the authors.

The purpose of this investigation was to examine the length vs. total weight, length vs. tissue weight and length vs. meat weight relationships of the large *Neptunids* which have actual or potential value to the eastern Bering Sea snail fishery. The relationships of shell length to female-gonad-weight and penis-weight were examined to determine generalized sizes at sexual maturity.

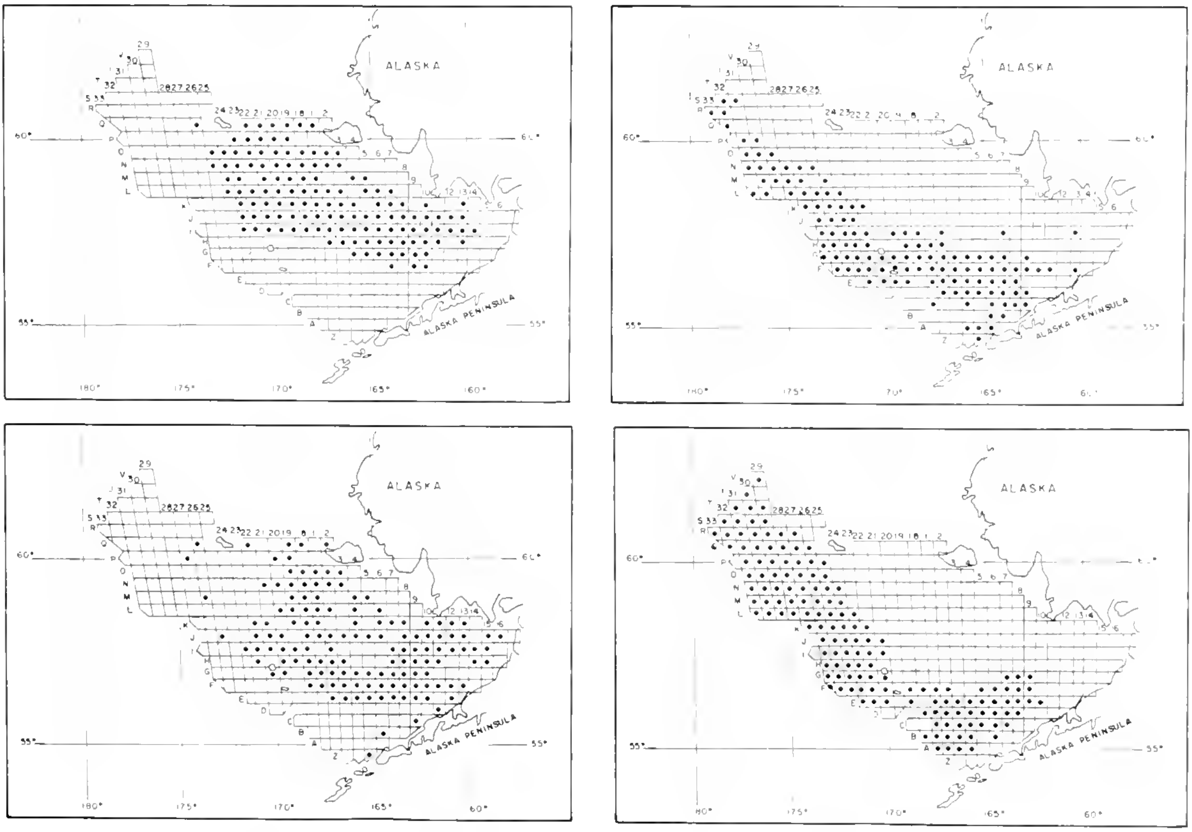

FIG. 2. *Distribution of four large* Neptunea *in the eastern Bering Sea, clockwise from upper left,* Neptunea heros, N. lyrata, N. pribiloffensis, N. ventricosa.

TABLE 1. *Locations and dates of collections of samples of* Neptunea heros, N. lyrata, N. pribiloffensis, N. ventricosa, *examined. (Locations of the sampling stations shown in Figure 2).*

Date of Collection	Sampling Stations	Location Latitude	Location Longitude	*N. heros*	*N. lyrata*	*N. pribiloffensis*	*N. ventricosa*
8-20-75	L-24	58°39′	172°17′	—	—	13	—
8-23-75	K-23	58°10′	171°52′	—	—	21	—
8-24-75	J-22	57°51′	171°06′	—	—	14	—
8-24-75	H-24	57°12′	172°13′	—	11	22	—
8-24-75	O-01	59°40′	167°59′	—	—	—	20
8-24-75	O-18	59°40′	168°38′	—	—	—	8
8-27-75	H-22	57°20′	170°40′	—	—	5	—
8-27-75	N-01	59°20′	167°26′	—	—	—	32
8-27-75	N-02	59°20′	167°16′	—	—	—	3
8-27-75	N-18	59°20′	168°32′	—	—	—	13
8-27-75	N-19	59°20′	169°10′	—	—	—	10
8-28-75	J-01	58°01′	167°43′	14	—	—	2
8-28-75	M-01	59°00′	167°54′	—	—	—	4
8-28-75	M-18	59°00′	168°34′	—	—	—	4
8-28-75	M-19	59°00′	169°09′	19	—	—	5
8-28-75	M-20	59°01′	169°45′	36	—	—	—
8-28-75	N-20	59°20′	169°52′	—	—	—	5
8-29-75	L-18	58°40′	168°24′	10	78	—	—
8-29-75	L-19	58°40′	169°05′	14	—	—	5
8-29-75	L-20	58°40′	169°42′	10	—	—	3
8-30-75	K-01	58°20′	167°50′	—	—	—	3
8-30-75	K-18	58°20′	168°27′	14	—	—	1
8-30-75	K-19	58°20′	169°05′	—	—	—	2
8-31-75	F-18	56°40′	168°18′	—	33	—	—
8-31-75	H-01	57°20′	167°41′	—	10	—	7
8-31-75	I-01	57°41′	167°45′	30	—	—	10
8-31-75	K-18	57°41′	168°22′	—	—	—	2
8-31-75	J-18	58°00′	168°23′	—	—	—	1
9-02-75	C-04	55°30′	166°04′	—	—	14	—
9-16-75	D-07	56°00′	164°01′	—	8	26	—
9-17-75	A-03	54°59′	166°16′	—	—	21	—
9-18-75	B-03	55°14′	166°39′	—	—	3	—
9-24-75	E-06	56°20′	164°35′	—	—	5	1
9-24-75	E-07	56°11′	164°16′	—	—	14	—
9-24-75	F-06	56°40′	164°35′	—	39	28	15
10-06-75	J-11	58°00′	161°29′	—	—	—	5
10-06-75	J-12	57°50′	161°08′	—	—	—	2
10-06-75	K-13	58°09′	160°09′	—	—	—	12
10-13-75	J-02	58°00′	167°08′	32	—	—	—
10-14-75	J-03	58°01′	166°30′	—	—	—	7
10-14-75	J-04	58°00′	165°51′	—	—	—	11
— — —	—	—	—	35	—	—	4
			Total	214	179	186	197

METHODS

The size-weight relationships of 214 *Neptunea heros*, 179 *N. lyrata*, 186 *N. pribiloffensis*, and 197 *N. ventricosa* were examined. The specimens were collected in the course of the 1975 NMFS synoptic trawl survey of the eastern Bering Sea shelf. Location and dates of collection are given in Table 1.

All collections were made with an Eastern otter trawl constructed with 10.2 cm mesh on the wings and body and 8.8 cm mesh in the intermediate section of the codend. The codend was lined with 3.2 cm mesh web. Very few snails less than 4.0 cm in length are retained by this gear.

Specimens were taken from random samples collected and preserved in 10% formalin aboard the vessel. In the laboratory, individual shell lengths (the distance from the apex of the spire to the end of the siphonal canal) were determined. Each shell was cleaned of all encrusting material and total weight recorded to the nearest gram. The animals were removed from their shells and total tissue, female gonad and accompanying connective tissue, penis, and edible meat were weighed to the nearest tenth of a gram. Digestive organs, respiratory tissue, gonad and opercula were removed from each specimen to obtain edible-meat-weight. Weights were taken with a precision balance, and plots, regression lines and regression equations were determined and plotted by computer. The Gauss-Jordan method was used in the solution of all normal equations (Cooley and Lohnes, 1962; Ostle, 1954).

RESULTS

The equations describing the relationships between shell length and total weight, tissue weight, edible-meat-weight, female-gonad-weight and penis-weight are presented in Table 2 (also see Figs. 3 to 18). Formalin preserved edible-meat-weight was found to average 26.8% (± 4.5%), 30.5% (±6.1%), 30.6% (±5.2%), and 27.9% (±4.4%) for *Neptunea heros*, *N. lyrata*, *N. pribiloffensis*, and *N. ventricosa* respectively.

TABLE 2. *Size-weight relationships of four species of* Neptunea *from the eastern Bering Sea See Figs. 3 to 18*

	N. heros	N. lyrata	N. pribiloffensis	N. ventricosa
Total Wt., g=	0.0347 L[a]$^{3.63557}$	0.0411 $L^{3.09406}$	0.0381 $L^{3.41344}$	0.0439 $L^{3.22321}$
Tissue Wt., g=	0.0256 $L^{3.85089}$	0.0267 $L^{3.61768}$	0.0266 $L^{3.99233}$	0.0298 $L^{3.71237}$
Edible Meat Wt., g =	0.0225 $L^{3.91420}$	0.0238 $L^{3.59984}$	0.0241 $L^{3.83347}$	0.0253 $L^{3.80735}$
Female gonad Wt., g=	0.0098 $L^{12.63105}$	0.0098 $L^{9.28419}$	0.0109 $L^{10.2459}$	0.0113 $L^{14.90757}$
Penis Wt., g =	0.0101 $L^{12.72427}$	0.0095 $L^{10.1389}$	0.0102 $L^{10.63264}$	0.0115 $L^{28.02691}$

[a] L = total shell length (mm)

In all of the diagrams of shell length vs. female gonad or penis weight some scattering among points representing the larger specimens is apparent (Figs. 11 to 18); however, a generalized size at which sexual maturity is approached can be determined by the curves. Female *Neptunea heros* *N. lyrata*, *N. pribiloffensis*, and *N. ventricosa* exhibit sudden increases in gonad-weight when their shell lengths are approximately 110, 110, 105, and 102 mm respectively. Males of all four species display similar increases in the relationship of penis-weight to shell length. These increases occur for males at approximately 95, 100, 90, and 87 mm for *N. heros*, *N. lyrata*, *N. pribiloffensis*, and *N. ventricosa* respectively.

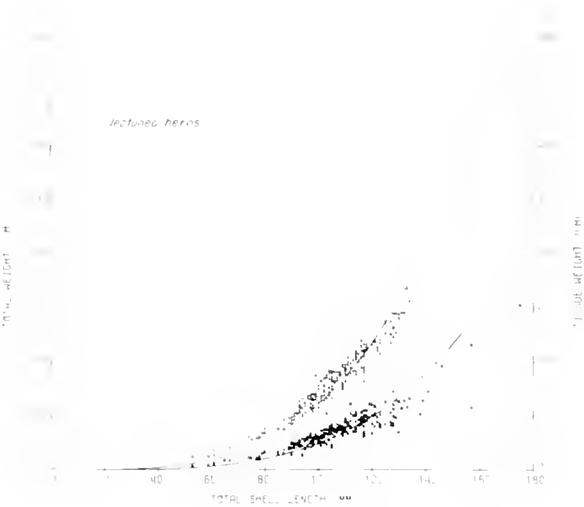

FIG. 3. *The relationship of total shell length to total weight and tissue-weight for Neptunea heros from the eastern Bering Sea.*

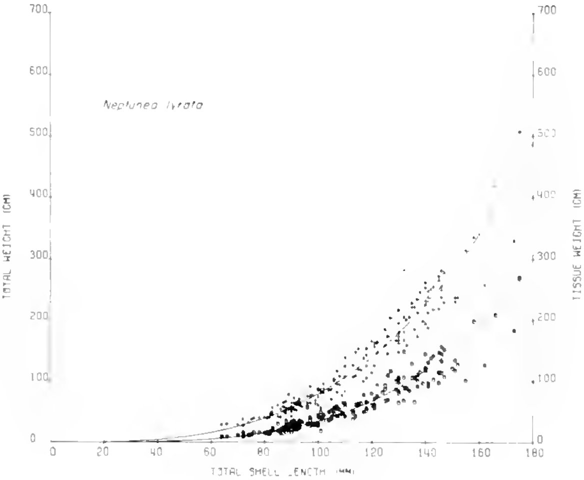

FIG.4.*The relationship of total shell length to total weight and tissue-weight for* Neptunea lyrata *from the eastern Bering Sea.*

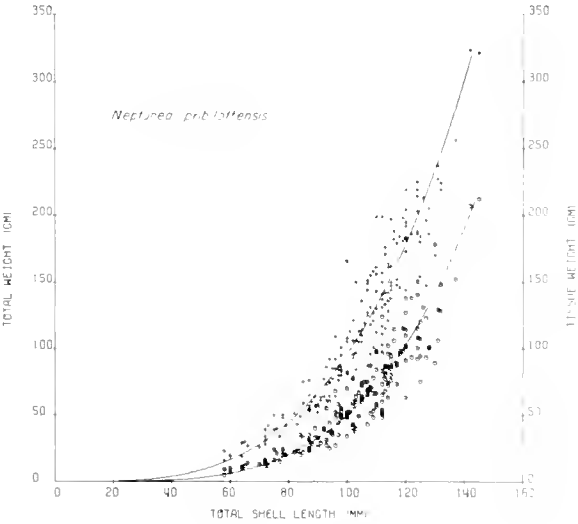

FIG. 5.*The relationship of total shell length to total weight and tissue-weight for* Neptunea pribiloffensis from the eastern Bering Sea.

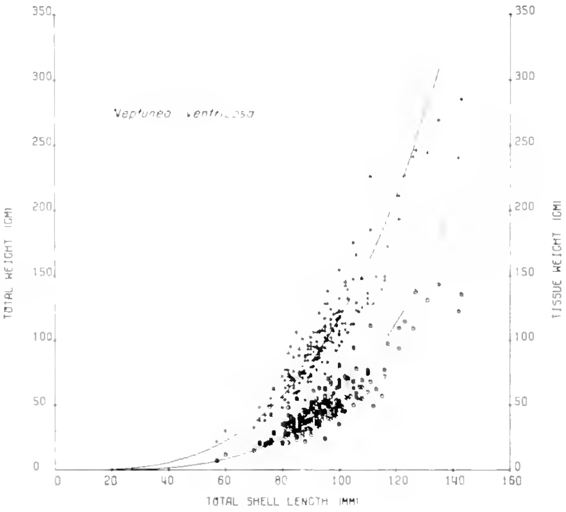

FIG. 6. *The relationship of total shell length to total weight and tissue-weight for Neptunea ventricosa from the eastern Bering Sea.*

DISCUSSION

Rae Baxter (Alaska Dep. Fish and Game, Bethel, AK: personal communication), working with *Neptunea lyrata* from an isolated Bristol Bay population, reported an edible meat recovery of 22% for specimens with an average length of 55 mm. Individuals of this small size were unavailable for this study. No other data is available concerning the percentage of recoverable meats for individual species of eastern Bering Sea gastropods; however, Japan Fishery Agency data (U. S. Embassy, Tokyo, Japan) for both total weight and recovered meat weight of the 1974 harvest indicates an edible meat recovery of 27%. Although this is an average of the recoveries of ten or more species, the value compares favorably with those generated for the four Neptunea examined. Possible differences between formalin preserved edible-meat-weights used in our study and the fresh weights that Japanese data are based upon have not been critically examined.

Females of all four species of *Neptunea* examined appear to approach sexual maturity at shell lengths of 10 to 15 mm larger than do males of the same species (Figs. 11 to 18). Similar observations have been made for *N. antigua* (L.) from Danish waters (Pearce and Thorson, 1967). Female *Nep-*

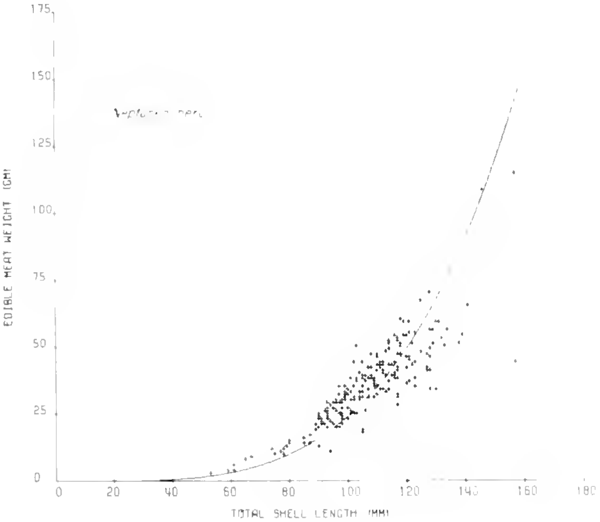

FIG. 7. *The relationship between total shell length and edible-meat-weight for* Neptunea heros *from the eastern Bering Sea.*

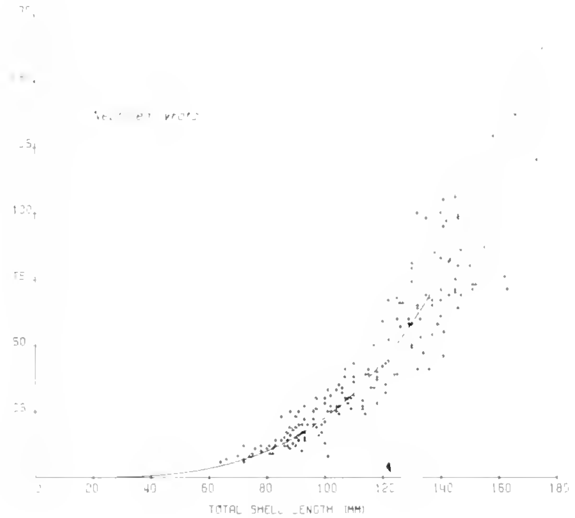

FIG. 8. *The relationship between total shell length and edible-meat-weight for* Neptunea lyrata *from the eastern Bering Sea.*

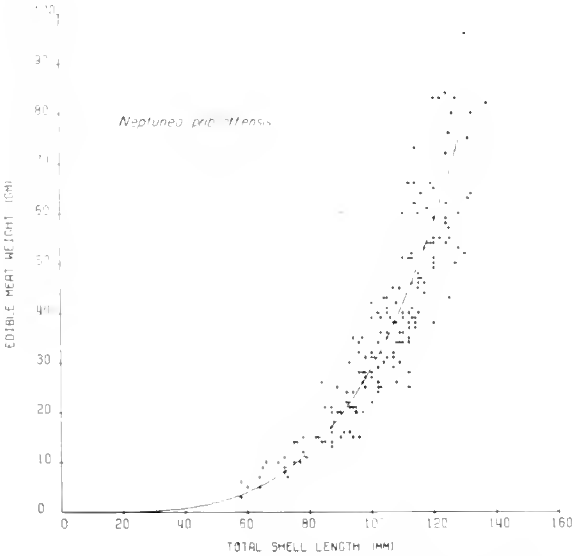

FIG. 9. *The relationship between total shell length and edible-meat-weight for* Neptunea pribiloffensis *from the eastern Bering Sea.*

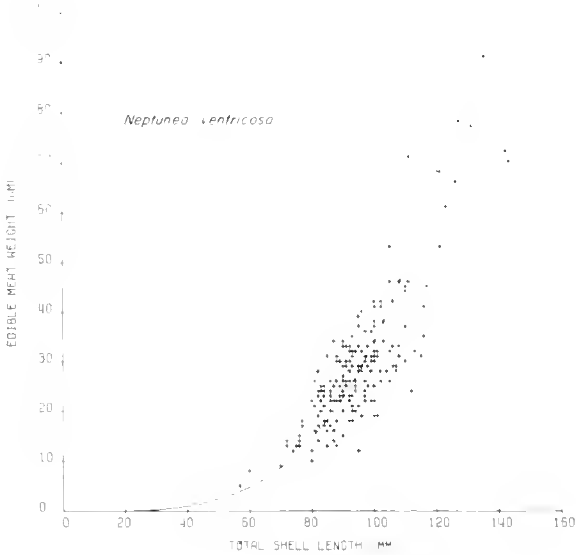

FIG. 10. *The relationship between total shell length and edible-meat-weight for* Neptunea ventricosa *from the eastern Bering Sea.*

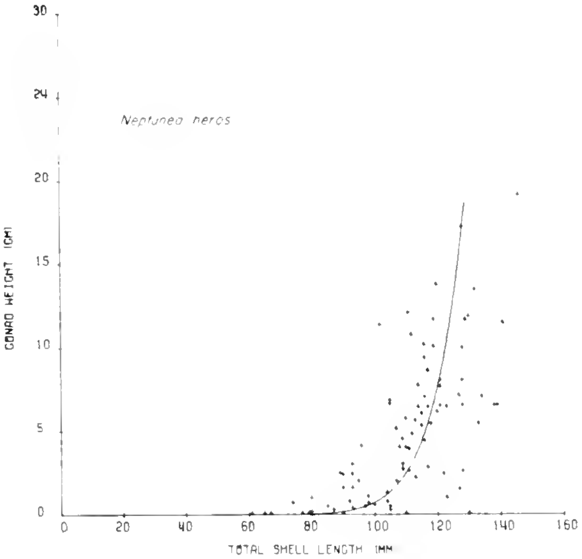

FIG. 11. *The relationship between total shell length and female-gonad-weight for* Neptunea heros *in the eastern Bering Sea.*

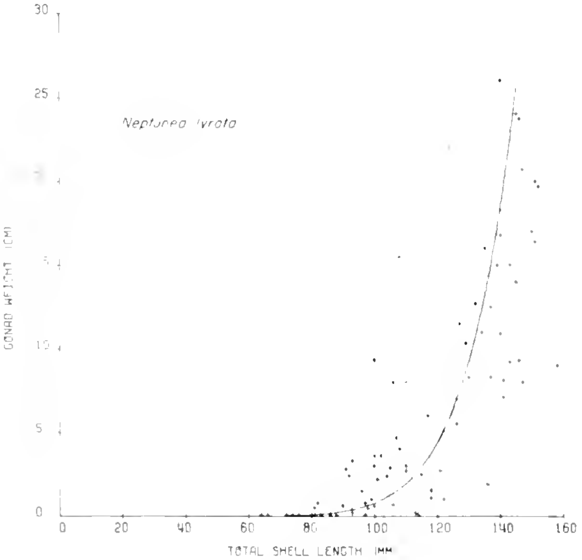

FIG. 12. *The relationship between total shell length and female-gonad-weight for* Neptunea lyrata *in the eastern Bering Sea.*

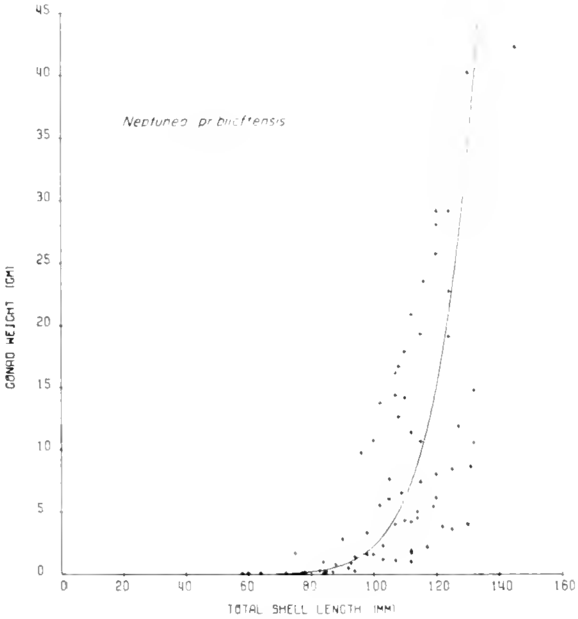

FIG. 13. *The relationship between total shell length and female-gonad-weight for Neptunea pribiloffensis in the eastern Bering Sea.*

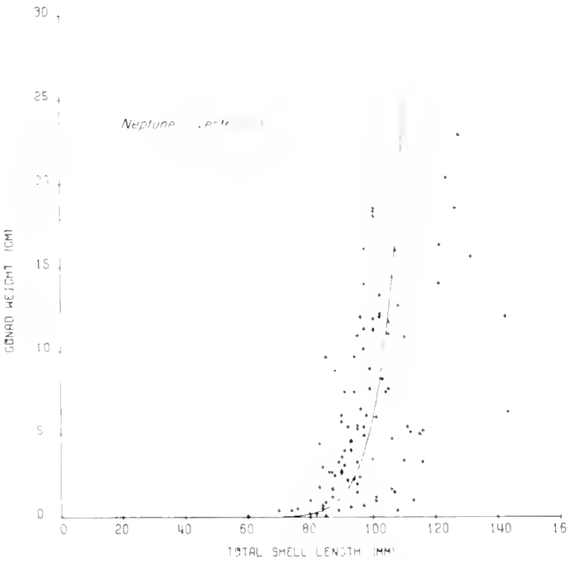

FIG. 14. *The relationship between total shell length and female-gonad-weight for* Neptunea ventricosa *in the eastern Bering Sea.*

tunea also tend to reach larger sizes than males of the same species (Pearce and Thorson, 1967; Nagai, 1974; Kaimmer *et. al.*, 1976).

Nagai (1974) reported the average live weights of *Neptunea pribiloffensis* captured in the pot fishery to be 107 g for females and 92.5 g for males. Female *N. pribiloffensis* of this weight would have approximate shell lengths of 103 mm and males 99 mm (Fig. 5). Individuals of this size may be just approaching maturity (Figs. 13, 17) and may not have spawned before capture.

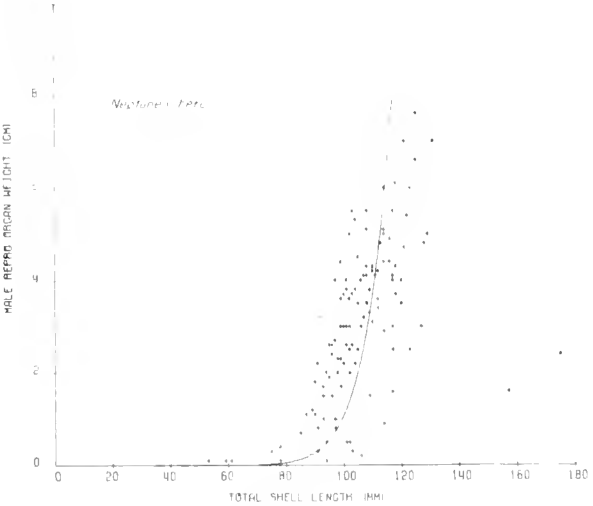

FIG. 15. *The relationship between total shell length and penis-weight for* Neptunea heros *in the eastern Bering Sea.*

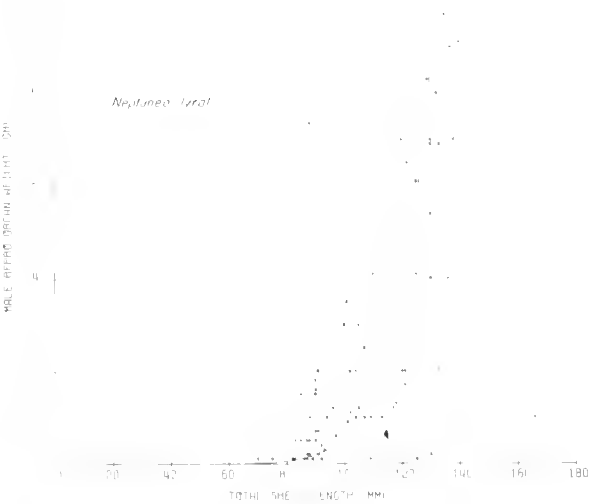

FIG. 16. *The relationship between total shell length and penis-weight for* Neptunea lyrata *in the eastern Bering Sea.*

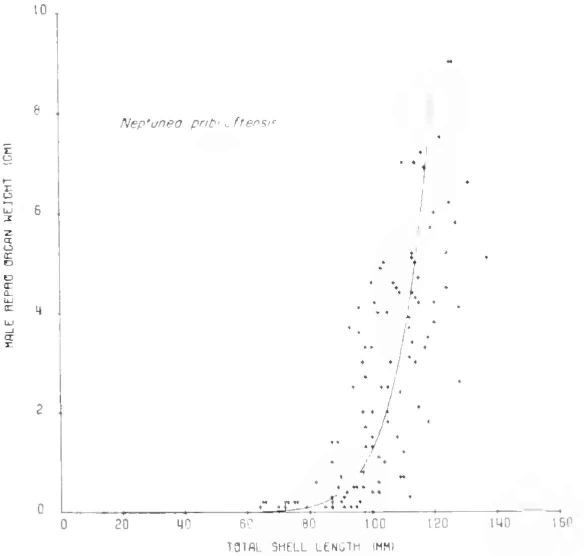

FIG. 17. *The relationship between total shell length and penis-weight for* Neptunea pribiloffensis *in the eastern Bering Sea.*

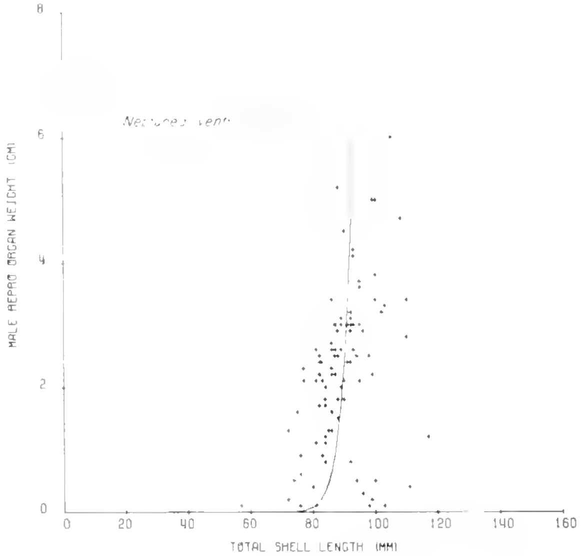

FIG. 18. *The relationship between total shell length and penis-weight for* Neptunea ventricosa *in the eastern Bering Sea.*

ACKNOWLEDGMENTS

We would like to thank the following IMS and NMFS staff members: Carol Bennie, LoHama Schaeffer, and Marilyn Buker for typing and editing; Rosemary Hobson for computer programming assistance; Howard Feder for computer time under Grant 04-5-158-41; Judy Paul and Alan Spalinger for general assistance.

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SEA ANEMONE PREDATION ON LARVAL OYSTERS IN CHESAPEAKE BAY (MARYLAND)

Clyde L. MacKenzie, Jr.

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
MIDDLE ATLANTIC COASTAL FISHERIES CENTER
SANDY HOOK LABORATORY
HIGHLANDS, NEW JERSEY 07732

ABSTRACT

Diadumene leucolena, *a sea anemone, is indicated as a biological controlling feature of oyster populations throughout the Maryland portion of Chesapeake Bay, where significant predators had not been reported. A survey showed that* D. leucolena *densities (no./m^2) averaged 103.5 on beds of live oysters and 176.2 on shell beds.* D. leucolena *was observed to be a voracious predator of oyster larvae. The findings suggest that* D. leucolena *substantially limits abundance of the oyster.*

INTRODUCTION

Diadumene leucolena, sea anemone, has widespread distribution in Maryland portion of Chesapeake Bay, yet little is known of its ecological significance, especially its possible role as a predator of pelagic larvae of mollusks such as the oyster (*Crassostrea virginica*). According to Thorson (1950), coelenterates prey on animal larvae in Europe. Orton (1922) states that a scyphozoan (*Aurelia aurita*) ingests European oyster (*Ostrea edulis*) larvae. Anthozoan feeding on invertebrate larvae has not been examined in North America. However, it may be a significant limiting feature of many invertebrate populations, including commercial mollusks.

Oysters are widely distributed in Chesapeake Bay. They grow on beds of various sizes and concentrations in most rivers, creeks, embayments, and straits on both the western and eastern shores of Chesapeake Bay, extending northward to about Baltimore and southward to the Virginia Capes (Lippson, 1973). Maryland is believed to be essentially free of predators that control or limit the oyster populations. The most serious oyster predators of eastern North America, i.e., oyster drills (*Urosalpinx cinerea* and *Eupleura caudata*) and starfish (*Asterias forbesi*) are scarce or absent because salinities below 15 parts per thousand are too low for their existence. The Maryland portion of the bay shows salinities below this point for much of the year. The blue crab (*Callinectes sapidus*) is present, but is not a significant oyster predator (Van Engel, 1958). The flatworm (*Stylochus ellipticus*) is also present, but is believed to be a minor oyster predator (Webster and Medford, 1961; Christensen, 1973). Mud crabs (family Xanthidae), that have been shown by MacKenzie (1970, a) to prey on oyster spat, are abundant in Maryland, and may also be minor oyster predators. Oysters have supported a substantial commercial fishery in Maryland since the mid-1880's (Engle, 1956; Lyles, 1969; Sieling, 1970).

The objective of this study was to determine the role of *Diadumene leucolena* as a predator of oyster larvae and to estimate its significance in controlling abundance of oysters.

MATERIALS AND METHODS

The density of *D. leucolena* was determined on 14 beds in six major oyster areas throughout

Maryland between July 8 and July 11, 1974 (Figure 1). Normally, early July is the beginning of the oyster larvae setting season that extends into September (Beaven, 1955). The areas selected to determine *D. leucolena* density were those indicated by Beaven (1955) and Lippson (1973) to be good oyster setting areas that are where most commercial oystering activity occurs. The following three bed types were examined: (1) beds of seed and market oysters; (2) beds of blank shells spread in 1971, 1972 and 1973; and (3) beds of shells dredged from beneath the bottom of the bay and spread in spring, 1974. Water depth over the beds ranged from 2.7 to 5 m.

Population density estimates of *D. leucolena* were made once on each bed by scuba divers who collected all individual anemones in a number of small measured areas. The anemones along with oysters, shells, and other material were put in a bag and brought to the surface for immediate counting while they were live. About 1.4 cl (2 pecks) of material were gathered from each bed.

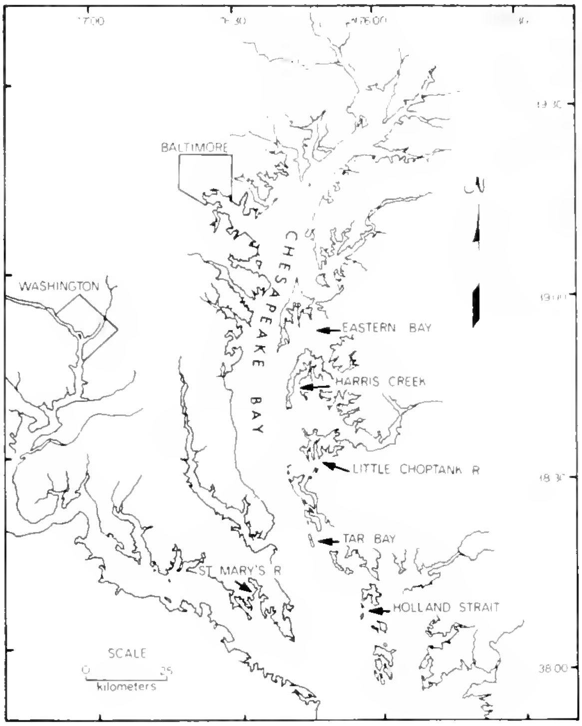

FIG. 1. *Maryland portion of Chesapeake Bay indicating location of survey sites. Arrows point to six oyster areas surveyed.*

The *D. leucolena* found were uniformly large and therefore considered to be fully grown adults. No small presumably 0-age group individuals were observed.

In the laboratory, fully-developed, ready-to-set oyster larvae were exposed to anemones. Ten to 30 larvae were placed in 1-liter plastic containers with sea water containing individual anemones. *D. leucolena* behavior in relation to the larvae that contacted their tentacles was observed through a compound microscope.

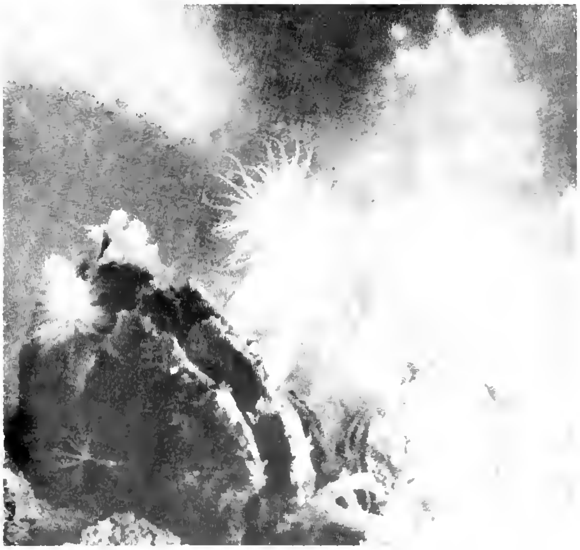

FIG. 2. *A group of sea anemones,* Diadumene leucolena, *attached to a cluster of oysters in Chesapeake Bay (from Klingel and Culver, 1955).*

RESULTS

Survey Results. Diadumene leucolena was found in all the areas surveyed. It grew on beds of both live oysters and blank shells that had been on a bed for at least a year (Figure 2), but none occurred on shells that had been spread in spring, 1974. Thus, it is probable that the larval settlement phase of the *D.leucolena* reproductive cycle had not begun by early July. *D. leucolena* grew on all sides of oyster and shell surfaces in contact with the water. The most dense populations were found in Harris Creek, Little Choptank River, Tar Bay, and Holland Strait, and fewer grew in Eastern Bay and St. Marys River (Table 1).

TABLE 1. *Average density of sea anemones on various oyster beds in Maryland, water depth, salinity, and bed type. Under bed type, years denote dates when shells were spread on beds by the State of Maryland.*

		Average Number of Anemones/m^2	Depth (m)	Salinity (ppt)	Bed Type
Eastern Bay					
Parson's Island	1.	36	5.0	11.0	Live oysters
	2.	19			1971-73 shells
Harris Creek					
Seaths Point		127	3.3	—	Live oysters
Middle Ground		16	3.3	—	1971-73 shells
Mill Point		0	2.7	—	1974 shells
Little Choptank River					
Casson's Bar		103	5.0	11.5	Live oysters
Ragged Point		0	—	11.7	1974 shells
Tar Bay					
Bluff Point		118	5.0	13.7	Live oysters
Windmill Point		508	2.7	13.8	1971-73 shells
Holland Strait					
Church Rock		219	3.3	13.9	Live oysters
Chain Shoal		332	5.0	14.5	1971-73 shells
St. Mary's River					
Thompson's Shore		18	3.3	13.5	Live oysters
Church Point		6	4.0	13.5	1971-73 shells
Thompson's Shore		0	3.3	13.5	1974 shells

Population densities (no./m^2 averaged 103.5 (range, 18 to 219) anemones on live oysters, and 176.2 (range, 6 to 508) anemones on shells spread in 1971, 1972, and 1973. Fewer anemones grew on live oysters than on shells, because in the process of feeding, probably oysters interfere with the settlement behavior of *D. leucolena*, thereby reducing its numbers.

Laboratory Observations. Diadumene leucolena captured and consumed all oyster larvae that contacted a tentacle. At the contact point, the tentacle bent vigorously and sharply and involuted longitudinally, locking the larva against it. Immediately, the bent tentacle section that held the larva moved toward the anemone mouth, that in turn opened in the direction of the tentacle (Figure 3). The larva was then released into the mouth, and passed down the gullet, while the tentacle returned to its original position.

Individual *D. leucolena* were able to capture more than one larva per minute, and once three larvae were captured simultaneously.

DISCUSSION

Diadumene leucolena probably has general distribution in Chesapeake Bay, certainly where environmental conditions are similar to those found in this study. For instance, Merrill and Boss (1966) found it on a bed in the lower Patuxent River in 3.3 m of water, while Klingel and Culver (1955) also found it in the Virginia portion of the Chesapeake Bay. *D. leucolena* is dependent on a firm substratum for its existence and grows on stones and pier pilings, as well as oysters and shells. The anemone is absent on bottoms consisting of mud or sand.

D. leucolena has high abundance and occupies much space on the commercial oyster beds of Maryland, which means it probably removes quantities of macroplankton near the bottom. *D. leucolena* is an opportunistic feeder and would in-

FIG. 3. *Sea anemone holding captured oyster larva (see arrow) on tentacle. Note the mouth opening in direction of larva.*

gest molluscan larvae, including the oyster and soft-shell clam (*Mya arenaria*), also important in commerce (Shaw and Hamons, 1974). During scuba observations, the anemone was the only visible predator of oyster larvae on the bottom. Earlier observations (unpublished) showed that the oyster and barnacles (species not identified), two common filter feeders, do not consume fully-developed oyster larvae. Possible presence of predators in the water was not examined. I believe that *D. leucolena* may be highly destructive to oyster larvae because they congregate near the bottom before setting. If so, the anemone would greatly reduce abundance of the oyster throughout the Maryland portion of Chesapeake Bay.

Accordingly, control of *D. leucolena* on oyster and shell beds should increase oyster abundance. Application of quicklime (CaO), that effectively kill the starfish without harmful environmental side effects in more saline waters (MacKenzie, 1970, a, b), might also kill the anemone. Reduction in abundance of the anemone should be followed by greater abundance of oyster.

ACKNOWLEDGMENTS

I thank F. William Sieling, III, and Frank Nelson, Department of Natural Resources, State of Maryland, for assistance in collecting field samples; and Warren S. Landers, National Marine Fisheries Service, Milford, Connecticut, for supplying oyster larvae.

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ABSTRACTS OF THE TECHNICAL PAPERS PRESENTED AT THE 1976 NSA CONVENTION

GROWTH OF MARKED RANGIA CLAMS IN THE POTOMAC RIVER

Aven M. Andersen
Michael D. Bilger

*Inland Environmental Laboratory
Center for Environmental and Estuarine Studies
University of Maryland
College Park, Maryland 20742*

As part of a pilot study on reproduction and growth of brackish-water clams, *Rangia cuneata*, in Maryland, a total of 456 clams were dug, marked, and planted into five square-meter plots near Lower Cedar Point. Then, from 3 months to 2 years later, attempts were made to recover them. About 25% have never been recovered, about 13% were dead when recovered, and about 62% were recovered live at least once. A few were recovered as many as five times. Most of those that were alive when recovered had grown little or not at all. A few grew considerably. The greatest percentage increase in length was for a clam that grew from 23 mm to 41 mm (78%) in 277 days. The general lack of growth in these marked clams is supported by the failure of modal lengths of monthly random samples of wild clams to change much with time. The irregular and poor growth of the marked clams casts doubt on the usefulness of shell markings for aging Rangia in this area.

MANILA CLAM RESEEDING PROSPECTS IN WASHINGTON STATE

Kenneth K. Chew

*College of Fisheries
University of Washington
Seattle, Washington 98195*

During the past two and half years, the Washington State Departments of Fisheries, Parks and Natural Resources and the National Marine Fisheries Service have joined with the College of Fisheries and the Washington Sea Grant in studies centered around the planting of hatchery-reared seed Manila clams (*Venerupis japonica*) on Puget Sound beaches to investigate the feasibility of the culture and to refine the techniques of planting and site selection. The state-of-the-art for technique used for planting seed clams, recovery and substrate sediment size and predation problems were discussed.

The probability of successful harvesting seeded clams at this point is still uncertain. Results from all of our studies tend to indicate that in most beaches tested, one might expect between 0-25% recovery at harvest. Most of the studies monitored after one year reveal recovery of less than 10%. However, enclosure cage studies with ¼ inch mesh screens consistently provided high recovery and the potential reason for this is discussed.

GROWTH AND SURVIVAL OF CULTCHLESS SPAT PLANTED IN NOMINI AND LOWER MACHODOC CREEKS IN 1973

Dexter S. Haven

*Virginia Institute of Marine Science
Gloucester Point, Virginia 23062*

Cultchless spat were planted in Lower Machodoc and Nomini Creeks in October, 1973, by the Virginia Marine Resources Commission and were subsequently monitored for growth and survival by the Virginia Institute of Marine Science. The study ended in July 1975.

About 12 acres were planted at a density of one

million spat per acre. By July 1975 about 80% had died in Lower Machodoc Creek; in Nomini Creek mortality was 73%.

There was an initial mortality of small spat (20%) less than ½inch long shortly after planting. However, the cause of death of the larger spat which died later was not apparent.

From October 1973 to July 1975, spat grew from an average size of 0.9 inches to 2.1 inches.

AGE AND GROWTH OF PROTOTHACA STAMINEA (CONRAD) AND SAXIDOMUS GIGANTEUS (DESHAYES) AT KIKET ISLAND, WASHINGTON

Jonathan P. Houghton

Dames & Moore
Seattle, Washington

As part of an intensive survey of the intertidal ecology of Kiket Island, Washington, a detailed investigation was made of the distribution, abundance, age, and growth of the two recreationally important venerid clams, the native littleneck, *Protothaca staminea* Conrad, and the butter clam, *Saxidomus giganteus* Deshayes.

Collections were made on eight transects encompassing a variety of bottom types about the island. I examined a series of 0.25 m^2 quadrats randomly located along fixed beach contours over two years' time to evaluate the abundance of distribution of these species.

Von Bertalanffy growth equations were fitted to length data for clams for various locations about the island. Tests for differences in growth rate of *P. staminea* showed growth to be best near mean lower low water and less rapid at higher and lower tide levels. Growth was also better on the north side of the island than at the same tidal level on the south side. Several hydrographic features such as a higher and more stable regime of temperature and salinity on the north side may account for this.

Age frequency curves and "cumulative survivorship" curves were constructed and used to predict numbers of clams expected in each cohort at each location. These figures, combined with the average weight gained per year for each cohort were summed for a smoothed estimation of production and standing crop of *P. staminea* and *S. giganteus*. About ninety percent of the total standing crop of *P. staminea* (3,319 kg) was on the north side of the island.

A high correlation was found between the location of areas with a high diversity and richness of invertebrates in general, and areas with high densities, good growth and substantial production and standing crop of *P. staminea* and *S. giganteus*. It is suggested that the same environmental factors control all of these phenomena.

THE SYSTEMATIC IDENTIFICATION OF COMMERCIALLY USEABLE SOURCES OF NATURAL OYSTER SPAT IN EASTERN CANADA

Rene E. Lavoie

Environment Canada
Fisheries & Marine Service
Halifax, Nova Scotia

In Canada, the American oyster *Crassostrea virginica* lives in the southwest portion of the Gulf of St. Lawrence through part of the provinces of New Brunswick, Prince Edward Island and Nova Scotia. Most of the landings come from fishing the natural populations. A leasehold industry is gradually developing but it is dependent on the natural populations for its stocking and seed oysters.

A five year oyster spatfall monitoring program was conducted between 1971 and 1975 to identify reliable and commercially useable sources of natural oyster spat for the benefit of the leaseholders. The program involved 134 stations distributed in 39 bays and estuaries in the provinces of New Brunswick and Prince Edward Island. The stations were visited weekly from mid-June to early September. The program identified eleven bays and estuaries which regularly produced a commercial set between 1971 and 1975.

This paper also examines some of the physical parameters which appear to affect the relative spat production success of three of the commercially useable sources identified by the spatfall monitoring program. Further habitat and population studies were conducted in Caraquet Bay and the Buctouche River in New Brunswick, and in the Bideford River in Prince Edward Island. Physical factors of the environment, biological parameters of the oyster populations as well as different ratios expressing the relationship between the oyster populations and their environment were correlated with the average oyster set recorded during the spatfall monitoring program. This study showed a significant negative correlation between tidal exchange in the estuaries and spatfall success. The study also demonstrated a very significant positive correlation between the number of flow diversions per unit area in the estuaries and oyster spatfall success.

ANNUAL STRUCTURAL CHANGES IN THE INNER SHELL LAYER OF *GEUKENSIA (=MODIOLUS) DEMISSA*

Richard A. Lutz

Department of Oceanography
University of Maine
Walpole, Maine

Seasonal cycles of growth were found to be reflected in structural patterns within the inner shell layer of the Atlantic ribbed mussel, *Geukensia (=Modiolus) demissa*, providing a method of age and growth rate determination. Monthly samples of mussels were obtained over a two-year period from both a natural intertidal population and an experimentally rafted population in the Damariscotta estuary, Lincoln County, Maine. Examination of acetate peels prepared from polished and etched longitudinal shell sections revealed the presence of at least two, and often four, distinct crystalline structural types within the inner shell layer. Scanning electron microscopic examination of both the inner layer growth surface and fractured shell sections revealed that the deposition of nacreous structure was restricted to the relatively warm months between May and September. During the remainder of the year, several crystalline patterns were observed all of which, when viewed in longitudinal sections, present a prismatic- like appearance, structurally very similar to myostracal prisms found within the shells of numerous bivalves.

Examination of *G. demissa* specimens from geographically isolated populations from Maine to Florida suggests a correlation between the mean annual temperature range and the structural composition of the inner shell layer. The shell structure of this species can potentially be used for determining paleotemperatures.

OBSERVATIONS OF SEA SCALLOP STOCKS ON GEORGES BANK AND MIDDLE ATLANTIC SHELF IN 1975

Clyde L. MacKenzie, Jr. and Arthur S. Merrill

Sandy Hook Laboratory
Middle Atlantic Coastal Fisheries Center
National Marine Fisheries Service
Highlands, New Jersey

Two resource assessment surveys (R/V *Albatross* IV) for sea scallops from Georges Bank southward to Cape Hatteras, North Carolina were made in 1975. Scallops were most abundant on Northern Edge and Northeast Peak on Georges Bank, and south of Long Island and east of the northern New Jersey coast on Middle Atlantic Shelf. A widespread scallop set occurred on Georges Bank and Middle Atlantic Shelf in 1972. The set was sufficiently abundant to predict a significant increase in commercial scallop landings in the near future.

A COMPARISON OF GROWTH AND SURVIVAL OF SUBTIDAL *CRASSOSTREA VIRGINICA* (GMELIN) IN FOUR SOUTH CAROLINA SALT MARSH IMPOUNDMENTS

John J. Manzi and Victor G. Burrell, Jr.

Marine Resources Research Institute
Charleston, South Carolina 29412

Four South Carolina salt marsh impoundments and their associated tidal creeks or estuaries were assessed as tracts for the culture of subtidal *Crassostrea virginica*. The impoundments were chosen primarily for their diversity and ranged from old large impoundments with appreciable tidal exchange and surrounded by extensive low marsh, to new small impoundments with little tidal exchange and surrounded by maritime forest. Floating and bottom hardware cloth trays (1.22 x 0.61 x 0.14 m) each holding 200 seed oysters (initial $\bar{y}$ = 43.8 mm) were placed at each location and sampled monthly for growth and survival. Coincidental monthly estimates of primary production (^{14}C), phytoplankton concentrations and total organic carbon were performed. Ancillary data collected biweekly at all locations included standard hydrographic information (temperature, salinity, pH, and turbidity) and nutrient determinations (nitrates, nitrites, orthophosphates and silicates).

Results indicated that over a six month period (October — April) growth at all locations was significantly (α = 0.001) greater in ponds than in adjacent creeks and greater in floating than bottom trays. Growth means ranged from as little as 1.00 mm month^{-1} in the Wando River, to median values of approximately 2.25 mm month^{-1} in tidal creeks, to a relatively high growth rate of 3.11 mm month^{-1} in Blue Heron Pond (Kiawah Island). Survival was high in all areas ranging from 85.0% at Blue Heron Pond to 94.5% at Kiawah Creek. There were no significant differences in survival in comparisons between all locations. A direct correlation between growth in oysters and primary production and phytoplankton biomass was established. This relationship was reiterated by indications of an inverse correlation between nutrient concentrations and growth.

AN EPIZOOTIC OF "DERMO" DISEASE IN OYSTERS IN THE MARYLAND PORTION OF THE CHESAPEAKE BAY.

Sara V. Otto and George E. Krantz

Maryland Department of Natural Resources
Fisheries Administration
State Laboratory
Oxford, Maryland 21654

University of Maryland
Center for Environmental &
Estuarine Studies
Horn Point Environmental Labs.
Cambridge, Maryland 21613

An outbreak of "Dermo" disease of epizootic (epidemic) proportions has been documented in the Maryland portion of the Chesapeake Bay. Prevalence of this disease has reached 100% on specific bars. Badly affected oyster bars have experienced 25% to 60% mortality in one year. Historical data and past oyster bar surveys (1960 to 1971) are compared to the geographic distribution, disease intensity, and oyster mortality in 1975. Some observations suggest that a new strain of "Dermo" — highly adapted to the low salinity Maryland estuarine environment — may be a factor in the upsurgence of this disease. Some possible management practices to control the disease and maintain commercial oyster production are discussed.

EFFECTS OF THREE TOXICANTS ON OYSTERS (*CRASSOSTREA VIRGINICA*) EXPOSED CONTINUOUSLY FOR TWO YEARS

Patrick R. Parrish[1], James M. Patrick, Jr.[2]
and Jerrold Forester[2]

[1]*EG&G, Bionomics*
Marine Research Laboratory
Route 6, Box 1002
Pensacola, Florida 32507

[2]*U. S. Environmental Protection Agency*
Gulf Breeze Laboratory
Sabine Island
Gulf Breeze, Florida 32561

Three separate populations of oysters were exposed continuously for 104 weeks in flowing, natural sea water in the laboratory to $0.01 \mu g/\ell$ of Aroclor® 1254 or p,p′-DDT and its metabolites or dieldrin. Maximum residues (based on µg of toxicant per g of tissue) occurred after 8 weeks of exposure; average whole-body residues (wet weight) of five oysters from each treatment analyzed individually were: Aroclor® 1254, 1.65 µg/g; DDT (and metabolites DDD and DDE), 0.46 µg/g; and dieldrin, 0.08 µg/g. Seasonal patterns of accumulation and loss of the three toxicants were similar and were apparently related to spawning. Toxicant residues decreased 45% to 81% in early July and late October, 1972, and 44% to 91% in late October, 1973. (Low spat sets in water adjacent to the laboratory indicated minimal spawning in wild oyster populations during the spring of 1973.) Growth rate (height and in-water weight) of exposed oysters was not significantly different from that of control oysters (Student's t-test; $P<0.05$) after 72 weeks of exposure. Mortality was not significant (≤9%) in any group during the entire study.

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EVALUATION OF A SULPHATE LAKE STRAIN OF *ARTEMIA* AS A FOOD FOR LARVAE OF THE GRASS SHRIMP, *PALAEMONETES PUGIO*

Anthony J. Provenzano, Jr. and Joseph W. Goy

Institute of Oceanography
Old Dominion University
Norfolk, Virginia 23508

Artemia nauplii from a newly available commercial supply originating in a Canadian sulphate lake were tested against Artemia from two other sources for effectiveness in supporting larval development of the grass shrimp, *Palaemonetes pugio*.Groups of 24 shrimp larvae pooled from three females were reared in isolation, each larva in 25 ml of static artificial sea water at 25°C and 17 p.p.t. Water was changed daily and newly hatched nauplii were provided daily at a concentration of 5-35 nauplii/ml for the Canadian strain and 40 nauplii/ml for the other two strains.

Survival rate to metamorphosis for larvae fed with Canadian *Artemia* (71%) was as good as that for larvae fed with San Francisco *Artemia* (63%) and clearly superior to that for larvae fed with Great Salt Lake *Artemia* (29%). No significant difference was found in mean number of stages required to metamorphosis or in mean time to metamorphosis between groups fed the three strains.

Hatching consistency of the Canadian cysts was inferior to that of the other tested strains when 48 hours was allowed for hatching and when hatching procedures were similar for all three strains. The hatching medium and procedures recommended by the supplier did not give results superior to those obtained with diluted sea water. However, longer hatching time may provide satisfactory hatch rates for the Canadian *Artemia*. If hatching consistency can be improved with modified hatching methods, this new source may be a satisfactory and very welcome supplement to presently limited supplies.

SOUTH CAROLINA'S HYDRAULIC ESCALATOR HARVESTER FISHERY

Raymond J. Rhodes, Willis J. Keith
and V. G. Burrell, Jr.

South Carolina Marine Resources Center
S. C. Wildlife and Marine Resources Department
Charleston, South Carolina 29412

Beginning in 1974 the delta area of the North and South Santee River in South Carolina were experimentally opened to hydraulic escalator harvester operations. During the 1974-75 clam season in South Santee and North Santee river, 31,538 "bags" (250 individuals per bag) of hard clams, mostly *Mercenaria mercenaria*, were harvested by 9 vessels. In the recent 1975-76 season, 25,948 bags were harvested from the North Santee Bay by 7 vessels. The estimated mean hourly catches in the South Santee River, North Santee River and North Santee Bay were 10.1, 10.8 and 19.8 bags per hour respectively.

Besides regulatory constraints on vessel permits and operating days, exvessel prices, equipment malfunctions and weather conditions limited the fishing time. The effectiveness of fishing input (e.g. vessel characteristics, crew size, captain skills, etc.) will be discussed.

THE EFFICIENCY OF "NITROGEN" TRANSFER IN ARTIFICIAL UPWELLING MARICULTURE. I. THE CONVERSION OF DEEP-SEA WATER DISSOLVED NITRATE TO PHYTOPLANKTON PROTEIN TO *TAPES SEMIDECUSSATA* MEAT-PROTEIN IN A FULLY MANAGED SYSTEM.[1]

Oswald A. Roels, Thomas E. Dorsey,
Kenneth Rodde, Scott Laurence,
Richard Lyon and Paul W. McDonald

The University of Texas Marine Science Institute,
Port Aransas Marine Laboratory,
Port Aransas, Texas 78373

The efficiency of conversion of deep-sea water dissolved nitrate to phytoplankton protein to *Tapes semidecussata* meat-protein was determined in the St. Croix Artificial Upwelling mariculture system, during a five-week experiment.

Chaetoceros curvisetus (STX-167, a centric diatom) and an unidentified naked flagellate (S-1, isolated by Guillard from the Sargasso Sea) were individually grown in continuous culture in concrete tanks on shore, using nutrient-rich sea water containing 31 μeq NO_3^- $liter^{-1}$ pumped from 870-m depth. During the five week experimental period, 69% of the deep water nitrate-nitrogen was converted into algal protein-nitrogen. Twenty percent of the incoming deep water nitrate was not converted by the phytoplankton at the 24-hour turnover rate used in this system. The 11% of deep-water nitrate-nitrogen, unaccounted for in the study, was probably present in the form of non-protein nitrogen in the cells and possibly as dissolved organic nitrogen in the medium. The two algal cultures were mixed and the mixture was fed at 1 ml/sec. to 4-liter shellfish containers holding 35, 70 or 140 g of 13-mm long *T. semidecussata*. Simultaneously, the same mixture was fed at 2 ml/sec to shellfish containers holding 35, 50, 70, 100 or 140 g of 13-mm long *T. semidecussata*. Each shellfish treatment was run in duplicate. At nine-day intervals the shellfish in each treatment were culled back to the starting weight. At the 1 ml/sec flow rate, the efficiency of conversion of phytoplankton protein to shellfish meat protein averaged 33%. At the 2 ml/sec flow rate, this efficiency averaged 30%. An average of 75% of phytoplankton protein nitrogen entering the shellfish tanks could be accounted for as clam meat and shell protein nitrogen, particulate protein nitrogen in the effluent from the shellfish tanks, particulate protein nitrogen deposited in the tanks, and dissolved ammonia and nitrate formed in the tanks. Particulate protein deposited in these tanks as fecal matter, debris, wall growth, etc., appeared to be a function of the amount of algae entering the shellfish tanks rather than the mass of shellfish in the tanks.

The maximum shellfish weight gain was obtained with the 100-g 2-ml/sec treatment. The lowest weight gain was registered by the 35-g 1-ml/sec shellfish. The fastest increase in length of individual shellfish was achieved at the 35-g 2-ml/sec treatment. The slowest increase in length occurred in the 140-g 1-ml/sec group. In this study, the fastest growing clams were the least efficient food converters.

Detailed analysis of the results of this experiment provides valuable guidance for the design of a shellfish mariculture system where the trade-off between efficiency of food conversion and the time required for the animals to reach market size will be guided by economic considerations.

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PRELIMINARY OBSERVATIONS ON A SHORT-CLAW GROWTH FORM OF THE MALAYSIAN PRAWN, *MACROBRACHIUM ROSENBERGII* (DE MAN)

Paul A. Sandifer and Theodore I. J. Smith

Marine Resources Research Institute
Charleston, South Carolina 29412

During the 1975 harvest of ponds used for experimental cultivation of the Malaysian prawn, *Macrobrachium rosenbergii*,in South Carolina, a short-claw growth form was noted. The proportions of short-claw prawns in the pond populations were not determined, but several preliminary observations were made. First, the short claws were generally golden in color as opposed to the dark blue color of the claws in the "normal" long-claw form. Second, the short-(golden) claw form was noted almost exclusively among males. Third, the claws of the short-claw form were smaller by about 30-70% in length and 80-250% in weight as compared to normally clawed males of similar total length. Fourth, because of their smaller claws, short-claw males generally tended to be slightly smaller in total weight than long-claw animals of identical total length. Fifth, the tail comprises about 5-8% more of the total body weight in the short-claw form. Thus, for the same total weight of prawn, the short-claw form yields more tail meat than does the long-claw form. Sixth, the short-claw animals appear to be somewhat less aggressive than long-claw specimens. However, this observation requires careful verification. It is now important to determine if the short-claw form is an inherited or environmentally controlled trait and if it is sex linked. In the future manipulation of prawn populations to produce more short-claw animals might reduce mortalities due to aggressive interactions as well as increase the yield of marketable prawn tails.

BARATARIA BASIN: SALINITY CHANGES AND OYSTER DISTRIBUTION

Virginia R. Van Sickle, Barney B. Barrett
and Ted B. Ford

Center for Wetland Resources,
Louisiana State University,
Baton Rouge, La. 70803.

Division of Oyster Water Bottoms and Seafoods,
Louisiana Wildlife and Fisheries Commission,
P. O. Box 14526,
Baton Rouge, La. 70808.

Natural processes such as erosion, subsidence, and rise in sea level have contributed to a gradual alteration of salinity regimes in coastal Louisiana. The rate of change has been accelerated in areas of intense industrial and residential development such as the Barataria Basin, where over 9,000 acres of marshland have been lost by dredging. Salinity data compiled for a twenty-year period have documented increasing salinity in the Barataria estuary. Salinity has increased at an average monthly rate of 0.01 ppt at St. Mary's Point, a station in upper Barataria Bay. During the past thirty years, natural oyster spatfall has occurred further and further inland, in bayous and lakes that previously had been too fresh to support oyster growth. The encroachment of highly saline Gulf water into present oyster-growing areas leads to mortalities resulting from the conch, *Thais haemostoma*, and the fungus, *Labyrinthomyxa marina*. In essence, the oyster industry in Barataria Basin is steadily being squeezed between encroaching salinity from the south and encroaching pollution from the north. As these two forces continue, availability of areas suitable for oyster production will decline.

SOME SPATIAL AND NUTRITIONAL EFFECTS ON THE CULTURING OF THE LARVAE OF *CRASSOSTREA VIRGINICA*, THE AMERICAN OYSTER

N. T. Windsor and John L. Dupuy

Virginia Institute of Marine Science
Gloucester Point, Virginia

Experiments were carried out on the spatial and nutritional aspects of the culturing of oyster larvae. Results indicate spatial requirements for the larvae to culture volume influences the percent yields of pediveligers and metamorphosed larvae.

The successful development of an algal diet consisting of three species which consistantly produce pediveligers in 7-10 days is described. In addition the effect of various algal densities on the larval growth rate and percent yield of pediveligers is also considered.

NSA PACIFIC COAST SECTION

DEVELOPMENT OF UNIVERSITY OF WASHINGTON'S EXPERIMENTAL OYSTER HATCHERY

John (Hal) Beattie

University of Washington
College of Fisheries,
Seattle, Washington

For the past five years the College of Fisheries at the University of Washington has been studying the problems of summer mortalities of Pacific Oysters in Washington state. Researchers have succeeded in simulating mortality situations in the laboratory and in isolating bacteria associated with the kill. The purpose of the development of this experimental shellfish hatchery is to investigate the possibility of using genetics to help reduce or eliminate summer kill. The methods include using surviving adult oysters of a laboratory challenge as brood stock, rearing the offspring on selected oyster beds in Washington state and challenging these oysters against Japanese oyster seed of the same age. In addition the tissues of parents and offspring will be tested using electrophoresis in order to examine inheritance patterns. The hatchery is a result of cooperation between the College of Fisheries, National Marine Fisheries Service, E. P. A., Washington State Department of Fisheries, several growers and the four shellfish hatcheries in Washington state.

ALGAL CHEMOSTATS AND OYSTER LARVAE

W. P. Breese, P. L. Donaghay,
R. E. Malouf, and L. F. Small

Oregon State University
Corvallis Oregon

A method of prolonged, continuous algal culture is described. The vessel contains 16 ℓ of algal culture with a density of from 3 to 10 million cells per ml. Sterility is established by using ozone gas and is maintained by using chlorine (3 to 5 ppm) in the dilution water.

Prolonged continuous algal culture may affect the food quality of the algae. Under certain culture conditions, *Pseudoisochrysis paradoxa* can become a highly superior food yielding enhanced growth and survival of Pacific oyster larvae. However, under different culture conditions this same species lost up to 90% of its food value. The poor food quality characteristic of this food type applied not only to Pacific oyster larvae, but also to brine shrimp. The reason for this phenomenon is not yet known, but is under investigation. These findings strongly suggest that although considerable potential exists for improving larval culture techniques, application of continuous culture techniques at this time may be premature.

MUSSEL STUDIES IN SEABECK BAY AND CLAM BAY

Linda Chaves-Michael

College of Fisheries
University of Washington
Seattle, Washington

A *Mytilus edulis* culture project was initiated during 1974 in Puget Sound by the College of Fisheries at the University of Washington. The methods used were to approximate Spanish raft culture methods. The initial goals were to determine a suitable setting substrate, time of setting during the year, growth time to market size and yield.

Synclove, a synthetic resembling manila rope was more promising than manila or oyster strings for catching mussel seed, yield, and durability. Market size (50 mm) was reached after only one year's growth.

During 1975 and 1976, mussel set prediction has been attempted by the examination of plankton samples for mussel larvae. The 1975 results were inconclusive as low water temperatures resulted in sporadic and minor mussel setting. The 1976 plankton samples are more promising as the presence of larvae in the water and mussel setting have been greater than during 1975.

The Mussel Culture Studies are a cooperative effort between the University of Washington, National Marine Fisheries Service and Sea Grant. A similar Sea Grant study is being conducted in the New England states. The results of the two studies will be compared.

PRELIMINARY FINDINGS ON A RECENT SUMMER KILL OF PACIFIC OYSTERS

Kenneth K. Chew

College of Fisheries
University of Washington
Seattle, Washington

Significant mortalities of Pacific oysters (*Crassostrea gigas*) have been recorded in Puget Sound, Willapa Bay, Washington and Humboldt Bay, California in the 1960's. Since 1970, the mortalities have subsided although there have apparently been isolated cases of low background mortalities from time to time during the summer.

There recently was a significant mortality discovered at Rocky Bay during the month of August, recording a mortality of 20-30% of the population. This occurred after a week of very warm temperatures and a low tide series. The mortalities revealed what appeared to be similar symptoms of mortalities occurring in the 1960's.

Observations were also made at Mud Bay, where 5-10% mortality occurred, although this may be considered background mortality.

Samples of oysters were taken from Rocky Bay and Mud Bay and challenged with water temperatures above 20° C. The results of these tests revealed similarities with some of our earlier laboratory challenges. The results of these tests and the approaches used to seek a better understanding of problems related to the stress conditions and the identification of potential pathogens are discussed.

RECENT CLAM STUDIES IN OREGON'S ESTUARIES

Thomas F. Gaumer

Oregon Department of Fish and Wildlife
Newport, Oregon

Intertidal and subtidal clam surveys have been conducted in ten of Oregon's estuaries since 1973. During these surveys we examined more than 1.1 million feet (325,280 m) of transect line and made 7,250 observations on the distribution, abundance and species composition of clams. In addition data were collected on substrate material and vegetation at each of the sample stations.

Commercial quantities of subtidal gaper clams, *Tresus capax*, were located and mapped in Tillamook, Yaquina and Coos bays. As a result, considerable interest has been generated in the commercial harvest of these clams. Special commercial harvesting permits were issued for Yaquina and Coos bays to evaluate the effects of a commercial fishery on the habitat and clam resources. The fishery failed to develop in Yaquina Bay due partially to poor marketing conditions. In Coos Bay the fishery produced over 55,000 pounds (25,166 kg) of gaper clams.

Statistical tests showed the gaper clam could most reliably be aged by counting the annuli in the chondrophore. Butter, *Saxidomus giganteus*, cockle, *Clinocardium nuttallii*, and littleneck, *Venerupis staminea*, clams were aged by counting the annuli on the exterior surface of the shell. Aging studies showed spawning or survival of clam set to be highly sporadic.

Plankton samples showed gaper clam larvae to be widely and generally evenly scattered throughout the channel areas and across the tideflats. Two periods of peak spawning were recorded in Yaquina Bay; both associated with the lunar cycle with maximum production of larvae at the periods of greatest tidal range.

A haplosporidian infection of the gaper clam was documented subtidally from five of Oregon's estuaries. Incidence ranged as high as 89% and appeared to widely distributed through the estuarine range of the clam. The infection appeared to be age dependent with older clams more heavily parasitized.

BIOCHEMICAL GENETIC IDENTIFICATION OF SPECIES AND HYBRIDS OF THE BERING SEA TANNER CRAB, *CHIONOECETES BAIRDI* AND *C. OPILIO.*

W. S. Grant, L. Bartlett*
and F. M. Utter

U. S. Dept. of Commerce
National Marine Fisheries Service
Northwest Fisheries Center
Seattle, Washington
**Kodiak Facility*

The eastern portion of the Bering Sea is an area of overlap in the distributions of the tanner crab, *Chionoecetes bairdi* and *C. opilio.* In this area the species hybridize, and recent abundance data indicate that hybrids make up about 20% of the total tanner crab population. The presence of the hybrid creates problems in resource assessment studies and is potentially problematical in commercial catch regulation because it is often difficult to distinguish the hybrid from its parent species. Morphological characters integrade and there is often disagreement as to which traits characterize the hybrid. This report is an extension of research by Allyn Johnson, which described proteins using electrophoresis that were diagnostic of each species and the hybrid. Using starch gel electrophoresis we assayed for 23 genetic loci. The average observed heterozygosities of *C. bairdi, C. Opilio* and the hybrids were 4.9, 6.3 and 12.9% respectively. The higher level of heterozygosity found in the hybrids resulted from the crossing of two separate strains. Using Rogers' (1972) index of genetic similarity (which ranges from 0 to 1.0) our biochemical data indicate that *C. bairdi* and *C. opilio* are very closely related (S = 0.907) and it is not surprising that hybrids form between them. Our results confirm the validity of using general proteins as a diagnostic character to distinguish the two species and the hybrid from each other.

THE ECONOMIC FEASIBILITY OF BRINE SHRIMP CULTURE UNDER SEMI-CONTROLLED CONDITIONS

Richard S. Johnston and Larry O. Rogers

Oregon State University
Corvallis, Oregon

During the summer of 1974, the authors cultured *artemia s.* on the campus of Oregon State University in outdoor ponds. This pre-pilot production scheme was part of an attempt to analyze the economic feasibility of producing *a. salina* eggs under semi-controlled conditions.

We observed, in contrast to other reports in the literature, that *artemia* over-wintered not only as eggs, but as both adults and juveniles as well.

Preliminary findings tend to indicate that *artemia* egg production alone, under the particular semi-controlled conditions chosen and at projected world prices, would not be economically feasible when associated with the high costs of land acquisition, pond construction, and pond maintenance which presently prevail. However, if *artemia* eggs are produced as a bi-product of solar salt manufacturing, it would appear that such an enterprise, using semi-controlled conditions, would be lucrative, being able to attract and retain resources.

The techniques used in this study may prove useful to aquaculturists who use *artemia* as feed for various cultured organisms.

THE DEMAND FOR PACIFIC OYSTERS: A PRELIMINARY REPORT

Richard S. Johnston and A. Nelson Swartz

Oregon State University
Corvallis, Oregon

Using highly aggregated data, we find the demand for Pacific oysters to be relatively price-elastic, in contrast to the price-inelastic relationship for all oysters uncovered by other researchers. Consumer demand appears to respond positively to increases in real income levels. Additional data on retail prices and shipments to particular geographical markets, inventory holdings and exports are needed for a more complete analysis.

SEA URCHINS — WASHINGTON'S NEWEST FISHERY —PRESENTS SOME PRICKLY-PROBLEMS

Chris Jones

Washington State Department of Fisheries
Brinnon, Washington

Washington's newest fishery is for red sea urchins (*Strongylocentrotus franciscanus*) which are harvested by divers in the waters of the Strait of Juan de Fuca and in the San Juan Islands. The gonads are extracted and cleaned, and exported, preferably fresh, to Japan. Through May of 1976, approximately 600,000 lb of urchins were harvested. The fishery was closed June through August because of low yield, caused by spawning in the spring. Gonad yield averages about 10% although it can range from about 5% to over 20% depending on spawning cycle and food availability. If the total harvest reaches 1-million lb this year, as expected, the value to the fishermen will be around $75,000 and the export value will exceed $200,000. Continued growth of the fishery will depend on the market, the number of divers in the fishery, and management decisions by the Washington Dept. of Fisheries designed to achieve a sustained level of harvest. Urchin populations are characterized by slow growth and recruitment; also the presence of large adults is believed to be a condition for either setting or early survival or urchins. In order to prevent overfishing, a minimum size of 3.75 inches has been imposed along with a rotation of areas open to fishing. Current studies are concentrating on estimating the extent of the resource and the time and conditions required for repopulation of a fished area.

MANILA CLAM RESEEDING STUDIES IN PUGET SOUND

Mark Miller, Charles D. Magoon,
Lynn Goodwin and Chris Jones

University of Washington,
Seattle, Washington

Department of Natural Resources
Seattle, Washington

Washington State Department of Fisheries
Olympia, Washington

Over the past two years the College of Fisheries and the Washington State Departments of Fisheries and Natural Resources with cooperation from the Washington State Department of Parks and the National Marine Fisheries Service, have taken part in studies involving the planting of hatchery-spawned Manila clams on Puget Sound beaches. Various reseeding experiments are being performed with small seed clams which may lead to a potential for rehabilitating overused clam beaches.

Factors such as tidal height, planting density, time of planting, size of seed on planting and substrate type are being considered. Other studies are being performed to determine important Manila clam predators. An effort is being made to protect seed clams from predators or environmental conditions by use of wire cages and plastic netting. Also, the experimental culture of Manilas in a large suspended sediment tray is being carried out. At all study areas recovery of seed clams generally has been relatively low over periods of one to two years; however, recovery at a particular tide level may be appreciable. Until better understanding of the losses of planted clams is attained, large scale reseeding should not be attempted on most Puget Sound beaches.

DUNGENESS CRAB MORTALITY FROM CHANNEL MAINTENANCE DREDGING IN GRAYS HARBOR, WASHINGTON

Herb Tegelberg and Ron Arthur

Determination of the distribution of Dungeness crabs (*Cancer magister*), and some effects of channel maintenance dredging on crabs were part of a dredging effects study in Grays Harbor funded by the Corps of Engineers. Sampling showed year-round residence of juvenile crabs in the ship channel east to Cow Point, and supported a previous assumption that Grays Harbor is an important "nursery" area for Dungeness crabs.

Maintenance dredging annually removes about 1 million yards by pipeline dredging of the upper reaches of the 30-foot-deep ship channel, and another 1 million yards by hopper dredging of the outer reaches. Screening of dredged material near the pipeline dredge discharge was an effective means of sampling for crab mortality, although debris and unstable bottom made the task difficult. Based on sampling of approximately 0.2 percent of the discharge during two-thirds of the dredging period, total mortality was estimated to be approximately 17,000 crabs in the 1975 pipeline dredging of 767,000 yards.

Direct sampling of a portion of the dredge material pumped by the hopper dredges *Pacific* and *Biddle* could not be accomplished during this study. This resulted in considerable experimentation with methods. Screening the hopper overflows and beam trawling in the disposal site were ineffective. A single airlift sampler used in the hopper had a potential of sampling 0.4% of the dredged volume pumped by the *Biddle*. Forty-four Dungeness crabs were captured in a volume of dredging material estimated to be equivalent to 3 minutes dredging time. Crab survival was poor with the exception of very small crabs (20-35 mm carapace width). More extensive sampling is needed, but the findings indicate that hopper dredging kills large numbers of Dungeness crabs in Grays Harbor. This would be expected to apply to other west coast estuaries. The sampling indicates that pipeline dredging causes less direct mortality than hopper dredging.

CURRENT STATUS OF SHELLFISH HARVEST PROBLEMS IN WASHINGTON STATE

Ronald E. Westley

Washington State Department of Fisheries
Brinnon, Washington

Many changes in laws and regulations effecting the commercial harvest of shellfish have either occurred or are being proposed. Some are good, some are creating problems. Some of these changes directly prohibit shellfish harvest, and some indirectly prohibit harvest by setting a lengthy and complex review system. All result in some cost in obtaining needed permits, and all create some amount of uncertainty. In most instances, the standards of acceptance appear vague and it is difficult to judge if permits can be obtained.

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