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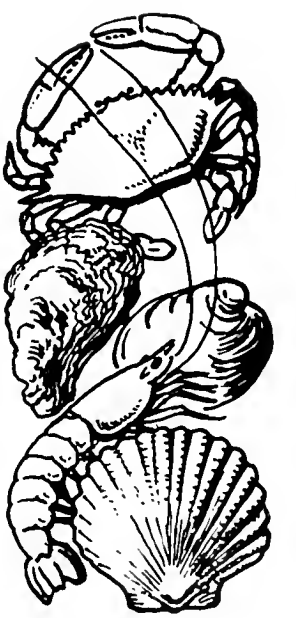

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ABSTRACTS OF TECHNICAL PAPERS PRESENTED AT THE 1969 NSA CONVENTION

SOME ASPECTS OF THE ECOLOGY, BIOLOGY AND FISHERY OF THE SUNRAY *VENUS* CLAM

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Preliminary ecological studies of the sunray venus clam, *Macrocallista nimbosa*, have been conducted in conjunction with an exploratory clam survey along the northwest Gulf coast of Florida. Environmental data on salinity, substrate types, population density of commercial size clams and associated fauna were collected and analysed. An attempt has been made to determine environmental parameters that control the presence of *M. nimbosa* and that may be used to indicate the possible presence of clam populations. Analyses of the associated fauna and laboratory and field experiments have determined some of the clam's predators and the various mechanisms they use to gain entrance into the tightly closed valves.

Preliminary growth studies, including shell measurements and height-frequencies, have been conducted to determine the growth rates and year classes present. Results of field and laboratory experiments indicate that extended migrations may be possible. *Macrocallista nimbosa* have been observed "swimming" in 1-2 foot spurts along the bottom of aquaria via water expulsion and foot propulsion. This locomotory activity may account for post larval recruitment as indicated by population studies.

Substrate selection experiments reveal that *M. nimbosa* prefers the fine-grained quartz sand of its natural environment rather than test substrates of mud, shell hash, mudshell hash mix or mud-sand mix.

Preliminary survey results indicate the presence of limited quantities of commercial-sized sunray venus clams east of Panama City, Florida, in addition to the commercial beds off Port St. Joe, Florida.

AN ANALYSIS BY SCANNING ELECTRON MICROSCOPY OF HOLE BORING BY THE SNAIL *UROSALPINX*

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Radulae of *Urosalpinx cinerea follyensis* and the surfaces of incomplete boreholes in the shell of *Crassostrea virginica*, *Mytilus edulis*, and *Mya arenaria* were examined by means of light and scanning electron microscopy. Hardness tests of radular teeth and shell of prey demonstrated that marginal teeth are harder than rachidian teeth, and that the range of hardness of rachidian teeth overlaps that of the three species of shell. Rasping is carried out by two, occasionally three, of the five rachidian cusps. Rasping patterns are shallow and asymmetric. Rachidian teeth are worn to the base with use; marginal teeth wear only slightly as they are employed mainly in feeding. The distance between the tips of rachidian cusps corresponds with the interval between the parallel cusp traces rasped by them in shell. During each rasping period snails scrape off about 1/10 to 1/5 of the surface of the chemically treated area of the bottom of the borehole.

Dissolution of shell is accomplished by secretion from the secretory disk of the accessory boring organ (ABO). With each application of the ABO, most or all of the radular marks of the previous rasping period are erased by solution of a thin layer of shell. The pattern of etching is specific for each of the shell species studied. In oyster and mussel shell, initial solubilization occurs through the organic non-mineralized prism sheaths, exposing prism forms shown by other workers to be distinctive for these species, and then proceeds into the organic-calcareous structure of individual prisms. Etching of *Mya* shell revealed no fundamental prismatic form, perhaps because of the softness of the shell. Shell penetra-

tion includes dissolution of both organic complexes and $CaCO_3$ crystals.

Shell boring by this snail is principally a chemical process, and borehole geometry is generally a reflection of the morphology of the ABO.

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[1] Aided by PHS grant DE 01870 from NIDR. Systematics-Ecology Program Contribution No. 194.

FIELD EXPERIMENTS TESTING THE USE OF AGGREGATE COVERS TO PROTECT JUVENILE CLAMS

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Wachapreague, Virginia

Juvenile clams ranging in height from .6 to over 20 mm were placed in a series of field experiments to test the use of various aggregates as protective covers. The aggregates used were crushed rock (2-3 cm crushed gabbra), pea gravel (1-3 cm stream gravels), crushed oyster shell or whole oyster shell. The survival rate was compared to unprotected areas. Survival of over 80% was accomplished in protected plots, while survival in the control plots was usually between 15 and 35%. Crabs were the major predators of juvenile clams in the test area.

A *GYMNODINIUM BREVE* "RED TIDE": OCCURRENCE OF TOXIC SHELLFISH [1]

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Abner C. Jones and
Alan A. Stevens

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An investigation of the relationship between a *Gymnodinium breve* bloom condition ("red tide") and toxic shellfish along Florida's west coast was conducted during September 1967. A limited number of water and shellfish samples were collected from 9 sampling stations in the Venice, Florida, area for toxicity determinations. Samples were also collected after the *G. breve* "red tide" to establish seawater and shellfish toxicity levels in the absence of "red tide" conditions.

G. breve population densities in seawater observed during the "red tide" ranged from 2,600 organisms/ml to a nondetectable level. Some of the variations in density were attributed to the combined effects of wind, tide and surf action.

All seawater samples, collected during the *G. breve* "red tide" and assayed for toxicity, contained an ether-soluble substance that was toxic to mice. Aerosolization of the toxic seawater by surf action appeared to be the cause of human respiratory and eye irritations. Dead fishes were observed in the water and on the beach at most stations.

The 4 types of edible shellfish (coquinas, *Donax variabilis;* hard clams, *Mercenaria campechiensis;* sunray clams, *Macrocallista nimbosa;* and oysters, *Crassostrea virginica)* collected during the "red tide" outbreak contained 550, 270, 140 and 75 mouse units of toxin/100g of shellfish meats, respectively. The degree to which the shellfish became toxic appeared to differ with the species and the proximity of their habitats to the Gulf of Mexico.

No toxic seawater, toxic shellfish, irritating surf-generated aerosols, or dead fishes were observed in the absence of *G. breve* "red tide" conditions.

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[1] Contribution No. 67: Gulf Coast Water Hygiene Laboratory, P. O. Box 158, Dauphin Island, Alabama 36528. A part of the Environmental Control Administration, Bureau of Water Hygiene, Rockville, Maryland 20852.

ABILITY OF BURIED OYSTERS TO CLEAR SEDIMENT FROM THE SHELL MARGIN

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Karla Leum and
Dorothy Macgregor

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Oysters were buried in polyethylene trays which were held in an outdoor aquarium supplied with running salt water. Some trays were filled with natural sediment and others with various grades of sand. The ability of these oysters to remove sediment from their shell margins was observed while they were buried in different positions and at varying depths beneath the substrate. Clearing ability was greatest in coarse sand and poorest in fine sand. Intermediate ability was shown in a mixture of sand sizes. Natural sediment composed of mixed sand and mud permitted better clearing than fine sand. Burial horizontally with the right valve down was the most favorable position for sediment clearance and vertical with the incurrent side up was the least successful position. Oysters partially buried vertically with the bill down tended to work more deeply into the bottom or fall over on either valve, and more

than half of them did not clear well enough to continue pumping water. Through shell movements and water pumping, oysters appeared able to resist moderate amounts of sedimentation or burial.

PHYSIOLOGY OF THE RIPE, SPAWNING AND SPENT SURF CLAM GONAD [1]

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The Atlantic surf clam, *Spisula solidissima* (Dillwyn), spawns during July and August in offshore New Jersey. Glycogen metabolism of the gonad was studied in addition to several enzyme systems of the testes and ovary. Total solids were determined monthly and were correlated with the histological and physiological changes in the gonads.

The ripe testes showed heavy concentrations of glycogen in the alveolar epithelium as well as in the zone of mature spermatozoa. Distribution of glycogen phosphorylase agreed well with glycogen localization. The testicular alveolar epithelium was also quite reactive for alkaline phosphatase, malic dehydrogenase and NADH dehydrogenase, the zone of mature spermatocytes also manifested high activities for the latter two enzymes. After spawning, glycogen and enzyme activities fell to low levels as the number of cells in each alveolus decreased markedly.

Ripe eggs exhibited high levels of glycogen in the cytoplasm. The ovarian alveolar epithelium displayed heavy deposits of glycogen particularly in the vicinity of the developing oocytes. Glycogen phosphorylase activity was prominent in the cytoplasm but not in the nuclei of ripe eggs. Acid and alkaline phosphatase activities were high in the alveolar epithelium of the ovary as well as the cytoplasm of developing eggs; no reactions were noted, however, in ripe eggs. Non-specific esterase, malic dehydrogenase and NADH dehydrogenase manifested high activities in the alveolar epithelium as well as in the cytoplasm of developing and ripe egg cells. After spawning, glycogen levels in remaining eggs were high; enzyme activities in residual eggs were just as intense as in the ripe and spawning ovary.

Total solids averaged 23% in early July just before spawning, then dropped to 21% in August after the first spawning. Thereafter, total solids fluctuated between 19 and 21%.

[1] The work reported here was supported by contracts Nos. 14-17-0003-180 and 14-17-0003-185 with the U. S. Bureau of Commercial Fisheries.

THE HISTOCHEMISTRY OF THE FOOT EPITHELIUM AND ASSOCIATED GLANDS OF THE SURF CLAM, *SPISULA SOLIDISSIMA* [1]

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The epithelium of the surf clam foot is folded into a regular series of undulations with depressed areas called "crypts" alternating with raised portions known as "crests." The epithelium along its entire length is composed of a simple columnar epithelium that rests on a thick mucoprotein connective tissue support. A striking difference is noted, however, between crypt and crest cells that constitute the foot epithelium. The cells that compose the crypts are a low columnar with prominent cilia. The nucleus occupies the basal half of the cell and stains deeply with basic dyes. The crypt cells, moreover, appear to be quite active metabolically since they manifest high activities for succinic dehydrogenase, cytochrome oxidase and alkaline phosphatase.

The cells that constitute the crests are much taller in height, lack prominent cilia and characteristically possess nuclei that do not stain with the usual basic dyes. Feulgen analysis reveals that the nucleus is intact; the cytoplasm, however, exhibits various stages of disintegration terminating in entire blocks of cells sloughing off in clusters. Each crest cell has in its distal half the swollen terminal portion of a branch duct from a subepithelial pedal gland. The enlarged areas of the ducts are called "terminal bulbs" and occupy most of the cell. Since the glands as well as the duct portions are PAS positive and amylase resistant, they confer upon the crest cells a strong PAS reaction.

Studies are in progress to determine the interrelationships between the crypt and crest cells, the functions of the subepithelial pedal glands and the role of the epithelium and subepithelial glands in the physiology of the foot.

[1] The work reported here was supported by contracts Nos. 14-17-0003-180 and 14-17-0003-185 with the U. S. Bureau of Commercial Fisheries.

STUDIES ON BRACKISH WATER CLAMS OF THE GENUS *RANGIA* IN LOUISIANA

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Shells of living and dead *Rangia* are abundant

in many Louisiana estuaries; in some they can be considered a community dominant. *Rangia* utilize areas marginal for other commercially important species, such as the oyster, *Crassostrea virginica*. The importance of *Rangia* for road-building is well known in Louisiana, but the meats have had only small use. The meat is nutritious and palatable, therefore has potential market value.

Knowledge concerning the ecology of this clam is very limited. Except for a small number of publications appearing during the present decade, there is virtually little in the literature concerning growth rates, population densities, size and age distributions, habitat and related life history.

Ecological studies leading to considerations of further commercial use of *Rangia* are being conducted in the Vermilion Bay area of Louisiana. Some of the objectives of this study are to determine (1) growth rates by planting clams of known size and harvesting them one year later, and by utilizing the modal-peak growth rate procedure over a one-year period; (2) population density variability and depth-population density correlations; (3) effects of substrate on population structure; and (4) the percent by weight of shells living and dead and mortality-size correlations.

Commercial raising and/or harvesting of *Rangia* is conceivable. Spawning under laboratory conditions has been observed, an indication that clam hatcheries might be used as a source of seed. There is some knowledge of the clam's predators; however, little is known about their parasites. Methods of management, such as planting, harvesting and protecting clam beds are needed and trial applications of our present knowledge should be made in suitable areas. A survey of *Rangia* populations should be made in all Louisiana estuaries. More research is needed if Louisiana and other states wish to realize the full economic potential of this clam.

"MSX" MORTALITIES IN RESISTANT AND SUSCEPTIBLE OYSTER STOCKS

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Previous reports have summarized the lines of evidence for the development of stocks of oysters (*Crassostrea virginica*) resistant to mortalities by *Minchinia nelsoni* (MSX). Evidence based on observations of natural populations of oysters has always been open to question. Stocks of resistant and susceptible oysters have been reared yearly in the laboratory since 1965, and exposed in paired lots to MSX infection in the field. Striking differences in mortality were first seen in the 1966 year-class stocks. In 1967 three MSX-selected strains of oysters and three imported susceptible strains were used as parent stocks for laboratory-reared spat. The six groups of spat were exposed first to MSX infection in September of 1967 and mortalities were tallied through June, 1969. After 14 months of exposure in lower Delaware Bay, 6-18% of the susceptible and 31-65% of the resistant stocks were surviving. After 21 months 3-8% of the susceptibles were surviving and 28-61% of the resistants. Comparing the most resistant and the most susceptible of the six stocks, the survival ratio is approximately 20:1.

GREGARIOUS SETTING IN THE AMERICAN OYSTER

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Patricia E. O'Brien

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Earlier experiments indicated that the presence of new oyster spat (*Crassostrea virginica*) on shells attracted setting larvae and stimulated set which ordinarily would not have occurred during the considered time period. Two-month-old spat located inside larval-proof plankton mesh bags stimulated setting on cultch located outside the bags. These results indicate that a water-borne pheromone may be involved.

More recent experiments have shown that water in which adult oysters had pumped was effective in stimulating set and modifying distribution of set on cultch shells. In a 2-hour period such water was effective in stimulating over twice the set found in control cultures. In the control cultures most of the set was located on few of many exposed cultch shells while in the cultures with the oyster waste water, the new set was more equally distributed on all exposed cultch shells. In the oyster waste water cultures, the pheromones apparently are more generally distributed resulting in a more even distribution of new set on cultch shells. In the control cultures, the new spat may emit pheromones which attract more set to the immediate area.

POLIOVIRUS UPTAKE AND ELIMINATION BY THE AMERICAN OYSTER, *CRASSOSTREA VIRGINICA*[1]

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Frederick E. Hamblet and
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The epidemiologic incrimination of shellfish as vectors in the transmission of infectious hepatitis virus has been well documented in the recent decade. During this period, concerted efforts were undertaken to elucidate the relationship of viruses and shellfish in order to make intelligent judgements as to the feasibility of artifically purifying virus-contaminated shellfish (depuration). In our laboratory, we have successfully used the flow-through seawater aquaria systems designed to study poliovirus and oysters. More recently, additional experiments designed to study poliovirus and oysters in the flow-through seawater aquaria systems have been completed. The subject of this report is concerned with the uptake and elimination of poliovirus type 1 by oysters subjected to two conditions of seawater turbidity. Methods used for recovering virus from seawater and oyster samples were also tested for effectiveness and plaque enumerative reliability.

In the virus uptake phase, the data indicated that oysters subjected to low turbidity (16-24 ppm) accumulated in 24 hr approximately three times as much virus (PFU ml) as those oysters subjected to high turbidity seawater (51-77 ppm). In the virus elimination phase, the data indicated that turbidity within the range of 8-80 ppm did not significantly influence virus elimination among the several sets of experimental oyster groups in 24 hr. In 48 hr, no virus (<0.2 PFU ml) was detected in any of the oyster groups.

These results provide supportive evidence that in a controlled environment (simulating natural conditions) oysters can effectively eliminate virus in 48 hr when they are exposed to an adequate and continuous flow of seawater of either "low" or "high" turbidity. However, caution should be exercised not to interpret these results as absolute since many factors remain to be identified before the safety of commercial depurated shellfish can be relied upon.

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[1] Contribution No. 63: Gulf Coast Water Hygiene Laboratory, P. O. Box 158, Dauphin Island, Alabama 36528. A part of the Environmental Control Administration, Bureau of Water Hygiene, Rockville, Maryland 20852.

AN UNUSUAL OCCURRENCE OF INTERNAL CALCIFICATION IN THE MANTLE OF THE QUAHOG

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During investigations of mucosubstances in the mantle of the quahog, *Mercenaria mercenaria*, one clam was found with an internal deposit of calcium carbonate. Histological investigations showed that the calcification was due to an involution of the outer epithelium of the mantle. Histochemical studies showed deposits of a glycosaminoglycan underlying the epithelial cells. This material was alcianophilic at pH 1.0 and 2.5 and reacted with aldehyde fuchsin following the alcian blue/aldehyde fuchsin reaction. In addition, there was more acidic mucous material throughout the mantle connective tissue in the area of the involution than could be expected in normal mantle connective tissue. The relationship between glycosaminoglycans and calcification is discussed.

STUDIES ON BRACKISH WATER CLAMS OF THE GENUS *RANGIA* IN TEXAS

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It has long been known that *Rangia (Rangia) cuneata* and *Rangia (Rangianella) flexuosa*, though members of the marine family Mactridae, are rare in the saltier lower portions of bays and become more abundant in the upper portions ("bay heads") where salinity is lowest and fluctuates most violently. Only recently has it been recognized that even the bay heads have salinities above the optimum for *Rangia* spp., and that *R. cuneata*, especially, attains its maximum abundance far up the river where the water is fresh more than half the time. *R. flexuosa* is less abundant than *R. cuneata* everywhere it occurs except in Clear Lake and perhaps in other "lake estuaries" on the west side of Galveston Bay. In Texas *R. cuneata* is reported from Nueces River, from Green Lake and Mission Lake (in the Guadalupe River delta), from San Jacinto River, from the delta distributaries of Trinity River, and from Neches River and Sabine River, as well as from St. Charles Bay, Hynes Bay, Matagorda Bay, Lavaca Bay, upper Galveston Bay, Trinity Bay, East Bay and Sabine Lake (a "lake estuary").

The density of *R. cuneata* populations in Neches River 5 miles above the port of Beaumont (25

miles above the junction of the river with Sabine Lake) may reach 496 clams/m² and probably averages well above 250/m². During 1951-1952 when a biological survey of Neches River was accompanied by a chemical study of its waters, the water here was "fresh" (below 0.3 ppt) for 208 days consecutively and for 65% of the first year of study, yet the clams appeared to flourish through the study period. During low-river periods in autumn salinity rose to 13 ppt.

A sample of *R. cuneata* taken at this station December 1951 ranged in length from 37-56 mm; most were 37-43 mm long and would be between 3 and 4 years old. A sample collected in the same locality January 1969 ranged from 35-55 mm in length (mode 41, mean 45 mm) and would be about the same age as the earlier sample. Smaller clams were conspicuously absent; probably reproduction and recruitment occurs only at intervals of several years. Mean shell weight of the 1969 sample was 22 g. Solid content of meats averaged 20%.

A population of *R. cuneata* of this size with an average density of 100 clams/m² would yield 91 g of dry meat or 460 g of wet meat/m² equal to 910 kg dry or 4,600 kg wet meat/hectare. Or in American units, 800 pounds dry meat or over 4,000 pounds wet meat/acre. The volume of meats would be 4,600 liters/hectare or 475 gal/acre. The same population would have shells weighing 22,000 kg/hectare or 19,400 lb/acre. If it took 4 years to get this production, the average annual production/acre would be about 1,000 lb of wet meat and 4,850 lb (2.73 yd³) of shell. *Rangia* shells sell for $3.50/yd³ in Louisiana, at the shell pile, and at least $4.25 in Texas, delivered. So the annual production of shells/acre, from a population of 100 clams/m², is worth approximately $10. *Rangia* meats are sold in North Carolina for approximately $.30/lb, so 1,000 lb would be worth about $300. However, the actual populations of *R. cuneata* in Neches River are much denser than 100/m² probably averaging 250/m². Such a population would produce meats worth $750 and shells worth $25, for a total value of $775/acre/year.

AN EXPERIMENTAL DEPURATION PLANT: OPERATION AND EVALUATION [1]

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A prototype (24 bu) commercial depuration plant was evaluated as to its operational suitability under prevailing environmental parameters reflective of Gulf waters. Results indicated that with proper selection of the plant location and basic structural design of the depuration system, commercial depuration of shellfish along the Gulf Coast is a feasible method for "cleaning" oysters harvested from restricted shellfish growing waters. Eight separate trials were conducted over a period of 15 months to cover all seasonal changes. A Kelly-Purdy UV treatment unit was used to irradiate the seawater during the course of the study. Clean-up procedures used at the end of each depuration period proved to be an effective and simple method to remove fouling debris and marine silt from the oysters, baskets and pallets.

The tank design permitted 3 pallets, each holding 16 baskets of 1/2 bu of oysters, to be stacked. Test baskets (6/pallet) of polluted oysters were considered as representative of all baskets on that pallet. They were located at each end and at the midpoint of each pallet. A fecal coliform MPN of 130/100 g of oyster meat or less was set as the cut-off point of acceptability as a marketable product. Seventy-two hours was selected as maximum time for the oysters to depurate. Of the 8 trials, the last 6 were conducted with a modified seawater flow system providing for greater vertival flow. Out of a total of approximately 285-1/2 bu baskets of oysters, 8 baskets failed to attain an MPN of 130/100 g of oysters meat or less during 3 of 6 trials.

Among the parameters measured for all trials were salinity, temperature, turbidity and dissolved oxygen. All measures were taken at 0, 24, 48 and 72 hr. For all trials, salinity ranged from 10.8-28 ppt; temperature 16-30°C; turbidity 8-54 JTU and dissolved oxygen 2.8-7.9 ppm. There did not appear to be any effect on oyster quality during depuration as determined by % wet/dry weight and % glycogen content of oyster meats.

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[1] Contribution No. 66: Gulf Coast Water Hygiene Laboratory, P. O. Box 158, Dauphin Island, Alabama 36528. A part of the Environmental Control Administration, Bureau of Water Hygiene, Rockville, Maryland 20852.

A STUDY OF THE ELIMINATION OF ZINC FROM OYSTERS FROM UPPER MOBILE BAY [1]

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The routine surveillance of the trace metal content of oysters *(Crassostrea virginica)* and growing waters was undertaken to provide information to assist in the evaluation of trace metal occurrence with industrial pollution of the estuarine environment. The monthly surveillance of the

trace metal content of oysters from different stations in Mobile Bay revealed that oysters from a reef in the upper part of the Bay had a consistently high burden of zinc. The median zinc content of oysters from this reef during 1968 was 2,000 mg/kg wet tissue. The median zinc content of oysters from 7 other reefs ranged from 350-603 mg/kg during the same period. The zinc content of the water at each location was determined in grab samples; the median zinc content for every station was either 0.002 or 0.003 mg/liter.

Comparison of zinc analyses of various tissues from the highly burdened oysters with those of oysters from one of the other reefs indicated that the mantle was the site of a great portion of the zinc burden.

Oysters initially containing 2,200 mg zinc/kg were dredged from the reef in upper Mobile Bay and transported to Dauphin Island and maintained in the wet laboratory in flowing bay water. Oysters were removed at intervals and analyzed for zinc. The zinc content began to decrease after 12 weeks, but after more than 6 months the zinc content was still above 1,500 mg/kg. These results indicated that relaying oysters for the purpose of zinc elimination may be impractical.

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[1] Contribution No. 64: Gulf Coast Water Hygiene Laboratory, P. O. Box 158, Dauphin Island, Alabama 36528. A part of the Environmental Control Administration, Bureau of Water Hygiene, Rockville, Maryland 20852.

THE COMBINED EFFECTS OF SALINITY AND TEMPERATURE ON THE FEEDING, REPRODUCTIVE AND SURVIVAL RATES OF *EUPLEURA CAUDATA* (SAY) AND *UROSALPINX CINEREA* (SAY) (PROSOBRANCHIA: MURICIDAE)

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Studies were conducted under controlled laboratory conditions to determine the combined effects of salinity and temperature on certain fundamental activities of *Urosalpinx cinerea* and *Eupleura caudata* indigenous to Long Island Sound. The results indicated that oyster drills demonstrate changes in their rates of feeding, reproduction and survival in response to changes in salinity and temperature.

The feeding rates of *U. cinerea* and *E. caudata* are affected by both salinity and temperature. Both drill species consumed few *Crassostrea virginica* spat at the lowest temperature and salinity combination studied (15.0°C, 12.5 ppt). The rate of feeding increased with increased temperature and salinity, with the maximum feeding observed at the highest combination studied (25.0°C, 26.5 ppt). At all temperature and salinity combinations *U. cinerea* consumed more oyster spat than did *E. caudata*. It would seem, therefore, that *U. cinerea* is probably the more voracious predator of *C. virginica*.

Both gastropods exhibited cannibalism in the presence of alternative food sources, but *E. caudata* did so to a greater extent than *U. cinerea*. Cannibalism increased as feeding rates increased and the highest incidence of cannibalism was observed at optimum feeding conditions. In all instances in which active cannibalism was observed the predators were female drills.

The mortality rates of both species of drills increased with increasing temperature and decreasing salinity. The highest mortality occurred at the lowest salinity and highest temperature combination (25.0°C, 12.5 ppt) and the lowest, at the highest salinity and lowest temperature (15.0°C, 26.5 ppt). *Eupleura caudata* was less tolerant than *U. cinerea* to low salinities at all temperatures.

The number of egg cases deposited by *U. cinerea* and *E. caudata* also was temperature and salinity dependent. *Urosalpinx cinerea* began ovipositing at 20.0°C and 20.0 ppt and *E. caudata* began ovipositing at 15.0°C and at 20.0 ppt. The number of egg capsules deposited by both species of drills increased with each increase in temperature and salinity, with the maximum number deposited at 25.0°C and 26.5 ppt. The number of eggs per capsule did not appear to be affected by temperature and salinity.

DETERMINATION OF MERCURY IN OYSTERS BY DITHIZONE[1]

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Human poisoning from ingesting methyl mercury chloride in seafoods occurred in Japan in 1953 and later in 1966. This disease, referred to as Minamata Disease, is mercury poisoning. The wide use of mercury compounds in manufacturing processes and in agriculture for seed treatment has created a need for a suitable method for measuring mercury compounds inadvertantly introduced into the environment.

A tissue digestion procedure developed in our

laboratory that uses nitric acid as the digestant followed by the application of atomic absorption spectrophotometry for trace metal analyses of oysters has been shown to have a high level of sensitivity for many common types of trace metals. However, this method fails to detect mercury in concentrations less than 15 ppm.

Consequently, a concerted effort was undertaken to develop a method for detecting mercury in oysters that had a high level of sensitivity. Accordingly, a tissue digestion procedure for oysters was developed that uses concentrated sulfuric acid, water and potassium permanganate. Following digestion, the highly sensitive dithizone method is used for detecting and quantitating the mercury content. The order of sensitivity of the newly developed specialized dithizone method was 2 μg, an obvious and dramatic improvement over atomic absorption spectrophotometry.

Of particular importance is the fact that the chemical literature usually warns of the volatility of mercury and recommends a rather elaborate and involved digestion procedure for prevention of mercury loss. In this regard, nitric acid should not be used for digestion because of the production of nitrogen oxides that would, in all probability, carry the mercury vapor thus causing low recovery. A unique feature of the modified tissue digestion procedure is that no outside heat is needed such as hot plates or burners. Heat is generated solely from the action of the concentrated sulfuric acid, water and potassium permanganate when added to the 20 g aliquots of oyster homogenates.

The newly developed tissue digestion procedure coupled with the highly sensitive dithizone method satisfies the immediate need for a reliable simple, rapid and sensitive method for determining mercury in oysters.

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[1] Contribution No. 65: Gulf Coast Water Hygiene Laboratory, P. O. Box 158, Dauphin Island, Alabama 36528. A part of the Environmental Control Administration, Bureau of Water Hygiene, Rockville, Maryland 20852.

THE SPECIES AND DISTRIBUTION OF QUAHOG CLAMS *MERCENARIA*

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Two species of quahog clams, the northern *Mercenaira mercenaria* and the southern *M. campechiensis*, along with several subspecies, occur along the Atlantic Coast of North America. The northern quahog ranges from Canada southward to Florida and the northern Gulf of Mexico. The southern ranges from New Jersey to Florida, the Gulf of Mexico and is reported from the West Indies. The northern is confined to inshore waters of bays, inlets and estuaries, except specimens that have been taken offshore on the northwest coast of Florida. The southern quahog occurs only offshore in the more northern part of its range (although one typical *M. campechiensis* was seen from the mouth of Chesapeake Bay), but occurs inshore south of Cape Canaveral, Florida and in both habitats in the Gulf of Mexico.

It is concluded that the subspecies *M. mercenaria notata* has no validity based on breeding studies and the occurrence of the subspecific trait in both northern and southern quahogs. Museum specimens labeled *M. mercenaria alba* seem to be bleached *M. mercenaria*. The northern species is mostly represented by *M. mercenaria texana* below Cape Canaveral and in the Gulf of Mexico. The northern and southern quahog species hybridize readily in the laboratory and the F_2 hybrids have been reared. Shell morphology of about 3/4 of the F_2's is very similar to the subspecies *M. mercenaria texana* and it suggests this subspecies is a naturally occurring hybrid between the two forms.

CELLULAR MECHANISMS INVOLVED IN THE REPAIR OF DIGESTIVE TISSUES OF THE PACIFIC OYSTER DESTROYED BY IONIZING RADIATION

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A brief description of the degenerative phase in digestive tubules, gut and the stomach following ionizing radiation is given. Complete denudation is the ultimate observable manifestation in the digestive tubule degenerative syndrome. All normal epithelial cells associated with this structure (i.e. crypt or generative cells, secretory and absorptive cells) disappear and only an abnormal squamous cell lining remains. Mechanisms of cell repopulation or regeneration include differentiation of hemocytes (possibly only one), build up of cell "nests" or epithelial islands through mitotic division and finally migration of these cells from the islands which ultimately results in re-epitheliazation. Degenerative changes which occur in the gut and stomach initially involve light to massive

hemocytic infiltration and, depending on the dosage received, terminates with a slight decrease in epithelial cell number, localized ulcerations or cell fragmentation involving a rather large surface area. Cell mechanisms involved in the repopulation of injured gut and stomach tissues are, at this time, not completely understood although the probable role of mitotic division is discussed.

"MSX" INFECTIONS IN RESISTANT AND SUSCEPTIBLE OYSTER STOCKS

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By cutting frontal sections at regular intervals through the gills and palps and a short distance into the visceral mass, the onset, course of infection and host-parasite interactions to *Minchinia nelsoni* were monitored in three resistant and three susceptible 1967 year-class laboratory reared stocks. After first exposure to the enzootic waters of Delaware Bay in September, 1967, 47% of the susceptible and 63% of the resistant spat had patent infections by mid-winter. By April, 1968, 73% of the susceptible and 80% of the resistant spat had patent infections indicating that all stocks were equally susceptible to new infections and that all spat were probably infected. With rare exceptions the infections at this time were still confined to epithelia of gills and palps. During April-June these localized infections in susceptible spat increased greatly in intensity and spread to all tissues. The prevalence level increased to 87%. In contrast, most infections in the resistant stocks decreased in intensity and remained restricted to gill and palp tissue. The prevalence level dropped to 23%. This contrast became even more pronounced by July when the prevalence level in resistant spat dropped to 7% while remaining at 87% in the susceptible spat. These data indicate a high-level of innate resistance to *M. nelsoni* in some stocks, but that this resistance may not be expressed during periods of low water temperature.

EVIDENCE FOR A POTENTIAL SPAT PRODUCING AREA IN CHESAPEAKE BAY

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In 1967, a spatfall monitoring program was established in the Manokin River, a tributary of Chesapeake Bay on the southern Eastern Shore of Maryland, in an effort to determine the patterns of mass movement of oyster larvae during a spawning and setting period. Data obtained from a dye study not only demonstrated the tidal current patterns of the river but also predicted the most probable movements of such larvae. In 1968, based on the results of this dye study, two shell cultch plantings were made in the river; one toward the mouth of the river and the other about five miles up-stream from the first. In addition, five sites were chosen in the river for the placement of rafts supplied with off-bottom, hanging shell cultch. Subsequent examination of the cultch from the seven areas demonstrated that 1968 was a peak oyster setting year in the river and that suspended cultch methods of spat capture were far superior to on-bottom cultch methods. The lowest average number of spat per shell using suspended cultch was 10, a good commercial set. Suspended cultch from a raft site near the mouth of the river yielded 17 spat per shell. The on-bottom set at this site was negligible and an average of only 1 spat per shell was found at the up-river site. The use of a large scale, economically feasible method of off-bottom capture in this river and others could result in the development of valuable spat producing areas of very real benefit to the industry.

EFFECTS OF SPOIL DISPOSAL ON THE BENTHOS OF THE UPPER CHESAPEAKE BAY

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Approximately 1.5 million yd^3 of fine sediments were removed by suction dredge from a 1.8 mile test section of the channel approach to the Chesapeake and Delaware Canal. The spoil was released 1,000 yards from the dredge site in water about 14 feet deep. The environment in this part of the Bay is not favorable to the commercial production of shellfish, but some mollusean species utilized by waterfowl are found there and it serves as a nursery and feeding area for many finfish. Salinities vary seasonally from 0 ppt in the spring to about 8 ppt in the autumn. Temperatures ranged from 2-29°C.

A van Veen grab was used to obtain samples of the benthos. Most of the 65 species observed in the study area were estuarine forms capable of living in a turbid environment. The dominant species were the isopod, *Cyathura polita*, the polychaete,

Scolecolepides viridis, and the amphipod, *Leptochierus plumulosus*. The sudden appearance of the brackish water clam, *Rangia cuneata*, which later became a dominant form, was a new species record for this area. Most of the invertebrates showed considerable variation in number and species related to seasonal changes in salinity.

Three methods used to determine the effects of dredging on the benthos were number of individuals, species diversity index and dry weight. A marked reduction in all values occurred in the channel area and spoil disposal area immediately after dredging. Recovery was nearly complete in these areas 12-18 months after dredging activities.

RESPONSE OF SHELLFISH TO TWO TOXIC DINOFLAGELLATES FROM THE GULF OF MEXICO[1]

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Laboratory cultures of *Gymnodinium breve* and *Gonyaulax monilata* were used to determine the effects of these toxic dinoflagellates from the Gulf of Mexico on several species of mollusks and crustaceans. The concentration of *G. monilata* cultures used in these studies varied from 0.7 million to 1.2 million cells/liter. Cultures with 5 to 10 million cells/liter were employed for the test with *G. breve*. Effects were evaluated by the mortality of test animals over 48 hr test period in 100%, 75%, 50%, 25% and 10% concentrations of the dinoflagellate cultures. One species of fish and two species of annelids were also tested. Activities of the test animals were also observed during the test period. Mortality date and observed responses of the test animals indicate that these dinoflagellates do not produce the same toxins. Effects of the toxins are apparently uniform within the major groups of animals tested. Fish were most sensitive to both *G. breve* and *G. monilata;* crustaceans showed resistance to both; annelids and mollusks were more sensitive to *G. monilata* than to *G. breve*.

[1] Supported by U.S. Public Health Service grant FD-00151 and Organized Research Fund, Texas A & M University.

GROWTH OF OYSTER LARVAE, *CRASSOSTREA VIRGINICA*, OF VARIOUS SIZES IN DIFFERENT CONCENTRATIONS OF THE CHRYSOPHYTE, *ISOCHRYSIS GALBANA*

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Hatchery operators mass culturing oyster larvae have found it desirable to separate a brood of larvae periodically according to size, and then grow larvae of a similar size together. The size separation is effected by washing the larvae through a series of screens of different mesh size. Little is known about the concentration of algal food required for optimum growth of oyster larvae of different sizes. The present study was undertaken to provide this information for future use in our pilot hatchery operations.

A series of 48 hr experiments was performed using different concentrations of *Isochrysis galbana* as food for one-liter cultures of 15,000 oyster larvae each. For each experiment larvae that had been reared exclusively on a diet of *I. galbana* were passed through a series of screens and larvae of the appropriate size selected. Larvae of 7 different size groups were tested, and in each test 8 food concentrations were used. A sufficient volume of *I. galbana* to give the desired concentrations of cells was added to the cultures initially and again 24 hr later. The growth increments of larvae at each feeding concentration were determined at the end of each 48 hr experiment.

The concentration of *I. galbana* that gave the maximum increase in length was considered to be the optimum feeding concentration. In instances where two consecutive concentrations gave equal growth the lower concentration was considered optimum. For the larval sizes studied, the optimum concentrations of *I. galbana* ranged from 0.19×10^{-2} ml to 3.25×10^{-2} ml of packed cells per liter of larval culture, or from approximately 19,000 to 325,000 cells/ml of larval culture. Larvae that averaged 74 μ in length grew best at a concentration of 0.19×10^{-2} ml of packed cells per liter. Optimum concentrations for larvae of other sizes were: 80 μ larvae - 0.56×10^{-2}ml/l; 107 μ - 1.25×10^{-2}ml/l; 140 μ - 1.50×10^{-2}ml/l; 170 μ - 1.75×10^{-2}ml/l; 200 μ - 2.75×10^{-2}ml/l; 246 μ - 3.25×10^{-2}ml/l.

A subsequent test using these increasing food concentrations as the larvae increased in size gave a growth rate superior to that obtained by previous investigators using a constant feeding rate.

ACUTE TEMPERATURE TOLERANCE OF OYSTER LARVAE AS RELATED TO POWER PLANT OPERATION

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Experiments are under way to determine the short-term temperature tolerance of shellfish larvae. Such information is necessary to evaluate the effects of power plant condenser cooling on entrained life stages of commercial estuarine species. In the initial trials, using a thermal gradient block, normal development of oyster embryos was impaired at 30-34° C in 1-16 hr exposures. Later experiments determined thermal tolerance of oyster larvae down to 10 sec exposures. Results and their relevance to power plant operation on estuaries are discussed.

RAFT PRODUCTION OF SEED OYSTERS IN UPPER CHESAPEAKE BAY

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The feasibility of catching seed oysters on shells suspended from rafts has been under investigation since 1965 by the Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland. These studies are being conducted in 2 areas in Talbot County, Harris Creek and Broad Creek, which are known historically for excellent annual oyster sets.

The rafts are made of 2 styrofoam logs (10" x 20" x 9'), each of which is sandwiched between equal lengths of 1" x 10" boards. Thirteen 2" x 4" x 8' boards (from which strings of shells are later suspended) are nailed, about 1 ft apart, at right angles to the top 1" x 10" board. The rafts are moored in groups of 5 with a single 100 lb mushroom anchor.

Shells suspended from the rafts collected an average of about 25 spat per shell in 1965, but less than 2 per shell in 1966. The low count in 1966 was the result of heavy fouling and late setting.

In 1967 and 1968, shells were initially stored on top of the rafts, and were not placed in the water until daily tests showed that setting had begun to intensify. This method reduced fouling and an excellent oyster set was caught on all the shells.

Although raft-caught seed is out of reach of predators restricted to the bottom, those with pelagic larvae, e.g. the flatworm, *Stylochus ellipticus*, can set on the suspended shells and cause heavy mortalities. Such a mortality from flatworm predation occurred in the 1968 raft-caught seed. Studies are now underway to control flatworm predation either by chemical treatment of shells or by moving the seed immediately after setting to areas low in flatworm abundance.

The catching of seed oysters on suspended shells appears to have commercial application in Upper Chesapeake Bay once the mortalities caused by flatworms are reduced. Apparently the heavy mortalities caused by flatworms are mainly restricted to the Eastern Shore of the Bay; studies by the Department of Chesapeake Bay Affairs have shown little mortality of raft-caught seed in St. Mary's River.

FLUIDIZATION OF JUVENILE OYSTERS: A PROGRESS REPORT

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Fluidization of juvenile oysters is presently under study at the University of Massachusetts. Preliminary data have been taken and experimental apparatus has been designed and constructed to establish the feasibility and parameters of such a process. In an effort to intensify the population of oysters in a tower culture, fluidization appears as an engineering feasibility based on data so far. The biological desirability has yet to be established.

THE SURF CLAM FISHERY — 1968

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The surf clam industry depends on the New Jersey fishery for over 90% of the supply of surf clam meats. New York and Maryland each contribute about 5% to the supply.

Total 1968 landings were 40.1 million lb of meats. This was 5 million lb less than in 1967 de-

spite an increase of 0.7 million lb landed in New York and 4 million lb in Maryland. The deficit was caused by a 9.7 million lb decrease in the New Jersey landings. This was the first decrease in total landings in 10 years.

Total effort increased in New Jersey but the catch per hour dropped from 25 to 24 bu/hr at Point Pleasant and from 34 to 28 bu/hr at Cape May. As of December 1968, 30 clam boats were fishing out of Point Pleasant (4 less than in 1967), 42 boats were fishing off Cape May (16 more than in 1967) and about 5 vessels were based at Ocean City, Maryland (3 more than the year before). The average hours fished per day trip was 7.9 for the Cape May fleet and 9.8 for the Point Pleasant fleet in 1968. This is an hour per day trip more for each fleet than in 1967.

PROPOSED 50 BUSHEL PILOT PLANT FOR OYSTER PRODUCTION [1]

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Preliminary design studies indicate that a series of 4' x 4' tray-pallets in an 8 ft high tower, with a central water supply and discharge constitute an economically feasible system which could be scaled up from previous flow rate experiments.

The proposed pilot plant incorporates a CIP (cleaned in place) hydraulic feces removal system; a tray-pallet potentially useful during the oyster growth period and in wholesale marketing channels; a seawater distribution system that requires no disassembly while servicing the plant; and a discharge to the estuary which helps siphon more water into the plant. The plant is so designed that different age groups of oysters (beginning with 2-year-old size) can be handled.

The capital cost per mature (5 year) oyster produced is estimated at 3-4 cents per oyster. Previous operating cost studies have indicated the feasibility of pumping for such a system.

It is proposed to operate this pilot plant for 1 year including the winter season. Water flow rates will be programmed according to the plankton content of the water to minimize pumping costs. Data will be collected on oyster growth, condition, mortality, electric consumption, labor requirements and down time.

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[1] A project of the Massachusetts Technical Service Program, administered by COMTECH, University of Massachusetts, State Designated Agency, and supported, in part or wholly, by State and Federal funds under the authority of the State Technical Services Act of 1965, administered nationally by the Office of State Technical Services, U. S. Department of Commerce.

NSA PACIFIC COAST SECTION

METHODS OF ESTIMATING THE ABUNDANCE OF JUVENILE SPOT SHRIMP IN A SHALLOW NURSERY AREA

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Bureau of Commercial Fisheries
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The number of 1-year-old spot shrimp, *Pandalus platyceros*, in a small bay in southeastern Alaska was estimated by 5 methods. Four methods — 1 Schnabel and 3 Petersen estimates — were based on 1,448 marked shrimp in the population. The shrimp were marked by removal of the distal half of the left lateral uropod. These estimates ranged from 19,444 to 31,494 shrimp. The fifth method, an area-density estimate based on the number of shrimp counted by divers along a series of underwater transects, gave an estimate of 14,977 shrimp. The merits of the 5 methods were compared. The Schnabel and 1 of the Petersen estimates were probably the most accurate, and the area-density estimate was the most rapid.

SOME BEHAVIORAL ASPECTS OF SHRIMP IN RELATION TO COMMERCIAL TRAWL GEAR

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During research by the Bureau of Commercial Fisheries on commercial shrimp trawls off the Oregon and Washington coasts, many observations have been made on the behavior of shrimp within the influence of nets. Results suggest that pink shrimp, *Pandalus jordani*, can be separated from unwanted organisms and debris on the seabed by a strategically placed vertical wall of web in the mouth of the trawl.

Experiments on the vertical distribution of shrimp in a simulated trawl mouth reveal that the mean size of shrimp increases with height off bottom, and this vertical height may change significantly from day to day, perhaps associated with local meteorological conditions. Use of tickler chain did not increase the vertical height at which shrimp were caught, but did increase the total catch. The utility of different mesh sizes for retention of shrimp was determined by panels of various mesh sizes placed in front of small-mesh collector bags.

PRACTICAL PROBLEMS OF PHASING AN OYSTER HATCHERY INTO PRODUCTION

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A pilot oyster seed hatchery was constructed at the University's Marine Science Center in the spring of 1969. Since then the effort has been toward developing a flow pattern for seed production. We have encountered some difficulty in providing an assured supply of gametes. This is especially true with Native oyster, *Ostrea lurida*, and European oyster, *O. edulis*. For the Pacific and Kumamota oyster, *Crassostrea gigas*, our main problem has been an adequate supply of oysters of suitable condition for spawning. Mass food production has also presented some difficulties. Excessive temperatures have given us the most trouble. Provision had not been made to remove the heat from 3,200 watts of light in the algal rearing room. This led to temperatures in the algal rearing tanks in excess of 24°C which proved disastrous to the algal cultures. We installed an air conditioner to correct temperature problems. Other problems are concerned with duration of setting to make the best use of the setting tanks, maintaining an adequate supply of clean cultch material and handling and transport of the seed. We hope that we now have most of these problems under control and that we will soon be producing oyster seed.

RECENT RESEARCH ON CONTROL OF OYSTER DRILLS

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Screening of potential molluscicides intended for control of the Japanese oyster drill, *Ocenebra japonica*, is being carried out at the Point Whitney Shellfish Laboratory. Those producing significant mortalities at concentrations of 500 ppm or less after 4 hr exposure to the chemical were tested on associated species (oysters, clams and crabs) and are undergoing limited field tests. These chemicals include carbamates, halogenated salicylanilides, organic compounds of mercury and tin, as well as inorganic compounds of copper. The mercury and tin compounds at 100 ppm or less, and a salicylanilide at 250 ppm consistently produced 100% drill mortality. The carbamates caused swelling and distension of the soft tissues exposing the drills to predation. One of the carbamates produced variable results to 100% mortality at 500 ppm. Of the several copper compounds tested, cuprous oxide was the most effective causing 100% mortality of drills at 250 ppm. Barriers of chemically impregnated grease spread in a band across a vertical wall effectively blocked the passage of drills. The barriers were effective for 37 days in the laboratory before the grease began to slough from the wall. Homogenized and lyophilized female drill tissues and tissue extract tested on drills caused a clustering response. A tissue extract that provides an effective control method for drills has not yet been found.

SOME OBSERVATION ON LABORATORY SPAWNING OF THE GEODUCK, *PANOPE GENEROSA*, AND THE CULTURE OF ITS LARVAE

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Recent findings of large numbers of subtidal geoducks, *Panope generosa*, in Puget Sound have prompted the Washington State Department of Fisheries to consider a modest carefully managed commercial fishery on these large clams. Intelligent management of this resource requires con-

siderable knowledge of the life history and ecology of the species. This paper presents results of some observations on spawning of geoducks and culture of the larvae. The geoducks studied were collected from one subtidal population in Quilcene Bay. Geoducks appear to spawn in spring and early summer. Water temperatures of 15-16°C are needed to initiate spawning in the laboratory. Sexes are separate at any given time, and occur in a 50-50 ratio. Females show a definite seasonal gonadal cycle with the ovaries full of ovocytes during the winter, release of ova in the spring and early summer, followed by a period of inactivity until the rapid elaboration of ovocytes that begins in October. Males can be found in many different stages of sexual development during any month of the year. Newly released eggs are approximately 80 μ in diameter and are enclosed in a gelatinous sheath. Larvae reach the straight hinge stage after approximately 40 hr at 15-16°C. Temperatures of 20°C and higher have repeatedly produced mortalities of the early cleavage stages; however, the more advanced stages can tolerate temperatures to 22°C. Larvae fed unialgae cultures of *Phaeodactylum tricornutum* and *Monochrysis lutheri* and held at 14-17°C (which appears to be optimum temperature for geoduck larvae) have developed to the pediveliger stage (300 μ total length) in one month. Larvae lose their swimming ability at approximately 350 μ. The relatively low temperatures at which geoducks spawn (as low as 9°C in nature) cast some doubt on the assumption that mass spawnings and successful settings occur only during exceptionally warm summers.

AGE AND GROWTH OF GIANT PACIFIC SEA SCALLOPS IN THE GULF OF ALASKA

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Giant Pacific sea scallops, *Patinopecten caurinus*, in the Gulf of Alaska have a typically sigmoid-shaped growth curve with an inflection point at about 3 years of age or 55 mm shell height. Increase in shell height decreases thereafter, tending toward an upper asymptote that varies with geographical area. Sea scallops grow fastest off Kodiak Island and slowest off southeastern Alaska; between these areas their growth rate is intermediate. Within-age variability in shell height is greatest in scallops 2-4 years old and is much reduced and nearly constant thereafter, suggesting the presence of a compensating growth mechanism which limits variability in growth as scallops get older. Causes for the differences in scallop growth among the different areas have not been established but may be related to certain environmental conditions.

HYDRAULIC CLAM DREDGE TRIALS IN COASTAL WATERS OF WASHINGTON AND OREGON

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The size and composition of subtidal clam resources outside the intertidal area along our coast are relatively unknown. Based on reports by commercial fishermen of incidental clam catches in crab pots, subtidal populations of razor clams *(Siliqua patula)* and basket cockles *(Clinocardium nuttalli)* appear to be sizeable.

To learn more about the extent of these resources the Bureau of Commercial Fisheries initiated field work in May 1969. This work was pursued to (1) develop techniques for sampling clam populations along the coastal areas at depths of 5-20 fathoms using a 30-inch hydraulic clam dredge and (2) locate and delineate clam beds along the Washington and Oregon coasts. Many operational problems were encountered in sampling with the dredge, but all were corrected. Scuba divers were helpful in making observations on dredge performance. To avoid conflict with the Dungeness crab *(Cancer magister)* fishery, we had to select carefully areas of operation. In general catches of clams were negligible. Large catches of sand dollars were taken occasionally in shallow water (5-8 fathoms).

MUSSELS, A POTENTIAL SOURCE OF PROTEIN CONCENTRATE

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The expansion of mussel culture in several parts of the world suggests that mussels could provide a reliable source of raw material for processing into protein concentrates. Current yields of approximately 800 tons per acre in Spain would provide sufficient raw material on which to base a mussel protein concentrate operation. Pro-

tein concentrates produced from Puget Sound mussels *(Mytilus edulis)* contained 70% protein, dispersed readily in water, and had desirable flavor and odor characteristics. The nutritional characteristics of the protein were superior to casein and compared favorably with fish protein concentrate.

PROGRESS IN TANNER CRAB RESEARCH IN THE SOUTHEASTERN BERING SEA

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The Bureau of Commercial Fisheries has the responsibility of providing basic information on the biology and population dynamics of crab species in the Bering Sea fishery. The data collected have been instrumental in the reduction of quotas of king crabs, *Paralithodes camtschatica*, for the Japanese and Soviet fisheries in the Bering Sea, providing needed protection for this valuable resource. As king crab quotas were reduced, the Japanese and Soviets increased their harvest of two species of tanner crabs, *Chionoecetes bairdi* and *C. opilio*. The Auke Bay Laboratory collected data on tanner crabs during king crab trawl surveys in May-June 1968, September-October 1968 and April-May 1969. Data collected during the fall of 1968 were used in a preliminary analysis of the distribution of male and female tanner crabs by depth and geographic location. Both male and female tanner crabs were numerous at the mid-depths (30-50 fathoms) of their distribution range (15-60 fathoms). They were most abundant at depths where king crabs were relatively scarce. Male tanner crabs were ubiquitously distributed over the survey area, but females were distributed less extensively; both were most abundant in the part of the survey area west of 163° W. Long. thus, the main body of tanner crabs was distributed to the west and north of the greatest concentrations of king crabs. Information on relative abundance and size-frequency distributions of *C. bairdi* and *C. opilio* were presented.

A PROGRESS REPORT ON PANDALID SHRIMP CULTURE

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During 1969 the spot shrimp, *Pandalus platyceros*, and the side-stripe, *Pandalopsis dispar*, were studied for future culture purposes. Spot shrimp adults were acclimated to temperatures of 15 and 18°C for possible use in thermonuclear plant effluent. All adults fed and moulted normally but needed constant aeration. Female spot shrimp were kept through 2 moults after hatching their eggs, thus strengthening the concept that they spawn more than once. A new method was devised to successfully hatch eggs removed from the abdomen of the female. Side-stripe larvae were cultured through 7 stages but the post-larval stage was not attained.

EXPERIMENTAL TREATMENT OF THE JAPANESE OYSTER DRILL *OCENEBRA JAPONICA*, WITH POLYSTREAM, IN WILLAPA BAY, WASHINGTON

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Four 50 ft by 50 ft plots were treated with granular Polystream at rates of 1,600, 800, 400 and 200 lb/acre. The highest kill of drills *(Ocenebra japonica)* was achieved on the tract treated at 400 lb/acre (54.5% dead drills), followed by the 800 lb/acre tract (50.5% dead drills), and the 1,600 lb/acre tract (40.9% dead drills). The tract treated with Polystream at the rate of 200 lb/acre had a very low kill (9.0% dead drills). Observations over a period of 2 months showed that Polystream apparently does not directly kill the drill. It does immobilize them for up to 2 months. Circumstantial evidence showed that the hermit crab *(Pagurus hirsutiusculus)* and possibly the Dungeness crab *(Cancer magister)* attacked immobilized drills. The black mud snail *(Nassarius obsoletus)* left the treated area, although some were immobilized and attacked by crabs. Manila clams *(Tapes phillippinarum)*, cockles *(Clinocardium nuttalli)* and *Crepidula fornicata* were attacked and eaten by crabs, 1 and 2 days after application of Polystream. The Polystream appeared to be more effective on sandy ground than on muddy ground. It was still readily visible on the 1,600, 800 and 400 lb/acre tracts after 2 months.

PACIFIC OYSTER MORTALITIES AND ENVIRONMENTAL CONDITIONS IN WASHINGTON STATE

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This report summarizes information collected

from the spring 1964 to December 1967 by the Washington State Department of Fisheries, concerning the occurrence of Pacific oyster, *Crassostrea gigas*, mortalities and associated environmental conditions. Pacific oyster mortalities occur in the heads of productive estuaries during the late summer and early fall months. In general, mortalities commence when oysters reach the age of 2+ years in mortality areas although mortalities of oysters 1+ years are not uncommon. Differences in mortality occur on common stock oysters held at various locations within the mortality areas. At the same locations within these areas, differences in the time and magnitude of mortalities among oysters of 3 different ages have been observed. Oysters transferred from a high mortality area to a low mortality area before the end of June undergo reduced mortality, while oysters transplanted after June die at approximately the same rate as oysters remaining in the high mortality area. Oysters transplanted into a high mortality area die at the same rate as oysters continuously in the high mortality area. Oysters in mortality areas are characterized by high condition index values (above 12.0). Mortalities occur coincidentally with peaks of condition index and water temperature.

MANAGEMENT OF THE DEVELOPING WASHINGTON GEODUCK FISHERY

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Washington Department of Fisheries
Brinnon, Washington

In 1967 the Washington State Department of Fisheries initiated a survey to determine if subtidal stocks of clams exist in Puget Sound. During the survey extensive populations of the large clam, *Panope generosa*, were discovered. This discovery has led to consideration of harvest of this latent resource. Past utilization of geoducks has only been intertidal sport harvest. The surveys to date have located geoducks in approximately 15,000 acres of subtidal area. These areas contain an estimated 31,000 tons of meat. Average meat weight per clam is about 1.4 lb. Adequate biological information currently does not exist upon which a maximum sustained fishery can be based. However, because of a need for market testing and development, it seemed desirable to allow initiation of a limited commercial harvest. Accordingly, legislation was proposed to allow a carefully controlled fishery. The legislation passed with some modification. At the present time, commercial harvest of geoducks is to be permitted only by divers and at distances greater than 1/4 mile from shore and in water deeper than 10 ft below zero tide level. These requirements have the effect of placing about 2/3 of the known geoduck beds in a reserve, a rather substantial bulwark against over-harvest. Management of the remaining 5,000 acre area is to be a joint venture by the Department of Fisheries, which is responsible for the biological aspects, and the Department of Natural Resources, which controls the subtidal bottoms and is responsible for management of the land. Tracts approximately 75 acres in size will be leased to individuals for harvest. Because of uncertainties concerning the economics of a geoduck fishery and a lack of biological information, it is now contemplated that about 1/4 of the presently available 5,000 acres of geoduck beds will be initially leased. Surveys are continuing and we ultimately expect to locate substantially more than 15,000 acres of geoduck beds. Simultaneously, the Department of Fisheries has initiated biological experiments to provide the life history information needed to safeguard the stocks should a more intensive fishery prove desirable. These experiments are a combination of laboratory and field studies covering representative areas of Puget Sound. These studies include observation on spawning and setting, larvae culture, growth rate and natural mortality.

COMPARATIVE MORTALITY OF PACIFIC OYSTER FROM FIVE SOURCE AREAS

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As part of the study of Pacific oyster, *Crassostrea gigas*, adult mass mortality, the Washington State Department of Fisheries is conducting a project to determine if Pacific oyster seed from the 5 major sources is either resistant or susceptible to adult mass mortality. A side benefit from this study has been information on survival of oyster seed (prior to occurrence of adult mortality). Initial spat counts and surviving spat counts clearly separate the 5 strains of seed into 2 groups. The first group, Dabob Bay and Pendrell Sound, had high initial spat counts, and high numbers of surviving spat after 1 year. The second group, Mangoku-ura and Hojima (both from Japan), and Willapa Bay had low initial spat counts and low numbers of surviving spat. Determining the reason for the higher numbers of surviving spat from Dabob Bay and Pendrell Sound is complicated by the great difference in initial spat count, and assumed mortalities from crowding on high count seed. One obvious reason

for the higher numbers of surviving spat on the Dabob Bay and Pendrell Sound seed is the considerably greater numbers of initial spat. There is also a suggestion that after the 20 spat per shell density level is reached (probably the end point of crowding mortality) survival is better for Dabob Bay and Pendrell Sound; however, the available data are not conclusive.

SOME RELATIONSHIPS BETWEEN TEMPERATURE AND PACIFIC NORTHWEST SHELLFISH PRODUCTION

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With the advent of thermonuclear electric power plants in the Pacific Northwest, biological questions will be posed which can only be answered after long and exhaustive research. This is particularly true of shellfish since much publicity has been disseminated about the "potential benefits" to shellfish from "thermal enhancement" of the environment. Since the world will not stand still while the necessary research is carried out, decisions regarding disposal of rejected heat shall be made with or without the benefit of the required data. This summary is intended to provide a limited base of useful information on the effects of temperature on Pacific Northwest shellfish. In this report readily available temperature data are related to production of razor clams, crabs and oysters in Washington State. Data on response of hardshell clam larvae, Dungeness crab larvae and Pacific oyster setting to temperature are discussed.

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THE ROLE AND RESPONSIBILITY OF ESTUARINE BIOLOGISTS IN THE ACCELERATED DEVELOPMENT OF COASTAL AREAS[1]

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Nowhere is competition for environment and associated resources more acute than in our estuarine areas. These are most threatened by population pressures and technological advances. Their fate has been one of steady deterioration and destruction. Relatively few people fully comprehend how vital our estuarine areas are to the nation, how varied and complex are man's activities here, nor what their total impact is on the economic and social lives of our people.

I need not dwell here on the valuable contributions natural estuarine areas make to our nation's economy and to our general health and well-being. The public is beginning to become aware about something we as biologists have recognized for a long time; namely, the potential of these areas for sophisticated forms of animal husbandry — including aquaculture. And we do need to emphasize the valuable function natural estuarine areas serve as safety valves against which major storms can spend their fury. Surely these natural estuarine systems are a national heritage of scenic and, indeed, unique beauty and splendor, the variety of which can hardly be found anywhere in the world. They offer endless opportunities for a variety of valuable scientific studies.

We know, too, that they are threatened from all sides by an almost infinite number of uses which result in their alteration and even destruction. These destructive forces and the manner of destruction are well known.

We accept the fact that much of the past destruction had to be and we know, of course, that many more areas must also be sacrificed to satisfy economic and social demands that are in the national interest. However, we are also aware that had there been proper planning, had we had enough knowledge, and if there had been realistic constraints to control these kinds of destruction, things could have been different, at least in some areas. Some valuable fish and wildlife resources and some recreation and scenic areas need not have been degraded or destroyed. We know, too, that alteration of some of these coastal areas has cost society far more than the value gained. And, we suspect that the short-term gains achieved in some areas may turn out to be insignificant when compared with long-term gains that might have been derived if other uses had been prescribed.

There are now available new technology and engineering capabilities which allow us to explore, develop, and use our coastal areas in ways which were not possible only a decade ago. The trend is to look to the sea and its associated land mass to the extent that it is economically and technically possible. Future developments will not be more of the same. It is along our coasts that giant thermonuclear plants will be located. Desalinization and mineral extraction plants will be part of many of these giant industrial complexes with their accompanying effects on the environment we cannot yet really assess.

This new technology gives us supertankers and superjets but requires channels 100 feet in depth and massive landfills for oil terminals and airports. It enables us to dredge for minerals (gravel, shell, fertilizers) to a degree one cannot fully comprehend, let alone evaluate. It permits oil and gas exploitation that can threaten entire fisheries and other living resources.

Estuarine areas are a major source of new land but not just for homes, commerce, or industry. Recently, there was proposed an engineering scheme for a series of dykes from Cape Hatteras to Daytona and from Key West to New

[1] Remarks of Dr. Roland F. Smith, Assistant Director — Marine Resources, before a meeting of the Atlantic Estuarine Research Society at Atlantic Beach, North Carolina on 3 October 1968.

Orleans. This proposal enthusiastically cited the hundreds of square miles of new fertile land and thousands of new jobs that would be created. Not mentioned was the untold wealth in estuarine resources and existing jobs and recreational opportunities that would be lost nor the profound changes on our coastal circulation and weather that might result.

There are other schemes by planners and engineers which include creation of large freshwater impoundments out of Delaware and Chesapeake Bays, and Long Island Sound. There is a proposal for diversion of all of the freshwater entering Texas estuaries, one of our most valuable shrimp nursery areas. Another proposal calls for a deep draft ship channel, through the marshes, from New Orleans to Texas. About 45 square miles of Georgia estuarine areas are scheduled to be destroyed by strip mines. And so it goes.

The fact of the matter is that none of our estuarine systems, regardless of size, can support all of man's potential needs. How, then, do we go about deciding which of these needs can be permitted? Will the decision be in the national interest or to satisfy local demands? How do we consider all competing and conflicting uses? Who is to decide what any given area will be used for? Can we make a case for preservation of more estuarine areas in a reasonably natural condition?

Before I review the role of biologists, I should briefly outline some basic concepts and procedures that I believe must be adopted in any future management of our coastal zone if this is to serve the best interests of present and future generations.

1. Estuarine and coastal areas must be considered as regional ecologically oriented units, preferably as parts of large river basin complexes. This concept is now gradually becoming recognized as perhaps the only logical approach to sound management of coastal areas.

2. The multiple-use philosophy must prevail as a general guide for future planning. In general, the exploitation of a single resource or use that is contrary to other desirable uses cannot be permitted.

3. We must develop better techniques to evaluate all potential uses for a given area in terms of maximum long-run economic and social benefits. Comparable standards must be developed to evaluate all pertinent factors, especially cost/benefit values, if rational decisions regarding optimum use are to be made. Much more sophisticated approaches must be evolved for developing alternative solutions, predicting long-term trends, and compromising conflicting goals.

4. There must be closer harmony and coordination between agencies at all levels of government which have interests in these areas.

5. There must be a proper consideration given to both public and private enterprises in these coastal areas.

6. There must be developed strong and competent organizations, such as State or interstate authorities or compacts, to administer these areas. In most instances such machinery is not available or is not doing the job adequately. Such organizations must be staffed with people competent to analyze and develop quantitative environmental models for evaluating alternatives and capable of developing comprehensive plans for carrying out complete regional programs.

7. There must evolve some system of Federal standards to provide adequate guidelines and criteria throughout the country. Such Federal criteria might well employ the concept such as used in the development of our water quality standards. In other words, the Federal Government would stipulate a minimum set of criteria for the management of estuarine areas. Federal funds might be made available to encourage even higher standards.

8. Finally, there must be an informed public willing to support policies leading to the sound management of our estuarine and coastal zones.

I am convinced that one of the key roles in management of these estuarine systems must be played by estuarine biologists. They understand better than anyone else that any program for the development or management of an estuarine system must be consistent with existing natural processes — biological, physical, and chemical. They recognize that what man does and brings in must be fitted into the natural system — not forced upon it. The engineer's goal is to create a stable environment, yet we as biologists know that such an environment can only lead to the death of an estuary.

We have come to the terrible realization that we are not fully able to cope with the accelerated demands to alter our coastal environments. We have never had enough money to adequately study the dynamics of estuarine systems or the life histories of our most valuable species. We cannot even hazard a guess as to how much nursery area is required for any one of our valuable sport or commercial fishery resources, such as shrimp, striped bass, menhaden. The fact that some reputable scientists have even questioned if we need any estuarine environment for some of these species suggests that we do not really know what the environmental requirements may be for any one of these species or their food supply. We are a little better off for most of our

wildlife species, though this is hardly cause for complacency.

Perhaps, because we have been underfunded, sometimes because of State boundaries and institutional barriers, we have neglected to mount broad comprehensive studies comparable to the work of offshore biologists and oceanographers. We have failed to fully utilize the new technologies of instrumentation and computerization to collect and process our data. As a result, a great deal of our research has tended to be fragmentary and difficult to fit together.

Some time ago Robert Dow gave a paper [2] at a meeting of the Atlantic States Marine Fisheries Commission, from which I quote several paragraphs:

"There is only one place in this country, including Alaska, where Canada is due south of the United States. The fact that Canada is also north, east, and west of this same area need not cause any confusion for in that part of Maine we have a bird called the whiskeyjack and he's not confused. At least I don't believe he is and he does research too. Anyway he spends all his time running around in the puckerbrush collecting. That's why I think he must be doing research work, although I am not quite certain what kind of research he's doing and I guess he isn't either.

"Anyway, this bird collects all kinds of things; big things, little things, but mostly shiny things. When he's made a good collection he takes it home and hides it in a good safe hiding place — a sort of bucolic file. Then he goes back out in the puckerbrush and collects some more. And that's all he does. He doesn't use any of these things he's collected except maybe once in a while he trades some of them with his friends for items they have in their collections.

"That's the way we do fisheries research. Of course, I think we're much more advanced, culturally that is, than this bird. We collect things, too, especially shiny things, but often we consolidate them and send them out to all our friends and competitors so that they can see what good collectors we are. And they do the same thing for us."

Because so much of our work is piecemeal and haphazard we are usually forced to make guesses as to what the consequences of any given environmental change may be, or to take unsound positions, for example, to justify minimum freshwater flows into Delaware Bay solely on the basis of protecting its oyster resource. This is not to suggest that oyster resources in Delaware Bay are not important but it is an indictment on our profession that this is the only source of good data on which to base a claim for more freshwater. Surely, there are equally good or better reasons, such as to maintain a two-layered circulation system, or to better manage other fishery resources.

As estuarine biologists, there are seven major areas in which we have defined responsibility and in which we must consider increasing our effort:

1. Inventory all estuarine areas showing their condition and potential for supporting valuable living resources. We need to know what is happening to such areas, how they are being threatened. In short, we need to establish biological base lines as a foundation for further studies and evaluation. Some of this work is underway.

2. Acquire more specific knowledge about the life histories and environmental requirements of estuarine-dependent species.

3. Expand fundamental research in total estuarine systems to include studies in productivity, hydrology, nutrient circulation and transfers, species interaction, and biological indicators of environmental change.

4. Develop a sound basis for determining the economic benefit from natural estuarine areas and their living resources.

5. Eliminate institutional barriers that prevent sound and equitable management.

6. Develop and use sophisticated techniques to predict effects of proposed environmental alterations.

7. Develop more sophisticated estuarine husbandry programs, including techniques for increasing fish production by alteration of currents, mitigating effects of environmental alterations, controlled use of waste products, control of diseases and predators, and development of genetic strains more suited to moderately disturbed habitats.

I want to dwell on two areas where we as biologists are especially weak. First, we must develop sound criteria for evaluating the economic benefit to be derived from natural estuarine areas.

We are a long way from putting a price tag on fish and wildlife values and we have not even begun to equate aesthetic and other indirect benefits with jet ports and oil terminals.

Economists, engineers, and planners are rapidly moving in to fill this void. Too often we are not even aware of what they are doing though they may be on the same campus, or in the same

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[2] "Social Problems of Fisheries Research" by Robert L. Dow, Research Director, Dept. of Sea and Shore Fisheries, Augusta, Maine, App. 7 to Seventeenth Annual Report of the Atlantic States Marine Fisheries Commission, March, 1959.

office building, even using our data and interpreting it wrong. In one Atlantic coastal State, planners were completing a Master Plan for the State's wetlands across the hall from the offices of the Fish and Game Department without any input from that agency's biologists.

Again, I would like to quote Mr. Dow's paper. This time it is the closing paragraph:

"In recent years I have been forced by desperation to associate with economists. I have observed a gleam of increasing intensity in their eyes. Relatively unjaded by fisheries research they are young and vigorous, and they have not yet had their intellectual ears battered and buffeted by the frustrations, complexities, and contradictions of the commercial fisheries. And close on the heels of the economists is the whole array of specialists. Unless we look well to our tactical deployment the economists and the economists, all by their lonesome, will become the new dynasty in fisheries research . . . . . If we can't join them, we'd better go underground."

Secondly, our failure to use models — all kinds — physical, bioeconomic, ecosystem, simulation models at all levels and of all degrees of sophistication. Ecologists seem to fear them, yet despite their obvious shortcomings, models seem to be the only hope for testing a variety of hypotheses, alternatives, long-term trends, and for the analysis of a mass of data from a variety of disciplines and sources.

Models are limited by the choice of inputs and by the fact that parts of the ecosystem are not fully known. If you introduce garbage, that's what's going to come out and perhaps no one may ever know the difference. Properly used models can save us a fantastic amount of field work. They can tell us where gaps exist and what relevant data are needed.

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LOBSTER (*HOMARUS AMERICANUS*) FISHERY AND ECOLOGY IN PORT AU PORT BAY, NEWFOUNDLAND, 1960-65

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ABSTRACT

Port au Port Bay, a study area in a program of studies of lobster populations in various areas in Newfoundland, is relatively shallow with extensive lobster grounds. Substrate of the grounds includes glacial boulder train with seaweed and sandy patches, also small submarine limestone cliffs with talus, potholes and open shears, and talus slopes from coastal limestone cliffs. Length frequencies of commercial lobsters indicated that annual proportions of recruits were fairly constant at 57% for Boswarlos but decreased during 1961-65 from 47 to 40% for Shoal Point grounds. Fishing rate at Shoal Point could have been higher than it was during this period. Various length and weight relationships of chelate pereiopods and bodies of lobsters were obtained from samples. These may be compared with similar data on lobsters from other areas. Growth in length, indicated from marking and recovery of lobsters after moulting, averaged 10 mm (12%) in males and 9 mm (10%) in females. Moulting rate estimated from samples was approximately 90% annually, but from marked lobsters was 69%. Hypothetical increase in weight through one moult in males was 49% and in two moults 117%. This was less in females. Fifty-eight percent of the females were potentially ovigerous annually but only 17% of those taken in samples were ovigerous. Embryo development progressed to 1/3 yolk remaining in November, but had not progressed further in April. Females 74-103 mm in carapace length carried 7,000-23,000 eggs on pleopods. Lobster larvae were found to maintain position near lobster grounds in spite of wind effects, but more larvae were taken near the surface when it was calm than when it was windy. Observations on behaviour indicated that holding lobsters under crowded conditions reduced normal reaction intensity between lobsters. Holding in perforated capsules would help to simulate isolation of individual lobsters and prevent injuries. Lobsters, 66-113 mm in carapace length, feed mainly on polychaetes, periwinkles (Littorina *spp.*) *and rock crabs* (Cancer irroratus).

INTRODUCTION

Information on Port au Port Bay lobsters obtained during 1961-65 suggested that they were typical of comparatively isolated lobster populations in Newfoundland. The bay is narrow at its mouth and although some larvae may drift in or out (perhaps preventing genotypical isolation to some extent) the lobster populations there are under the influence of conditions that apparently cause them to be different from populations in other areas. Such differences have been observed, for example, in proportionate claw weights, growth increments, relative maturity and fecundity of several populations studied in Newfoundland. Also, estimates of annual moulting rates from random samples, and proportions of recruits to the fishery as seen in landings from Port au Port Bay were different from similar estimates from other

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Newfoundland areas. Possibly the fishery in the bay itself exploits lobster populations to a varying extent as is shown by differences between estimated fishing rates for Shoal Point and Boswarlos in Port au Port Bay. Comparing populations may help to give direction to fishing effort and to conservation by showing the localities where lobsters have the best marketable quality, where they are underfished or where their environment may be improved. This paper gives some basic characteristics of the Port au Port Bay lobster populations for comparison with lobsters from other localities in Newfoundland.

Comparisons between lobsters from different areas in Newfoundland were made by Templeman (1939, 1940 and 1944) and Templeman and Tibbo (1945). These authors studied lobsters in nearby St. Georges Bay as well as in Port au Port Bay. They measured lengths of lobsters from Boswarlos and Shoal Point. Templeman (1940) also tagged and released lobsters from St. Georges Bay in Port au Port Bay indicating distance of migration with time, and suggesting, however, that the extent of migrations in Port au Port Bay might have been influenced by the lobsters having originated in St. Georges Bay. Templeman and Tibbo (1945) suggested that lobsters in Port au Port Bay tended to be larger than those in St. Georges Bay because larger numbers of larvae settled in St. Georges Bay than in Port au Port Bay. This hypothesis seems to be untenable in view of the present-day sizes of lobsters in both bays, sizes of lobsters under various rates of exploitation and our preliminary work on larvae in Port au Port Bay.

LOBSTER LANDINGS IN PORT AU PORT BAY AND BAY OF ISLANDS 1955-65

The Department of Fisheries of Canada combine statistics of landings of lobsters from Port au Port Bay and Bay of Islands. The amount produced from each area is similar according to Mr. H. R. Sheppard of Lark Harbour who purchased lobsters from both areas. These areas have produced from one-sixth to one-seventh of the annual Newfoundland landings of lobsters from 1963 to 1965 (Fig. 1).

Lobster landings from Port au Port Bay and Bay of Islands reached a high of 1,200,000 lb in 1956 followed by a decrease to 440,000 lb in 1961. During 1956-61 there was an increase in the number of traps from 45,000 in 1956 to 57,000 in 1959, but a decrease to 41,000 by 1962. Following 1961, a substantial increase in landings occurred reaching 700,000 lb in 1963 and over 600,000 lb in 1964 and 1965. Meanwhile, the numbers of traps in use increased from 41,000 to 52,000 in these years (Fig. 1).

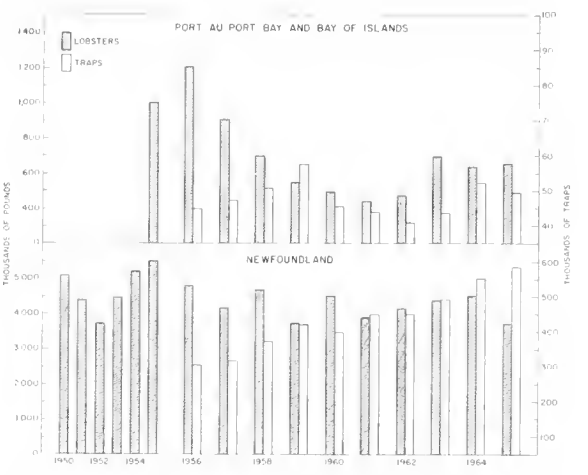

FIG. 1. *Total lobster landings and numbers of traps used in the lobster fishery in Port au Port Bay, Bay of Island, and in Newfoundland 1950-65.*

PHYSICAL FEATURES OF LOBSTER GROUNDS IN PORT AU PORT BAY

Port au Port Bay is about 100 square land miles (260 km²) in surface area, roughly circular but elongated and slightly narrowed at its mouth (Fig. 2). The greater part of this shallow bay is less than 10 fathoms (18 m) deep including all of West Bay and the lobster grounds from Boswarlos to the entrance of the bay (Fig. 3). However, East Bay is occupied largely by a trough about 25 fathoms (46 m) deep. The area below the 20 fathom contour is about 2 miles (3 km) wide and 8 miles (13 km) long. From lobster trap surveys and other observations, including Scuba diving, an inclusive estimate of the bottom area where lobsters are found is about 20 square miles (52 km²) or about one-fifth of the surface area (Fig. 3). The type of bottom on the lobster grounds consists of sands, silts, gravels, outcroppings of bedrock with slabs and crevices, numerous cobbles and glacial boulder train and blocky talus from cliffed shores or bedrock (Lilly, 1965[2]).

The main lobster grounds extend from Shoal Point to the outer edge of American Bank and Fox Island. Near Shoal Point are glacial remnants including many boulders, gravel and sandy patches. East of Shoal Point are many boulders,

[2] Lilly, H. D. 1965. Unpublished MS. Marine inventory West Newfoundland. Arda Project 20007. Report. 74 p.

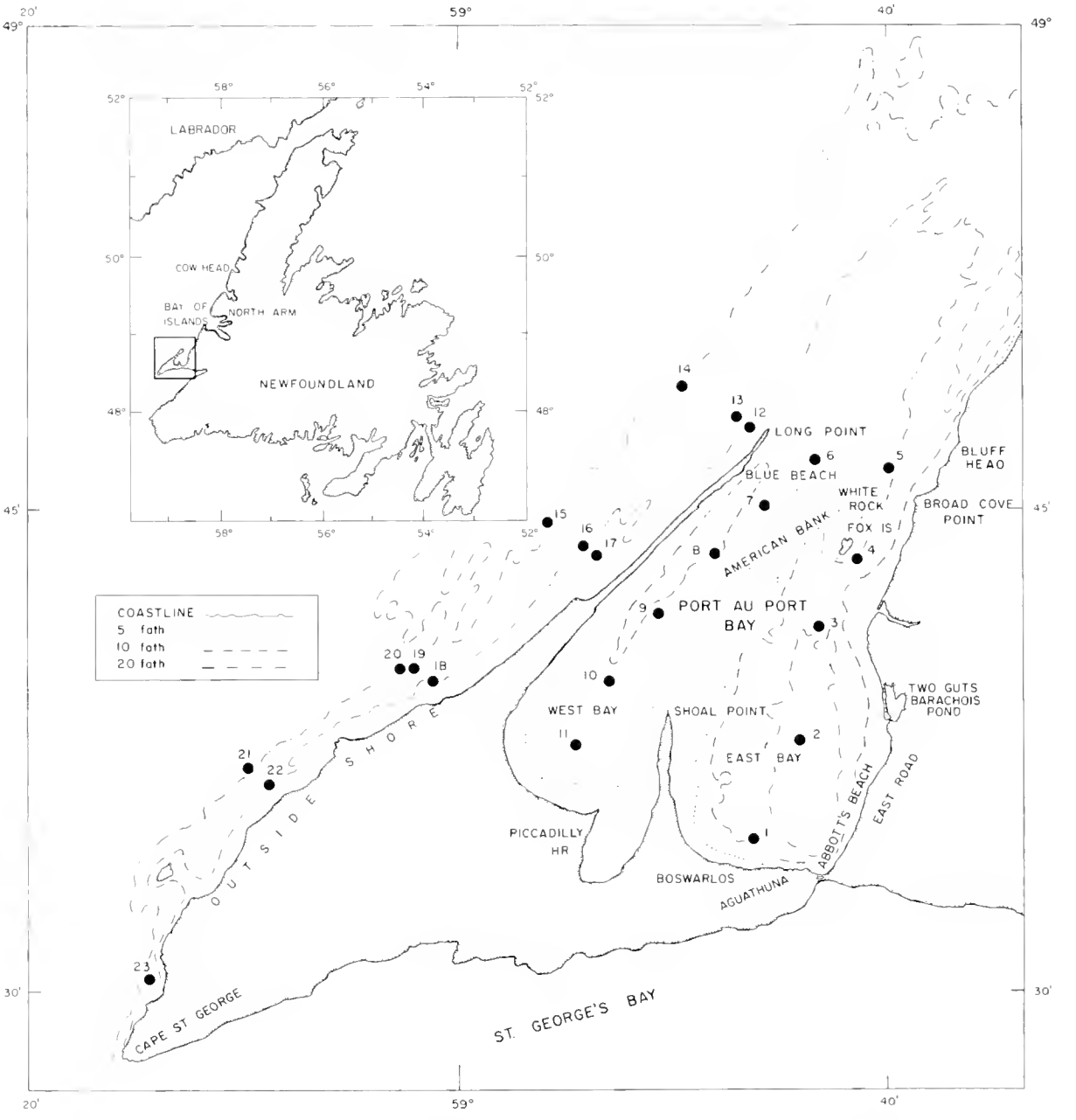

FIG. 2. *Map of Port au Port Bay and Bay of Islands, Newfoundland, with place names used in the text and hydrographic stations in Port au Port Bay.*

cobbles, slabs derived from bedrock, sandy patches and shaly outcrops. This type of bottom extends eastward from Shoal Point to Boswarlos. North of Shoal Point the glacial remnants extend to American Bank where the seascape is dominated by small submarine cliffs 4-6 feet (1-2 m) high with scattered talus slabs from thin-bedded limestone, some boulder train and with much of the bottom covered by shingle. The Fox Island grounds include a broad, shallow area north of the island consisting of limestone bedrock, gravel and boulders. The island itself is composed almost entirely of basic volcanic flows, pillowed flows and flow breccia. These rocks are

FIG. 3. *Map of Port au Port Bay showing lobster grounds by cross-hatching.*

characterized by great variation in their resistance to erosion even over a small area and consequently the submarine extension of the island contains numerous cracks, potholes and open shears. Between the exposures of bedrock are gravels and talus spread out by wave action. The White Rock ground north of the island consists of bedrock, some talus, large cobbles, gravel and shingle.

The Bluff Head grounds consist almost entirely of coarse blocky talus at the base of the 1,000-foot (305 m) cliffs. There are numerous holes and deep caves among these exceptionally large blocks. The Broad Cove Point grounds consist of talus, shingle, gravel and boulder train interrupted by large patches of sand. The East Road grounds, extending from Two Guts Barachois Pond to within one mile (1.6 km) from Abbott's Beach, consist chiefly of sand with moderate amounts of cover in the form of glacial debris derived from the glacial terrace nearby. West of Aguathuna is a narrow band of lobster ground consisting of bedrock with talus slabs and boulder train.

In West Bay there is limited lobster ground west of Shoal Point between the sands of the shore and the silty bottom of Piccadilly Harbour. West Bay itself has large interrupted tracts of sand, gravel and cobbles with scattered boulders and areas of muddy sand where scallops are found. A narrow strip of lobster ground stretches from near the head of West Bay along the east shore of Long Point to Blue Beach. This is formed from a comparatively narrow band of talus blocks of varying size at the foot of limestone cliffs and fanning out to a distance of about 200 yards (183 m). A study to determine the feasibility of blasting the cliffs to improve lobster cover was undertaken in 1966.

MATERIALS AND METHODS

Population sampling

During the commercial fishery for lobsters, monthly samples were obtained from a fisherman who kept about 150 undersized and ovigerous females as well as commercially acceptable males and females. These were examined when the required number had been obtained. After the fishery, which lasted from 20 April - 5 July, a fisherman was hired to fish about 50 lobster traps daily. All lobsters caught were kept in floating crates and examined at the end of the month. The regulation openings of 1-3/4 inches between the lower laths of the traps were closed by nailing on extra laths. Occasionally, when field personnel were present, the stomachs of some lobsters were preserved in 10% formalin.

The routine detailed examination of lobsters included measurements of carapace length in mm from the eye socket to the posterior edge of the carapace (lengths mentioned in this paper, unless specified, refers always to carapace length); total length from the tip of the rostrum to the end of the telson without setal fringe on a measuring board (nearest mm); greatest length (= length of propodus) of cutter and crusher claws (nearest mm); total weight and weights of crusher and cutter claws (= weight of all parts of the large 1st pereiopods each broken away at the autotomy point to nearest g or 1/4 oz); and greatest width of abdomen (2nd segment) of females (nearest mm). Assessment of maturity of each lobster was made: in females by cutting open the body membrane just behind the carapace and measuring several ova in water under a dissecting microscope, and in males by extracting the spermatophore organ from the 5th legs at the coxal-body joint and noting whether large or small. Before performing dissections on lobsters each one was killed instantly with a sharp knife by severing the frontal portion of the carapace including the oesophageal ganglia. Shell condition ("old" or "new") was recorded and a 1 x 1 inch piece of the pleuron from the right edge of the carapace was preserved in 7% formalin to determine shell condition by histological technique.

Fecundity

Females carrying eggs with eyed embryos were preserved in 10% formalin shortly after capture in May and June. The eggs were removed carefully from the pleopods and washed free of cement and setae before they were counted. Total volume and volumes of several small subsamples were measured by water displacement in a graduated cylinder. Numbers of eggs in these small subsamples were counted and averaged and the total number was calculated from the total volume. This method was checked by counts of all the eggs in about 1/4 of the lobsters from which eggs were counted and found to have an error of less than 2%.

Commercial catch tagging

About 1,000 lobsters, male and female, were purchased from the commercial catch, tagged with a strap tag and elastic band on the carapace dorsally (Wilder, 1954), and released in the legal fishing season.

Marking for growth studies

About 1,250 lobsters between 70 and 98 mm in carapace length were marked by drilling a 3 mm hole in each of two parts of the five-parted tail of the lobster. A code of lobster lengths was recorded according to which two parts were drilled (Wilder, 1953). Lobsters brought to the floats (a stack of shallow immersed trays) from 30 June-6 July 1962 were marked as they became available and put back in the floats. They were all released on 9 July in relatively shallow water east of Shoal Point. The following year fishermen were asked to watch for and return those lobsters with marks on the tail fan. About 5,000 lobsters from Shoal Point were examined for marks while measuring lobsters from the commercial catches. Each marked lobster was measured, condition of marks noted and whether or not the lobster had moulted.

Length measurements

Permission was obtained from lobster buyers to measure part of their lobster holdings. Measurements were taken at the floats or at anchored crates. Only carapace length to the nearest mm was measured.

Hydrography

Eleven stations in Port au Port Bay were occupied monthly from April to December, 1962. This number was reduced to five in 1963. Stations 12-23, just off the west shore of the peninsula (Outside Shore; Fig. 2), were occupied only infrequently because of lack of vessel time and weather conditions. A bathythermogram and bottom and surface temperatures were taken at each station. A surface water temperature was taken daily at a shore location in the bay either at Piccadilly or Boswarlos during the period of field work. Bottom temperatures at about 5 m were taken through the ice in the bay at least once a month in January, February and March.

Larval distribution

Surface tows with a 50 cm diameter ring and No. 000 mesh net (mesh opening about 1 mm) were made to determine the horizontal distribution of lobster larvae. The plankton net was towed at 2-3 knots ahead of a small boat. The rope for towing was taken through a single sheave block at the end of a 20-foot pole which was tied to the boat lengthwise and projecting over the bow.

A small-mesh butterfly net with a 6-foot handle was used to sweep the breaking waves on lee shores during storms in an attempt to capture larval lobsters or copepods. Also small debris in the landwash was collected and examined.

Behaviour

Captured lobsters were kept in a wooden crate (3 x 4 x 1-1/4 feet) divided into seven compartments each large enough to hold one lobster. The reactions of these lobsters to each other and to substrate were watched when they were transferred to a small aquarium 1-1/2 x 1 x 1-1/4 feet (46 x 30 x 38 mm) located in a small tent on the shore. Also lobsters which had been held in other crates and whose claws had been pegged were transferred to the aquarium. Their reactions were compared with those that had been held singly and unpegged. A 24 hr flow of seawater from two seven-gallon wooden tanks on a frame above the aquarium was regulated hy a metal clamp on the rubber tubing. Following each short term ex-

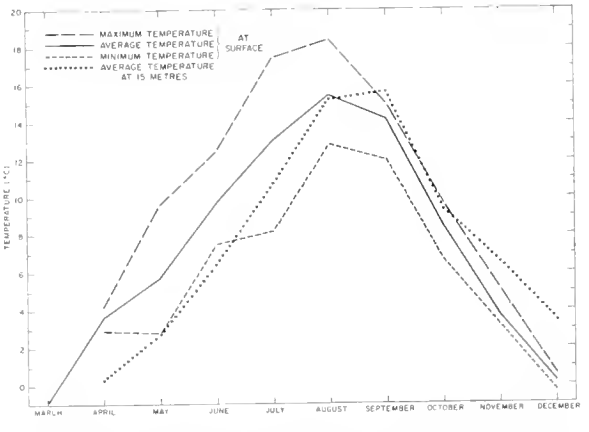

FIG. 4. *Monthly temperature regime in Port au Port Bay March-December, 1961-64.*

periment, the lobsters were returned to the floating crates.

HYDROGRAPHY OF PORT AU PORT BAY

The temperature regime for the lobster grounds at 15 m (8 fathoms) in the bay showed a gradual increase from averages of −1 C in March (at about 5 m) to 0.0 C in April, and 16 C in August and September. Temperatures then declined to 7°C in November and 4 C in December (Fig. 4). Salinity changed little during the year ranging from 30.5 to 31.5 ppt. Appreciably warmer conditions occurred in July and August 1961, averaging 2-3°C higher near the surface than in 1962-65. As might be expected, warming of water during May and June (Table 1) and cooling during September to October proceeded at a faster rate in Port au Port Bay than in the Gulf of St. Lawrence.

LENGTH AND WEIGHT RELATIONSHIPS

Lengths and weights were obtained mostly from lobsters 70-100 mm in carapace length. Least squares equations were computed to convert carapace lengths to total lengths and to abdomen widths (Table 2 and Figs. 5 and 16). Further equations for conversion of carapace lengths to total weights or to claw weights were computed and transformed by logarithms (Table 2). These gave relatively straight lines over the size range of lobsters more commonly present in these lobster populations subjected to fishing

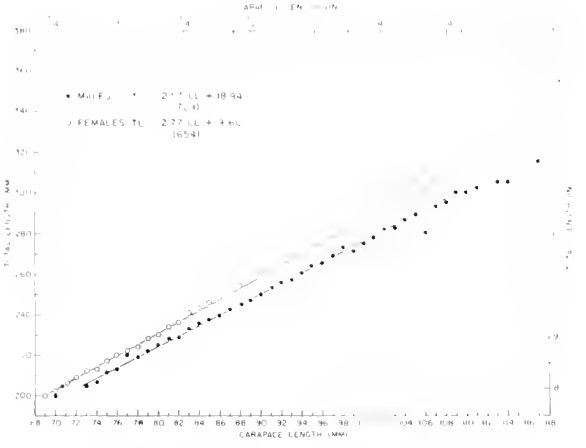

FIG. 5 *Regression lines of carapace length (CL) and total length (TL) in male and female* H. americanus *from Port au Port Bay, Newfoundland.*

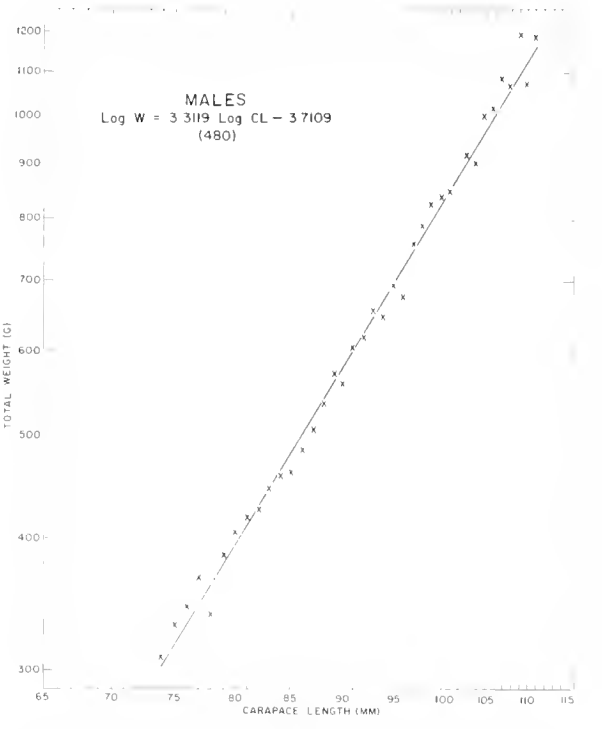

FIG. 6. *Total weight at each carapace length of male* H. americanus *from Port au Port Bay, Newfoundland.*

TABLE 1. *Temperature (°C) at Station 15 just outside Port au Port Bay and at Station 9 in the bay during the spring of 1962.*

Depth m	1 May Outside shore	23 April Port au Port Bay	29 May Outside shore	26 May Port au Port Bay	16 June Outside shore	29 June Port au Port Bay
0	0.7	1.4	4.5	6.4	5.5	10.6
5	0.7	1.3	4.3	6.3	5.5	10.0
10	0.7	0.8	4.0	5.6	5.5	8.2
15	0.7	0.7	3.8	—	5.0	—

TABLE 2. *Length and/or weight relationship equations for lobsters from Port au Port Bay, 1961-65. Graphs to illustrate some of these equations are in Figs. 5-8. (TL = total length, CL = carapace length, Cut = cutter claw, Cru = crusher claw, Abd Wd = abdomen width, TW = total weight, W = weight. Logs are to base 10.)*

Relationship	Sex	Equation	Length range	No. of specimens
			mm	
TL/CL	M	TL = 2.57 CL + 18.94	73-117	729
TL/CL	F	TL = 2.77 CL + 9.60	69-114	654
Cut L/CL	M	Cut L = 1.52 CL — 13.88	74-107	581
Cut L/CL	F	Cut L = 1.37 CL — 1.93	74-100	384
Cru L/CL	M	Cru L = 1.68 CL — 34.85	74-107	576
Cru L/CL	F	Cru L = 1.27 CL — 3.32	74-100	399
Abd Wd/CL	F	Abd Wd = 0.93 CL — 21.95	71-100	712
TW/CL	M	Log W = 3.3119 log CL — 3.7109	74-111	480
TW/CL	F	Log W = 2.7903 log CL — 2.7029	70-108	262
Cru W/CL	M	Log Cru W = 4.3045 log CL — 6.3077	74-117	481
Cru W/CL	F	Log Cru W = 2.6281 log CL — 3.1502	70-108	261
Cut W/CL	M	Log Cut W = 3.6424 log CL — 5.1610	74-117	481
Cut W/CL	F	Log Cut W = 2.7696 log CL — 3.5156	70-108	261
Cut W/Cut L	M	Log Cut W = 2.9802 log Cut L — 4.2746	93-168	515
Cut W/Cut L	F	Log Cut W = 2.6175 log Cut L — 3.5476	91-143	286
Cru W/Cru L	M	Log Cru W = 3.1739 log Cru L — 4.4545	86-155	519
Cru W/Cru L	F	Log Cru W = 2.6356 log Cru L — 3.4010	83-128	293

(Figs. 5-8). Some of these data indicated anomalies in individual lobsters such as might occur through regeneration of claws and these were omitted when seen. Comparisons of these relationships obtained for local lobster populations in Newfoundland have shown some outstanding differences between them. In this paper only one such comparison is made between Port au Port Bay and North Arm, Bay of Islands (Fig. 9).

Discussion

Templeman (1935, 1939 and 1944) showed that local populations of lobsters in the Maritimes differed in relative body proportions. He measured total length, carapace length and length of claws, etc. He expressed carapace lengths, etc., as percentages of total length. Differences in body proportions between lobsters from different areas were shown to result from differences in temperature between these areas. Tremblay, Dugal and Roy (1941), Corrivault and Tremblay (1948) and Wilder (1953) also computed equations to convert total lengths to carapace lengths and carapace or total lengths to weights. These were for local lobster populations but they show only minor differences between areas. Saul B. Saila and John Flowers (personal communication) have made multiple measurements of lobster body parts, and their mathematical analysis has shown differences between the deep offshore and the shallow inshore populations of lobsters of the northeastern United States.

The relationship between claw weight and body weight of lobsters from Port au Port Bay and North Arm (Bay of Islands) is an example of a difference between these populations. The claws are heavier for the size of lobster in North Arm than in Port au Port Bay (Fig. 9). The difference is apparently due to the male lobsters of North Arm maturing at a smaller size than those of Port au Port Bay, because the claws of male lobsters increase in weight at a faster rate after maturity (Templeman, 1935). The early maturity in North Arm is probably caused, partly at least, by a slightly but consistently higher summer temperature on the lobster grounds than in Port au Port Bay. However, the body weights of lobsters from North Arm are slightly less for their length than are those of lobsters from Port au Port Bay (Fig. 10) (the lobster body weight includes weight of all the legs except the large chelate pair or 1st pereiopods). This suggests a more fundamental difference than would be caused by early maturity alone. Morphometric and weight relationships, therefore, can be examined for lobsters from such comparatively isolated areas, and an assessment made of the market quality of these lobsters as shown by comparisons such as relative claw size, etc. Port au Port Bay has a larger area of lobster grounds and a larger lobster population than

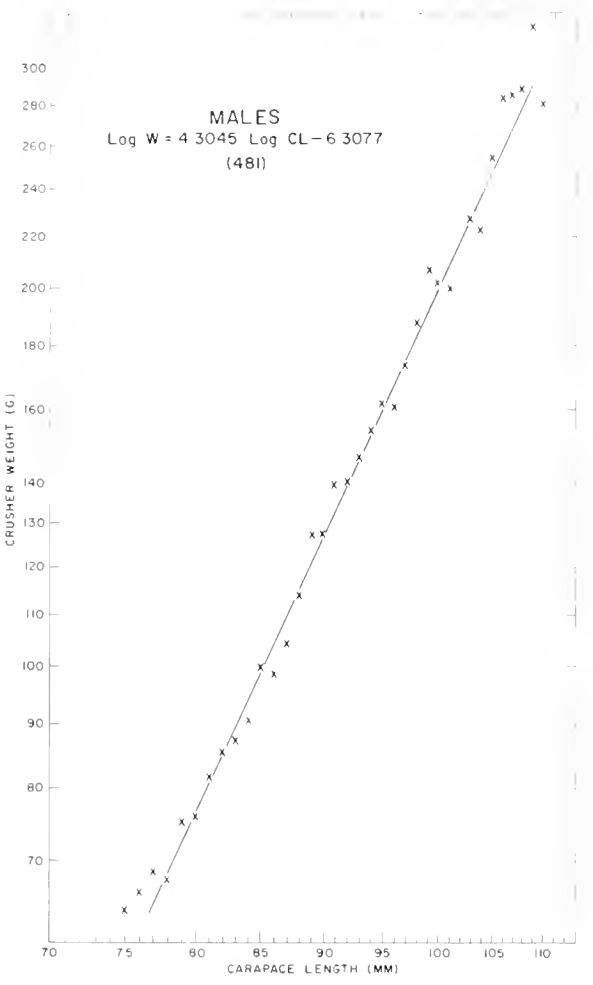

FIG. 7. *Weight of crusher claw at each carapace length of male* H. americanus *from Port au Port Bay, Newfoundland.*

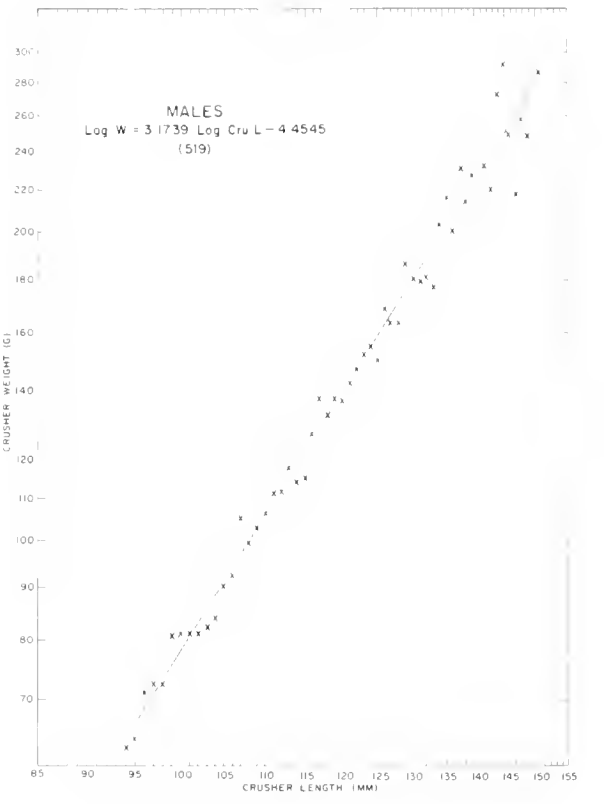

FIG. 8. *Weight at each length of crusher claw in male* H. americanus *from Port au Port Bay, Newfoundland.*

North Arm. Port au Port Bay lobsters stay in deeper water and farther from shore than in North Arm. Factors in ecology have caused selective events to occur over many generations and these have apparently produced lobsters typical of Port au Port Bay. It may be possible, therefore, that lobsters can be selected from certain areas because of their adaptation to shallow or deep waters or according to the conditions where they are found.

HYPOTHETICAL GAIN IN WEIGHT BY MOULTING

Individual lobsters were weighed in samples taken each month (except in the winter months of December-March) during 1962 and 1963. Weights of males (480) and females (262) from these samples were used to construct graphs (such as in Fig. 6) and equations (Table 2) to convert carapace lengths to weights. These equations were used to calculate hypothetical average gains in weight with increases in size by moulting. A marking and recovery experiment in 1962-63 indicated that males on moulting increased in carapace length by 10 mm and females by 9 mm on the average (see also section on growth in this paper). In male lobsters, for example, a length group of 71-80 mm (sublegal sizes in Newfoundland) would reach in one moult a length group of 81-90 mm. When this group moulted twice a length group of 91-100 mm would be reached on the average. Taking the average weights of each of these length groups, a hypothetical gain in weight on moulting once would be 49.2% of the initial weight and on moulting twice would be 117.7%. By a similar method of calculation, the corresponding figures for females would show hypothetical gains in weight of 37.3% for the first moult and 79.1% for the second moult.

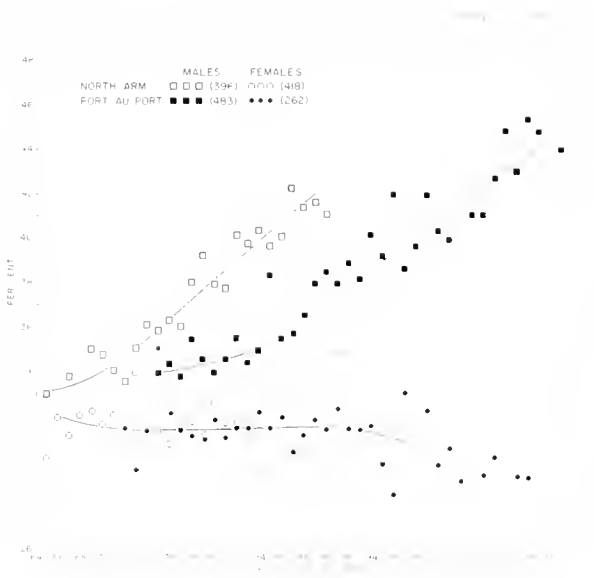

FIG. 9. *Weights of claws expressed as percentages of total weight in* H. americanus *at each carapace length from Port au Port Bay and Bay of Islands, Newfoundland.*

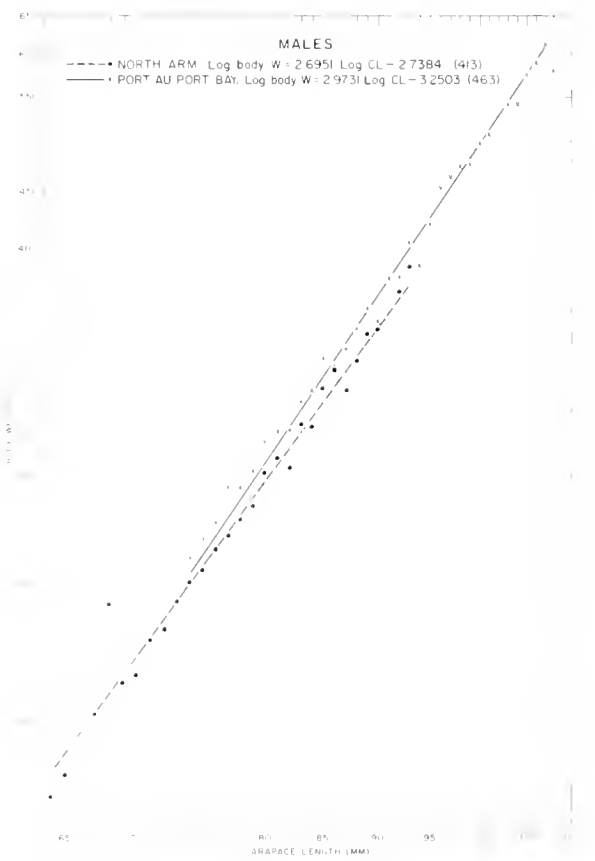

FIG. 10. *Body weight at each carapace length of male* H. americanus *from Port au Port Bay and North Arm, Bay of Islands, Newfoundland.*

Discussion

Wilder (1965) suggested that in a lobster population the gain in weight after moulting would more than offset the loss of weight from natural mortality. As an example of weight gain in a moult, Wilder (1963) found a 70% increase in one moult and 192% in two moults for male lobsters from Egmont Bay, Prince Edward Island which are considerably greater than our corresponding figures for Port au Port Bay lobsters. Nevertheless, because of the possible increase in the yield of weight of lobsters from lobster grounds by allowing small lobsters to moult, a rate of fishing which allowed some small lobsters to escape and moult at least once would most likely give a higher yield than one which took all the available small recruit lobsters each year. It goes without saying, of course, that conservation of the just sub-legal sizes of lobsters is of paramount importance to the annual yield from the fishery.

In consideration of the possibility of farming lobsters, it is apparent that because of the weight gain of lobsters in one moult, there is a good prospect of economic feasibility in holding male lobsters and feeding them until they moult (see also Squires, 1967[3]). This could be done near the moulting period and only a couple of months holding and feeding after the moult would be necessary for recovery of full meat quality (Stewart and Li, 1969).

PROPORTION OF RECRUITS TO THE FISHERY IN ANNUAL LANDINGS

From 1961 to 1965 (Squires, 1964[4]) I estimated the proportion of male recruits to the fishery in the commercial catch of lobsters in Port au Port Bay. Because the annual growth increment in males averaged 10 mm, I presumed that the average size reached by a lobster after moulting from a sub-legal size of 71 mm would be 81 mm and from the largest sub-legal size of 80 mm

[3] Squires, H. J. 1967. Unpublished MS. Suggested installations for holding and farming lobsters. Fish. Res. Bd. Can. Atl. Biol. Sta., Circ. 14:35-40.

[4] Squires, H. J. 1964. Unpublished MS. Annu. Rep. Fish. Res. Bd. Can. Biol. Sta., St. John's, append. 17:62-63.

would be 90 mm. Therefore, the part of the histogram of length frequency from 81-90 mm (Fig. 11) was taken to represent lobsters which had moulted and become large enough to be landed in the fishery for the first time. The proportion of these recruits in the catch was therefore estimated from the histograms of length frequencies of male lobsters annually. For best results the estimates should have been made from length frequencies of about 1,000 lobsters.

Discussion

Apparently there has always been a higher proportion of recruits to the fishery at Boswarlos than at Shoal Point (Fig. 11). While Boswarlos catches had only slightly fluctuating percentages of recruits close to 60% in the years 1961-65, the percentages of recruits at Shoal Point decreased from 47 to 40% in the years 1962-65. Apparently

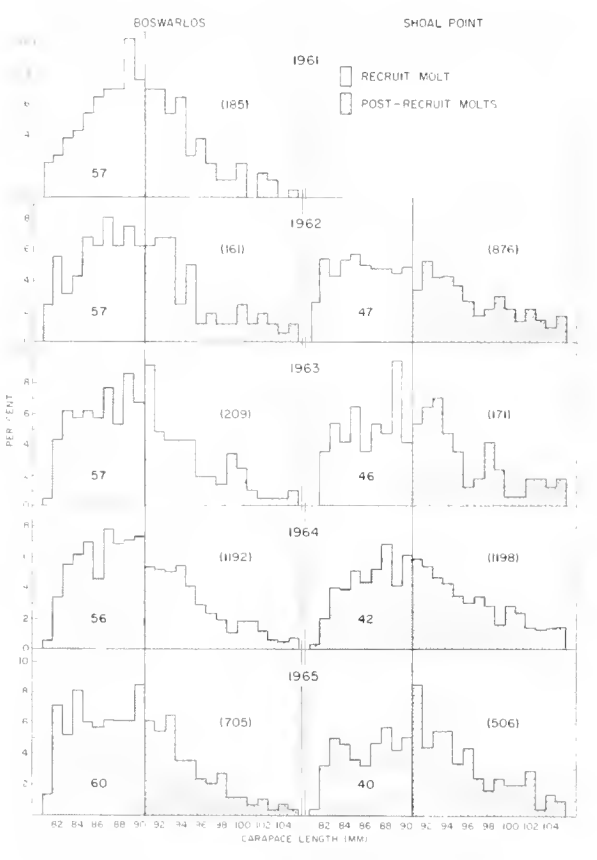

FIG. 11. *Proportion of recruits (numbers on the histograms are percentages of recruits) and post-recruits of male* H. americanus *in commercial landings in Port au Port Bay (Boswarlos and Shoal Point) during 1961-65. Numbers of males measured are shown in parentheses.*

Shoal Point lobster stocks, distributed over an area considerably larger than at Boswarlos, were being fished at a low rate during this period. The apparent decreasing proportion of recruits suggests that an optimum yield from the lobster stocks had not been reached, and the area could have been fished at a higher rate (perhaps by larger lobster boats and more traps) than it was. This annual decrease in proportions of recruits coincided with a decrease in the commercial fishing effort, since there were fewer fishermen at Fox Island for fishing these grounds than in previous years. The situation at Boswarlos was different. Since the lobster ground is close to shore it could be fished effectively by small boats. Here the lobster stocks were fished at a fairly high rate according to the high proportions of recruits in samples measured and the catch had been decreasing slightly each year according to reports by reliable fishermen and buyers.

Our calculations from measurements of lobsters made by Templeman (1939) indicated that the proportions of recruits to the fishery in the commercial catch in 1938 from Boswarlos and Shoal Point were 39 and 28%, respectively. Males and females were not separated in these measurements but the legal minimum length was 78 mm and not 81 mm as at present. For this reason the estimates would be about the same as for males alone and they were considerably lower than estimates obtained in 1961-65.

PROPORTION OF RECRUITS TO A FISHERY AND HYPOTHETICAL FISHING RATES

In any year the proportion of recruits to a fishery in a lobster population subjected to fishing depends on the rate of fishing of the previous year. For example, if 100% of the available legal-sized lobsters were taken in any year, barring immigration or emigration, the only lobsters (100%) available to the fishery in the following year would be recruits. However, if only 50% of the available lobsters were taken in any year (hypothetically all classes including recruits in this instance would be reduced by 50%), then the proportion of recruits represented in the population in the following year would be less than if 100% were taken. The hypothetical percentage of recruits represented in the population can be calculated by adding the percentages of other classes remaining after the population has been reduced by a fishing rate (Table 3). As shown by length frequencies, only three "year-classes" or moult-groups of males important to the fishery are present. Older and larger lobsters occur in comparatively small numbers: they become too large to be taken by conventional traps, and, eventually, natural mortality or emigration re-

TABLE 3. *Percent of recruits of lobsters in a fished lobster population at hypothetical fishing rates of 10-100%. (See text)*

Hypothetical fishing rate %	Proportion surviving a	b	c	d	$\frac{a}{a+b+c+d}$ Calculation	Percent of recruits in fishery
10	100	90	81	73	$\frac{100}{100+90+81+73}$	29
25	100	75	56	42	$\frac{100}{100+75+56+42}$	37
50	100	50	25	13	$\frac{100}{100+50+25+13}$	53
60	100	40	16	6	$\frac{100}{100+40+16+6}$	62
75	100	25	6	2	$\frac{100}{100+25+6+2}$	75
100	100	0	0	0	$\frac{100}{100}$	100

duces their numbers on the lobster grounds.

At a time when a lobster is about legal size, natural mortality on a lobster ground (including emigration) is presumably lower than at any other time in the life of the lobster. Fishing mortality, however, is very great: a proportion as high as 90% of the available lobsters at legal size may be taken by the fishery. Where numbers of lobsters involved in areas of study are over 50,000, for example, many natural deaths would have to occur to reach a significant proportion. Since we do not consider proportions as low as 5% in comparing proportions of groups in the fishery, this natural mortality is ignored. (If, for example, 5% of 50,000 lobsters or 2,500 commercial-sized lobsters died on a lobster ground in Newfoundland, the deaths would not escape notice and would be considered disastrous.)

A preliminary estimate of fishing rates from the percent of recruits to the fishery observed in lobster landings may be made given:

a = the proportion of recruits before exploitation;

b = the proportion of recruits surviving after first year exploitation;

c = the proportion of recruits surviving after second year exploitation;

d = the proportion of recruits surviving after third year exploitation;

and R = the proportion of recruits taken in the fishery

$$R = \frac{a}{a + b + c + d} \quad \text{(Table 3).}$$

Tagging in the fishery to estimate fishing rate

In 1961, 1,070 lobsters of commercial size were tagged with a carapace strap tag (Wilder, 1954) and released as evenly as possible over the bay without regard to depth. Inadvertently the release was accomplished with only 3-1/2 week remaining of the 11-1/2 weeks' seasonal lobster fishery. Tags recovered in 1961 amounted to 31% of the total released. In 1962, 1,007 lobsters were tagged and released one week after the fishery had begun. Of these tags 47% were recovered in 1962.

Discussion of tagging results

In spite of the difference in fishing effort (10 weeks compared with 3 weeks) the percentages of recovered tags in the two years were not too dissimilar. This may be due to the holding period of 11-15 days without food to which the lobsters were subjected in 1961. Their increased activity in search of food on release would contribute to considerable dispersal and to an increase in catchability. Lobsters were held for only 1-2 days in 1962, so on release they probably behaved like the untagged population.

Undoubtedly some of the tags taken by the fishermen were not returned. This would account in part for the lower percentage of recoveries (47%) than the proportion of recruits regularly taken in the fishery (male + female for the whole bay = about 57% in 1961-63; Squires, 1964[4]). However, the percentage of tags recovered as a measure of fishing rate must be corrected to account for changes in catchability after release and to account for the fishing effort expended before release of the tagged lobsters (Wilder, 1947).

TABLE 4. *Lobster larvae (mostly Stage II) taken under varying wind conditions in Port au Port Bay, 1962. (Onshore winds were always light, offshore winds occasionally heavy.)*

Condition	No. of tows	Tows with larvae	No. of larvae	Average No. of larvae per tow
Tows near shore with wind offshore	35	9	27	3
Tows near shore with wind onshore	31	11	501[a]	46
		(9)	(43)	(5)
Tows not near shore or near shore when calm	15	4	45	11

[a] 458 larvae taken the same evening in 2 tows near each other following an onshore northeast gale.

Paloheimo (1963) used data on landings and effort during the fishery for calculation of fishing rates, but effort in Port au Port Bay could not be recorded reliably.

Results of towing for lobster larvae and discussion on larvae and recruitment

Recruitment of lobsters to the fishery on particular grounds in Newfoundland may be relatively constant from year to year (Squires, 1964[4]). Generally, quite a large number of lobster larvae are produced by lobster populations (Wilder, 1965) and, apparently, significant numbers of larvae are able to maintain position close to parental grounds where they eventually settle. Plankton studies in Port au Port Bay in 1962 (Squires, 1963[5]) indicated that, although concentration of larvae down wind might occur through surface drift in storms, larvae were able to maintain their position near shore either when the wind was blowing onshore or offshore (Table 4). When towing was done, winds offshore were sometimes heavy but were always light when onshore (the boat was too small to work during heavy onshore winds). Since the greatest number of larvae appeared to be at the surface during calm conditions (Table 4), wind turbulence may have driven them from the surface. Wind influence, therefore, may be a deciding factor in vertical distribution of larvae. When plankton nets are towed at varying levels to indicate the vertical distribution of larvae (Templeman and Tibbo, 1945) the procedure requires that they be towed over comparatively deep water. This is, therefore, not necessarily an indication of vertical distribution of lobster larvae over the relatively shallow lobster grounds where most of them probably settle. Also, larvae drifting over deep water possibly occupy the near surface layer or at a limited depth until they sense the nearness of the shore from turbulence or the "noise" of surf (Ennis, 1968). Possibly vertical distribution of larvae over the lobster grounds would be more exactly shown by Scuba diving rather than from plankton net captures. Planktonic drift of some lobster larvae (Templeman and Tibbo, 1945) may be possible, however, and would be likely to bring at least some larvae to and from lobster populations near each other. This would generally compensate for losses of larvae and perhaps prevent genotypic isolation of populations. Given the hypothesis, therefore, that significant numbers of lobster larvae settle on all lobster grounds annually, a gradual reduction in such numbers appears inevitable through time and predation, etc. They are inevitably further reduced in number as their size and age increase. Probably eight or nine or more years of growth are required for lobsters to reach commercial size in Newfoundland. (For comparable ages of lobsters in warmer waters see Wilder, 1953; Hughes and Matthiessen, 1961.) In addition to natural mortality during this period, variations in individual rates of growth (by annual or lack of annual moulting) tend to cause considerable size range in a particular year class. The number in the particular size-group which first enters the fishery (at 81-90 mm in Port au Port Bay), therefore, may be relatively constant from year to year on any lobster ground in Newfoundland. Variations in catches from year to year may be accounted for largely by a) variations in effort resulting from weather conditions during the fishery or economic considerations, and b) variations in poaching on immediately sublegal sizes of lobsters during the previous year. Many fishermen assume a right to eat some sublegal-sized lobsters. Although this is cutting into production, they believe that they have a first claim on the resource and that they must sell all commercial-sized lobsters that they catch.

[5] Squires, H. J. 1963. Unpublished MS. Lobster research, 1962 Annu. Rep. Fish. Res. Bd. Can. Biol. Sta., St. John's append. 17:62-63.

GROWTH AND MOULTING

Estimates of the growth increment of male and female lobsters in Port au Port Bay indicated that males on moulting increased in length substantially more than females (Figs. 12 and 13). Males had

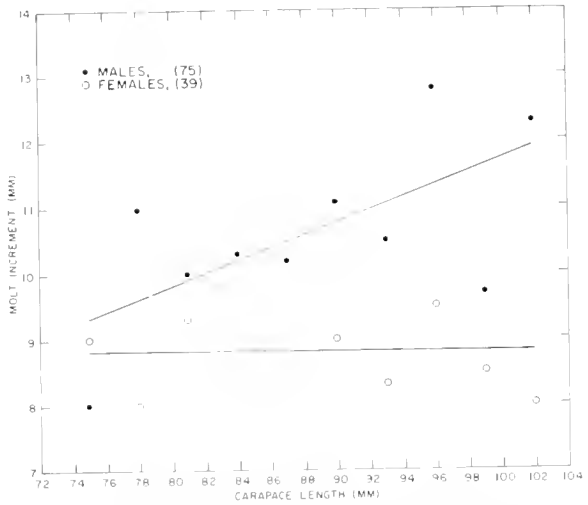

FIG. 12. *Growth increments of male and female* H. americanus *in one moult from various carapace lengths in Port au Port Bay, Newfoundland.*

a carapace length increment of 8.0-12.7 mm (about 12% increase in carapace length) and females 8.0-9.5 mm (about 10% increase in carapace length). The numbers of moulted lobsters found and remeasured were 75 males and 39 females out of totals of 568 males and 685 females marked. In addition 33 males and eight females were seen which had not moulted. The percent of males moulting after the handling incident to marking them was, therefore, 69%. But annual moulting in male lobsters of Port au Port Bay was about 90% as estimated from a sample which included 133 male lobsters taken in October 1964.

Discussion

Because female lobsters in Newfoundland mature at small sizes, their low growth increment in a moult appears to be directly related to the demand on body protein by the developing egg mass in the ovary. In autumn when the ova are increasing greatly in size and the lobsters are recovering from moulting, particularly low serum protein values were noted in nonovigerous female lobsters from Bonavista Bay, Newfoundland (Stewart and Li, 1969). Low rates of growth,

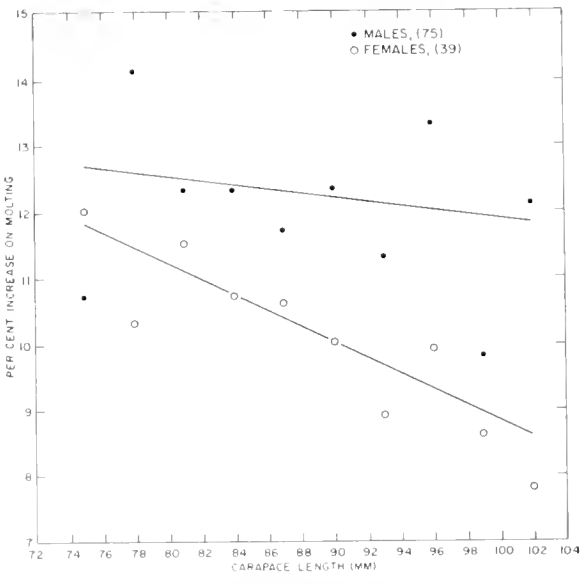

FIG. 13. *Percent increase in carapace length of male and female* H. americanus *in one moult from various carapace lengths in Port au Port Bay, Newfoundland.*

therefore, shown by smaller annual growth increments and a lower annual moulting rate keep most of the female lobsters within the commercial length range (81-111 mm) for about six years. Males usually spend only about three years at this size range.

The numbers of nonmoulters found in the specially treated sample of marked lobsters cannot be considered as representative of the numbers of nonmoulters in the population. The initial trapping and handling, the handling necessary to bore holes in the tail fan, the period of holding under crowded conditions (piled in immersed lobster crates), and the handling and exposure from crates to dory, and being transported out of water for about one hour all would contribute to causes for nonmoulting (see also Stewart and Squires, 1968).

MATURITY

Percentage of ovigerous female lobsters in populations

Templeman and Tibbo (1945) reviewed observations by many authors on the proportion of egg-bearing lobsters in samples from various populations. They concluded that, among the mature females captured, generally the highest percentage of ovigerous females that had been recorded was 33% but that considerably lower percentages had been recorded more frequently. They

concluded also that the proportion of ovigerous females caught in traps would be less than in populations, because ovigerous females would not trap as readily. They suggested, however, that an exception to this might occur in catches during the last few weeks of the fishing season in Newfoundland, the period just before egg laying and hatching of larvae. The highest percentage ovigerous in their late July and August catches in St. Georges Bay was 22%. They indicated also that higher percentages of ovigerous females occurred among larger lobsters than small, and cited comparisons with Placentia Bay lobsters. Among these the highest percentage recorded was 33% ovigerous in late June.

Potentially ovigerous female lobsters in populations

I have not found in the literature any mention of the size of ova (in the ovary) being measured to indicate stages of maturity in lobsters. In samples taken from Port au Port Bay during 1961-64 the percentage of ovigerous females annually (average 17%) was almost invariably smaller than the percentage of nonovigerous females with large ova (average 58%, Table 5). This agrees with the suggestion that ovigerous lobsters do not trap as readily as the others. Also, in agreement with Templeman and Tibbo (1945), the one exception to this in our sampling in Port au Port Bay occurred late in the fishing season (7 July, Table 5).

Discussion

Two important questions to be answered in a study of maturity is what proportion of females are likely to be ovigerous in a lobster population each year and what size may be reached in a given area before females become ovigerous. On the average, 58% of the females in samples examined in detail were potentially ovigerous annually in Port au Port Bay. Although the low percentage of ovigerous females in samples may be caused by factors such as gear selection, it may also be caused by losses of eggs. I have seen lobsters losing eggs and evidence of eggs having been resorbed (see also Templeman, 1940; Templeman and Tibbo, 1945) in females living in crowded conditions. Similar conditions may arise on lobster grounds through degrees of overcrowding, chance events such as being captured and released in a fishery, or some other cause.

On the other hand, the low percentage producing eggs (about 60%) is characteristic of a decapod crustacean which produces a batch of eggs once every two years (Squires, 1968). This low production of eggs is probably an adaptation to low temperature conditions, and unless it is phylogenetic, would probably change if the lobsters were exposed to consistently higher temperatures in their habitat. Some other decapod crustaceans apparently have a potential for producing eggs more frequently when they live in moderate temperatures than when they live in low temperatures (Squires, 1965, 1967 and 1968).

Size when first mature

Estimates of first maturity were based on smallest carapace length of females examined with large ova in the ovaries. For comparison, however, we also measured width of the 2nd segment of the abdomen (Templeman, 1935, 1936, 1939 and 1944) and also recorded smallest sizes of ovigerous lobsters from randon samples.

The size of female lobsters when first mature (with large ova) in Port au Port Bay was 72 mm (204 mm total length). At this length the abdomen

TABLE 5. *Maturity of lobsters in spring samples (May-June, 1961-64) from Port au Port Bay.*

Year	Total number examined for maturity	Nonovigerous		Ovigerous
		Small ova [a] 0.5-1.2 mm	Large ova 1.3-1.5 mm (Potentially ovigerous)	(Potentially ovigerous last year)
		% of total examined	% of total examined	% of total examined
1961	135	24	66	10
1962[b]	37	38	27	35
1963	46	20	54	26
1964	113	25	61	14
Average:		25	58	17

[a] Most ova in this category were less than 1.0 mm in diameter.

[b] Sample examined on 7 July.

width was 64% of the carapace length or about 22% of the total length. However, the smallest female found ovigerous in Port au Port Bay was 76 mm in length and the size when acceleration in relative abdomen width occurred was 78 mm (Fig. 14) and 224 mm in total length (Fig. 15). At

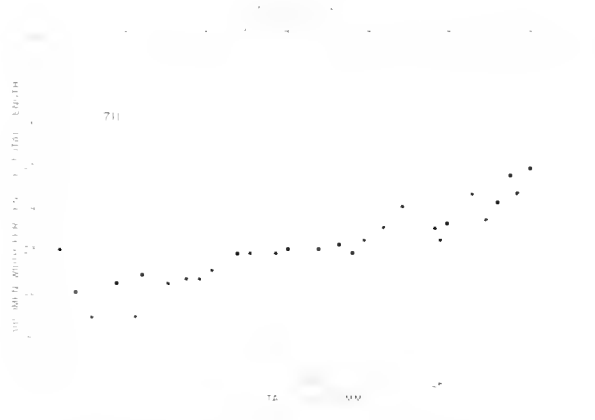

FIG. 14. *Abdomen width as a percentage of total length in female* H. americanus *from Port au Port Bay, Newfoundland.*

these lengths abdomen width was about 22.5% of the total length or 65% of the carapace length. Templeman's (1939) estimate (based on measurements of 76 lobsters) of first maturity of Port au Port Bay lobsters was at 215 mm in total length

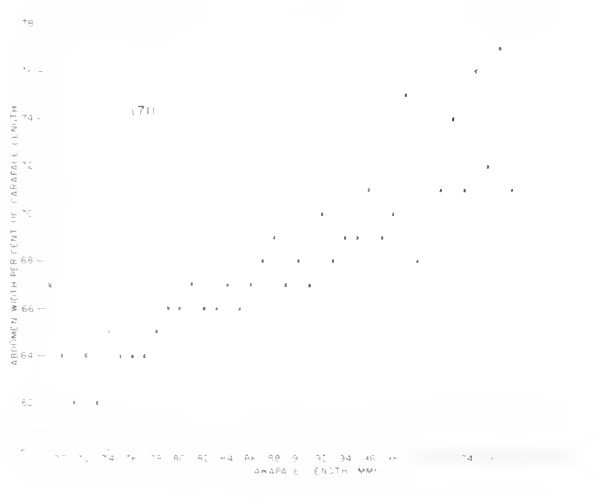

FIG. 15. *Abdomen width as a percentage of carapace length in female* H. americanus *from Port au Port Bay, Newfoundland.*

(74 mm CL), the point where abdomen width was 21.5% of the total length. In Port au Port Bay the abdomen width of females could be calculated from carapace length using the least squares equation: Abd. wd. = 0.93 CL — 21.95. (Fig. 16).

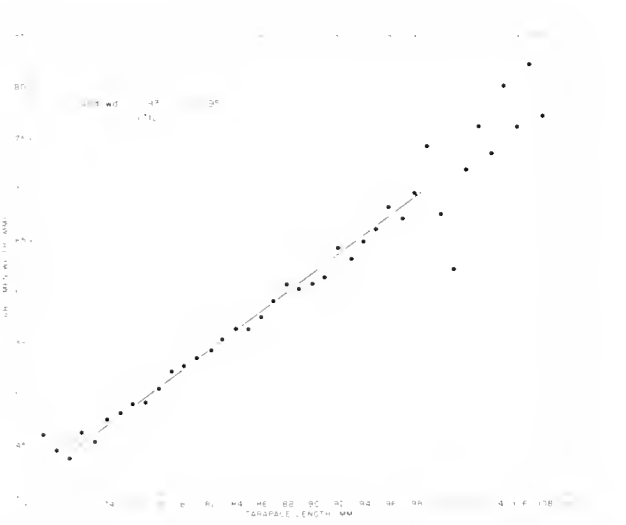

FIG. 16. *Abdomen width at each carapace length in female* H. americanus *from Port au Port Bay, Newfoundland.*

Discussion

Templeman (1935, 1939 and 1944) proposed that abdomen width, as a percent of total length of females, could be used as a criterion of maturity. He noticed that an increase in relative width of the abdomen began at a total length of 180-190 mm at Pointe du Chêne, N.B., where the smallest ovigerous females were 180 mm in total length. For western Newfoundland he suggested that lobsters with an abdomen width 21.5% of the total length would probably be ovigerous. The two figures for relative abdomen width later suggested by Templeman (1944), 20.6% and 23.5% of total length, represented the size of the smallest ovigerous lobsters and the size when half of all the lobsters were mature, respectively, in any particular locality (see also Templeman and Tibbo, 1945).

Apparently in many lobsters their length, when abdomen width shows a relative increase, may be somewhat greater than the length when eggs are first laid. This might occur because in Newfoundland eggs are frequently extruded by female lobsters that still have old shells (observed in many females examined in samples) and the first change in abdomen width would not occur until

they moulted a year after the eggs had hatched. Moulting incidence in first maturing female lobsters could vary greatly in different localities depending upon environmental factors (Templeman, 1935 and 1939). Comparisons between lobsters from different areas, therefore, should be based on the smallest size where acceleration in the relative increase in abdomen width occurs rather than on a fixed percentage that abdomen width is of carapace or whole length.

Embryo development

In samples from Port au Port Bay eggs had been extruded and showed high yolk content during August and early September. However, during late September and October development of eye pigment in embryos and decrease in yolk content had already occurred. By November and December most specimens examined had 1/3 to 3/4 yolk remaining and a few embryos appeared to be ready to hatch. However, the following April and May eggs had only slightly less yolk content (1/4 to 1/2 yolk remaining). Hatching occurred annually in late July and early August.

Discussion

I have found no reference in the literature to embryo development being followed in natural populations by the methods we used. In Port au Port Bay eye pigment first became visible in about 50% of the specimens examined in late September. The proportion of yolk present in those at that time was about one-half. A decrease in yolk content to one-third in late October and November suggested that with sustained moderate temperatures some hatching might take place in autumn. However, yolk proportions in eggs were almost the same in April and May as in November suggesting that embryo development had remained at a standstill through low winter temperatures.

FECUNDITY

Counts of eggs ready to hatch in 75 specimens indicated that from 7,000-23,000 eggs would be released from lobsters of 74-103 mm in carapace length in Port au Port Bay. Egg counts given by Herrick (1896) at these lengths were 6,300-18,700. Counts of ready-to-hatch eggs carried by lobsters were significantly fewer from Port au Port Bay for their size than those from Cow Head, Newfoundland. Although there is considerable variation in the numbers of eggs carried by individual lobsters of the same size in any area, the curve of average numbers in one area is apparently different from the curve of average numbers in another area. The average numbers of eggs at each carapace length of Port au Port Bay lobsters may be expressed as follows: Number of eggs = 379.6 CL — 21746.4 (Fig. 17).

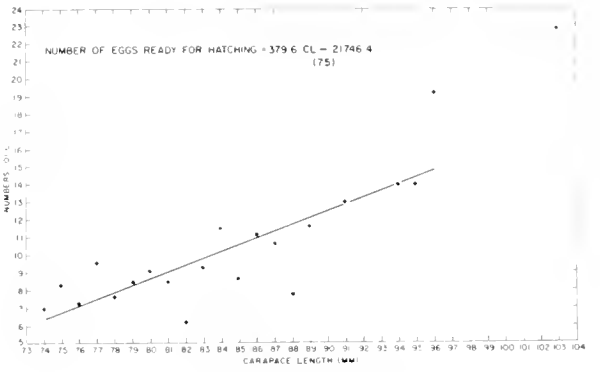

FIG. 17. *Calculated line of numbers of eggs ready for hatching carried by 75 females from Port au Port Bay, 1966.*

BEHAVIOUR

Experiments with lobsters in small aquaria confirmed that a ranked order of dominance was probable (Douglis, 1946; Fielder, 1965; Squires, 1965 and 1967 [3]). These experiments also showed that if lobsters had been held together, as in uncompartmented holding crates for a week or more, they did not react in a normal manner towards each other. Most lobsters used in the experiments were held singly in compartments in a large wooden crate. These had been caught and transferred to the compartments from the traps without immobilization of the dactyls of the claws and were not kept in a group for this reason. However, in many replicate experiments over several days some lobsters were introduced to each other which had not been kept alone; in some instances only two lobsters had been held together in a crate and in others many lobsters had been held in an undivided crate. In all instances such lobsters reacted only mildly or not at all to each other.

Discussion

These experiments indicated that there was a deviation from normal behaviour caused by handling or holding lobsters. Since lobsters held singly behaved normally as far as could be seen and retained their vigour and capacity for aggression, the question how to hold lobsters singly in an economical way for commercial purposes could be answered by placing each lobster in a cheap small container. It is suggested, therefore, that for ease of handling, a cylindrical plastic container with perforations (Squires, 1967 [3]; Ghelardi and Shoop, 1968) could be used to provide the lobster with virtual isolation as well as protection from injuries (Wilder and McLeese, 1961) while being commercially held in an immersed crate or tray.

TABLE 6. *Stomach contents of 182 lobsters taken shortly after being caught in Port au Port Bay and Bay of Islands, July-October, 1962-64.*

Stomach contents	% of total stomachs examined
Fish bones, bait	50
Polychaetes (jaws, chaetae, etc.)	37
Crab (*Cancer irroratus*, shell fragments, etc.)	27
Periwinkles (*Littorina* spp., opercula, bodies, shell)	22
Lobster shell (fragments sometimes filling stomach)	16
Small stones (most often one or two)	11
Whelks (*Natica* sp. and *Buccinum* sp.)	6
Mussel (*Mytilus* sp., shell, etc.)	4
Clams (*Mya*, *Mactra* and *Venus*)	3
Scallops (*Placopecten*)	3
Sea urchin (*Strongylocentrotus*, spines)	4
Sea star	3
Mud (with shell, etc., particles)	3
Empty	6
Brittle star, limpet, sea cucumber, *Pagurus*, amphipod, hydroid, brown seaweed	1 (each)

STOMACH CONTENTS

Stomachs were obtained from 182 lobsters at Boswarlos, Port au Port Bay and at Tortoise Head, Bay of Islands. At Boswarlos the highest percent of stomachs contained polychaetes while at Tortoise Head more contained shore crabs (*Cancer irroratus*), but the percent of stomachs containing other items varied only to a small extent. Since stomach contents were somewhat similar from lobsters of both areas the results were combined.

Fish bones, present in 50% of the stomachs, were possibly from fish bait used in the traps. Periwinkles (*Littorina* spp.) occurred in significant numbers. Their opercula were apparently not easily digested by lobsters since as many as 25 were counted in a single stomach. Bivalves (mostly *Mytilus* and *Mya*) were fairly common, occurring in about 10% of the stomachs. Their shell fragments indicated that they had been broken and eaten by the lobster. In about 1% of the stomachs examined, hermit crabs (*Pagurus* sp.), brittle stars, limpets, sea cucumbers, sea stars, amphipods, hydroids and brown seaweed were found attesting to the omniverous feeding of lobsters (Table 6).

ACKNOWLEDGMENTS

I would like to thank especially Mr. G. E. Tucker who assisted in all phases of the lobster investigations and wrote computer programs for processing the data. Thanks are due also to Messrs. Michael Abbott, William Goodyear and Daniel Lawlor of Abbott and Haliburton, Ltd., who assisted by allowing us to use their premises and by providing information on landings. Mr. Frank Jesso took us in his dory many times over the waters of the bay and gave invaluable assistance in lobster catching and use of his premises. The late H. D. Lilly, geologist at Memorial University, gave an analysis of the Long Point cliffs and the submarine topography of the lobster grounds in the bay.

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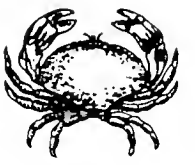

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ABUNDANCE AND DISTRIBUTION OF LARVAL LOBSTERS, *HOMARUS AMERICANUS*, OFF THE COAST OF SOUTHERN NEW ENGLAND[1]

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ABSTRACT

Lobster larvae were collected over a four-year period off southern New England. They were widely distributed in offshore waters and only three tows contained significant numbers of larvae. Inshore lobster larvae were most abundant during the latter part of June and July. They were found to be more concentrated in the western end of Long Island Sound and it is proposed that the direction of currents is responsible for this higher abundance. Survival rates from stage I to stage IV were estimated to be over 50% with very little mortality between stage II and stage III larvae.

INTRODUCTION

Little information is available on the distribution and abundance of larval lobsters in waters south of Canada. In Canada, Scarratt (1964) reviews the earlier literature and presents the results of a 13-year study of larval lobster abundance in Northumberland Strait. He was very successful in capturing stage I larvae, but his catch dropped off drastically for the later stages. Scarratt (1968) obtained rather similar results off Pictou, Nova Scotia.

South of Canada, the efforts of Sherman and Lewis (1967) in the coastal waters of central Maine are the only intensive attempt to capture larval lobsters. Herrick (1911) reports on a very limited attempt to collect larval lobsters in waters of southern New England and gives data on laboratory-reared larvae. Hadley (1906) and Hughes and Matthiessen (1962) report on hatching and rearing of larvae in holding tanks located in southern New England. Rogers, Cobb and Marshall (1968) report on a morphometric study of larval lobsters from off the southern New England coast. Many of their specimens were collected during the first two years of this project.

This investigation is an attempt to determine the distribution and abundance of lobster larvae off the coast of southern New England. The project was geared to determine time of first occurrence, distribution and relative abundance of larvae in the inshore waters and the spatiotemporal distribution of lobster larvae in one section of the offshore surface waters.

MATERIALS AND METHODS

All plankton tows were made with a circular net approximately 1.52 m in diameter at the mouth and tapering to a diameter of about 25 cm. The net is 5.18 m long and is made of knotless nylon with a mesh size of 1 mm. All tows were made at a speed of 3.0 to 3.5 knots and were 1/2 hr in duration. An attempt was made to tow the net with the rim just breaking the surface of the water and away from the propeller wash of the boat. The latter was attempted by either using the boom and positioning the net to the side or by towing some distance behind the boat. The sea condition was, however, the primary factor in determining whether an undisturbed surface sample was taken. It was only on an occasionally calm day that position of the net could be controlled.

The duration and area covered in the offshore collecting was limited by the size vessel available. The plan was to cover an area off southern New England which could be intensively sampled on a three-day cruise. This general area would be repeatedly sampled to gather data on the spacial and temporal distribution of lobster larvae in the

[1] Contribution No. 65, University of Connecticut, Marine Research Laboratory.

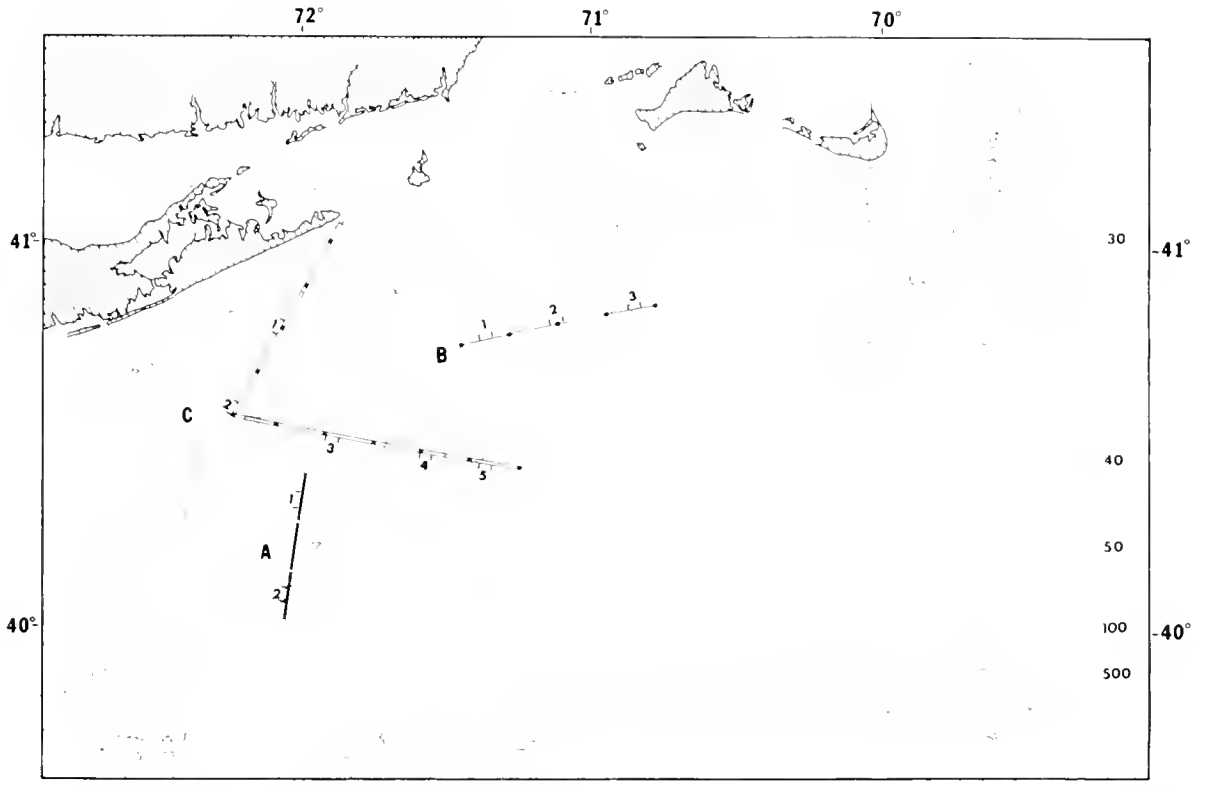

FIG. 1. *Offshore cruises and tow locations taken during 1966 when no lobster larvae were collected. Cruise A was taken on 5 August; Cruise B, 18 August; and Cruise C, 31 August. Dashes on either side of tow numbers are 1.5 nautical miles apart, the distance the net was towed.*

offshore waters. Sea conditions forced the postponement of some cruises and restricted the duration of others.

Inshore plankton tows were started in May of 1966, 1967 and 1968 and continued on a biweekly schedule until hatching was first evident. The plan was to then sample on a weekly schedule until lobster larvae were no longer collected. Cessation of sampling was caused by ctenophore abundance and not absence of larvae. The 1966 and most 1967 inshore sampling was restricted to the eastern end of Long Island and Fishers Island Sounds. The few tows taken in the middle and western sections of Long Island Sound caught more larvae than any other area sampled in 1967. The 1968 sampling program was thus expanded to 50 stations (Fig. 5) to determine whether a difference existed in the distribution or concentration of lobster larvae in the inshore waters. The 1969 program was restricted to evaluate whether the differences found in previous years were consistent from year to year.

Stations in Long Island Sound were grouped into three areas following the schematic diagram of currents presented by Riley (1952). The western end of Long Island Sound is composed of stations 1 through 15, 21, 22 and 23. The middle section is composed of stations 16 through 20, 24 and 25. The eastern section is made up of stations 26 through 36 which includes Fishers Island Sound. Stations 37 through 49 are all located outside of Long Island and Fishers Island Sounds, and are treated separately.

To facilitate discussion, the term "negative tow" is used to describe plankton tows which did not contain lobster larvae and "positive tow" for those containing lobster larvae.

The data are handled in two different ways for comparison. The 1968 collections from Long Island and Fishers Island Sounds are compared to each other on a catch per effort basis. The 1966, 1967, 1968 and 1969 collections are compared on an average catch basis where the negative tows are not considered in computing the averages. The sample is thus stratified by eliminating the negative tows from the computations. In fact, when the 1968 collections are compared to each other the sample is also stratified as all tows taken in

the spring prior to the first positive tow are not used in computing catch per effort. Thus, when the comparison is made between areas and years on the basis of average positive tow, the relative abundance of larvae is still being compared. The population is defined differently than that of catch per effort as there is the added condition that lobster larvae must occur for the sample to be considered. If larvae are more abundant in one area than in another, this difference will be evident whether all effort is considered or only tows containing larvae are considered in the averages. In fact, the consideration of only positive tows might be a more accurate index of relative abundance since we do not understand all factors which determine the presence of larvae at the surface.

We stratified the sample for the following reasons:

1. Lobster larvae are not randomly distributed throughout Long Island Sound. There are areas where larvae are never (Stations 1, 18, 25, 28, 31) or rarely (Stations 2, 11, 29, 32, 35, 36) collected.
2. Effort was not evenly distributed at all stations because: (a) ctenophore abundance was such that during July some stations could be sampled and others could not; (b) sea condition and distance traveled made it impossible to sample every station on some trips.

Survival rate is computed from a simple ratio as it was not known whether the rate was uniform between the four pelagic larval stages. In addition, recruitment from additional hatching larvae occurs throughout the sampling period at a non-uniform rate. Recruitment of larvae into Long Island Sound by surface currents is negligible as the ebb current is stronger than the flood in surface layers (Riley, 1956) and lobster larvae are very scarce in Block Island Sound (Table 2, Stations 37-50). The ratios of the total numbers of larvae collected throughout the season should give a good overall estimate of survival between the four

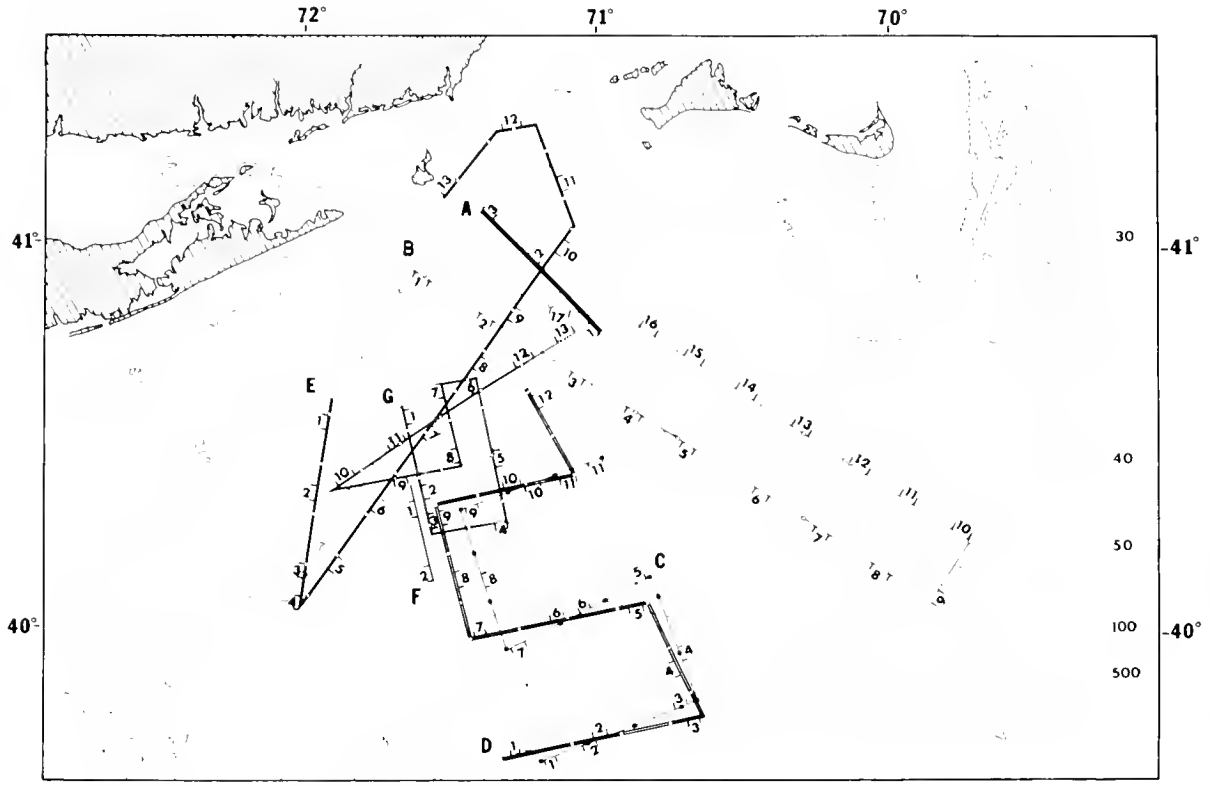

FIG. 2. *Offshore cruises and tow locations taken during 1966 when lobster larvae were collected. Cruise A was taken on 30 June; Cruise B, 6-7 July; Cruise C, 12-13 July; Cruise D, 21-22 July; Cruise E, 5 August; Cruise F, 10-11 August; Cruise G, 31 August-1 September. Dashes on either side of tow numbers are 1.5 nautical miles apart, the distance the net was towed.*

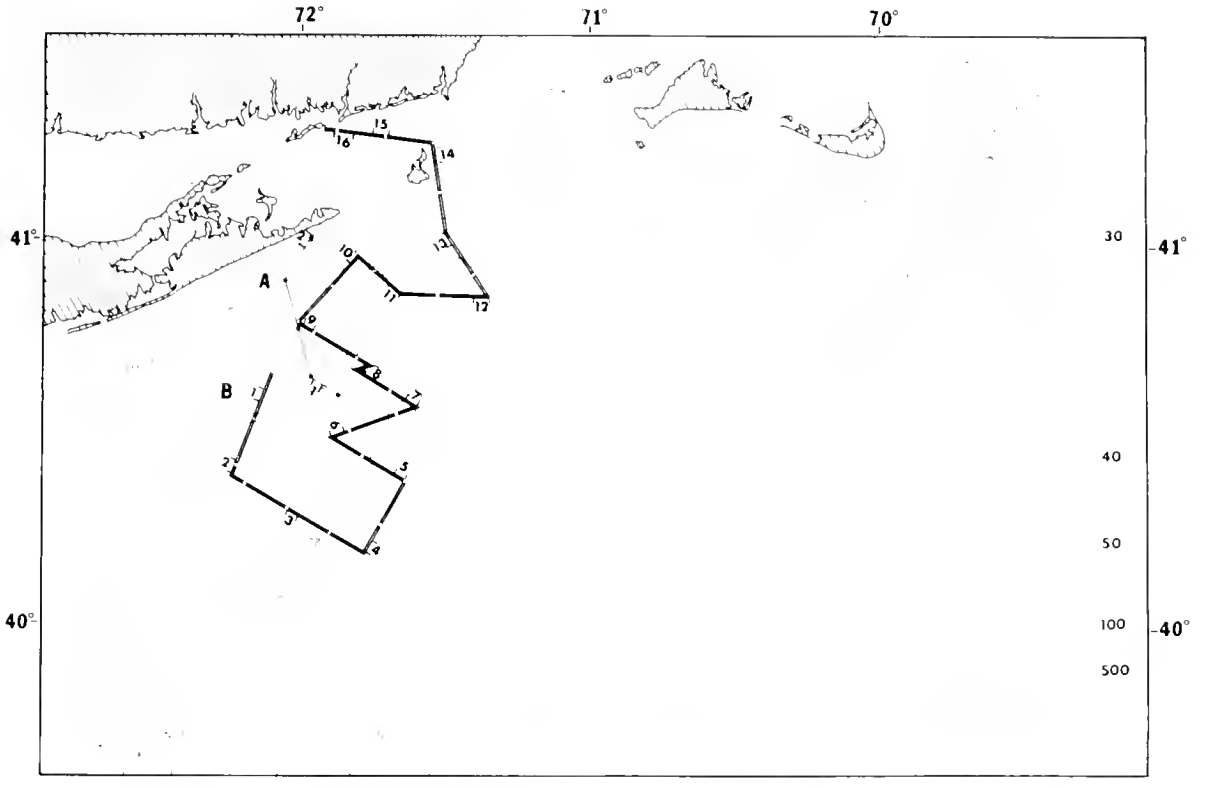

FIG. 3. *Offshore cruises and tow locations taken during 1967 when lobster larvae were collected. Cruise A was taken on 6 July and Cruise B on 17 August. Dashes on either side of tow numbers are 1.5 nautical miles apart, the distance the net was towed.*

pelagic larval stages as there does not appear to be a difference in the catchability of any stage. Only the 1968 collections are used to compute survival. Tests of significance are not run, as differences found are consistent and obviously significant.

OFFSHORE COLLECTIONS

The offshore plankton cruises in 1966 began in June and continued through August. Three short-duration cruises (Fig. 1) with all negative tows were taken during the time period when longer cruises produced positive results (Fig. 2). Figure 3 illustrates the cruises during which larval lobsters were collected in 1967.

Very few larval lobsters were collected from the offshore waters (Table 1). Larvae were scattered throughout all areas sampled and throughout the entire sampling period. The only area where a concentration of stage I larvae was found was 75 to 90 nautical miles south of Nantucket (Tows 7 and 9, Cruise B, Fig. 2). One collection in 1967, from an area about 35 nautical miles south of Montauk Point, Long Island, New York, contained 16 stage III larvae (Table 1). Other than these three collections, only 66 larvae were collected in 96 tows during 1966 and 1967. The relatively few lobster larvae collected from the offshore waters does not allow one to either draw definite conclusions on peak hatching time or to hypothesize on the distribution of larvae in relation to hydrographic parameters.

The purpose of the offshore sampling was to determine if a pattern of distribution of larvae existed. This in turn might help in understanding the relationship of the lobsters found in the Atlantic Ocean to those found in the sounds off southern New England. The distribution of the larvae was so scattered that the only conclusion which can be drawn is that lobster larvae appear to be present in the surface water out to the edge of the continental shelf at least throughout July and August. This distribution does not lend support to the idea that a distinct offshore population might exist.

INSHORE COLLECTIONS

First stage lobsters first appeared in the collections on 14 June 1966, 26 June 1967, 4 June 1968 and 19 June 1969. First stage larvae were still present each year when the abundance of the ctenophore, *Mnemiopsis leidyi*, made inshore plankton towing virtually impossible. In 1966, 1967 and 1969, the ctenophore became very abundant during the third week of July and continued to be present in high concentrations into October. Sampling was not prevented in 1968 until the first week of August. Figure 4 illustrates the occurrence of *M. leidyi* in the plankton collections. Plankton sampling is usually not possible when the percent of tows containing ctenophores approaches about 80. Most tows made under these conditions produced a few gallons of ctenophores and were almost entirely devoid of fish or crustacean larvae. The extent of the lobster hatching season is therefore not known. The data in Tables 3 and 4 indicate that the height of the hatching season generally occurs during the latter part of June and the first half of July. A significant number of larvae were collected in 1968 from the western end of Long Island Sound throughout the month of July.

The more extensive sampling in 1968 produced a total of 1372 lobster larvae (Table 2). Stations 37 through 50 (Fig. 5) yielded only five larvae. These few larvae made it impractical to compare these stations with other areas.

The weekly catch per effort of lobster larvae in 1968 (Table 3) was far greater in the western end of Long Island Sound than in the eastern. The data reveal a three to five times greater concen-

TABLE 1. *Number and stage of lobster larvae in each positive tow collected on offshore plankton cruises in 1966 and 1967. Locations are illustrated in Figures 2 and 3.*

Date	Cruise	Tow No.	Stage I	II	III	IV
1966						
30 June	A	2	0	0	2	1
		3	0	0	1	0
6-7 July	B	1	0	1	1	1
		5	0	1	1	0
		6	1	2	1	0
		7	10	0	0	0
		9	24	0	0	0
		11	1	0	0	0
		13	0	0	1	0
		15	0	0	0	1
		16	0	1	0	0
12-13 July	C	7	0	0	1	0
		8	5	1	0	0
		9	1	0	0	0
		10	0	0	1	0
21-22 July	D	6	1	1	2	1
		7	0	1	0	0
		8	3	0	0	0
		11	0	0	2	0
10-11 August	E	2	0	0	1	1
		3	0	1	0	0
		7	0	1	0	1
		8	0	1	1	1
		9	0	1	0	0
		10	2	0	1	1
		11	0	0	1	0
17 August	F	2	0	0	0	1
31 August-1 September	G	3	0	1	0	0
1967						
6 July	A	1	1	1	16	0
		2	5	2	0	0
17 August	B	6	1	0	1	2

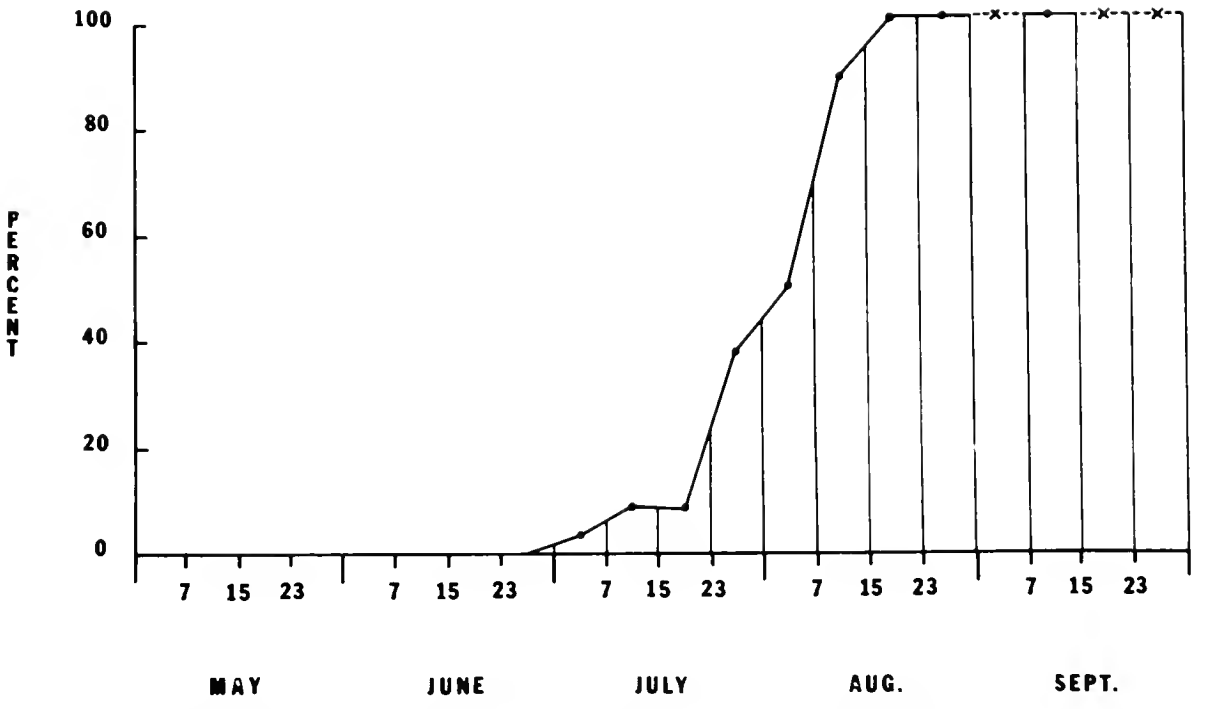

FIG. 4. *Weekly percentages of plankton tows which contained the ctenophore,* Mnemiopsis leidyi, *for all stations sampled in 1968.*

tration of larvae in the western end. The middle area of Long Island Sound has an anomalous situation with a greater abundance of larvae of stages III and IV than of stages I and II. The catch per effort figures for each station, Figure 6, and each stage, Figure 7, give excellent visual comparisons which show these differences.

The causes of the greater concentrations of larvae in the western end of Long Island are difficult to explain. The eastern end of the Sound consistently has a higher commercial landing of lobsters than the counties in the western end. Therefore, the concentrations and abundance of larvae would be expected to be higher in the eastern end. Movements of berried females are not known, but no evidence exists to show a differential migration of females to the western end of the Sound. Riley (1956) found that the ebb current is stronger than the flood in the surface layer of the Sound but weaker than the flood in

TABLE 2. *Number of lobster larvae taken in 1968.*

Period covered	Stations 1-36				Stations 37-50			
	Stage				Stage			
	I	II	III	IV	I	II	III	IV
1-7 June	3	0	0	0				
8- 15	23	1	0	0				
16-23	51	9	10	4				
24-30	64	21	32	10				
1-7 July	44	28	59	41	—	—	—	—
8-15	135	107	102	84	2	0	0	0
16-23	112	104	80	74	—	—	—	—
24-31	42	56	39	32	0	1	0	2
Total	474	326	322	245	2	1	0	2

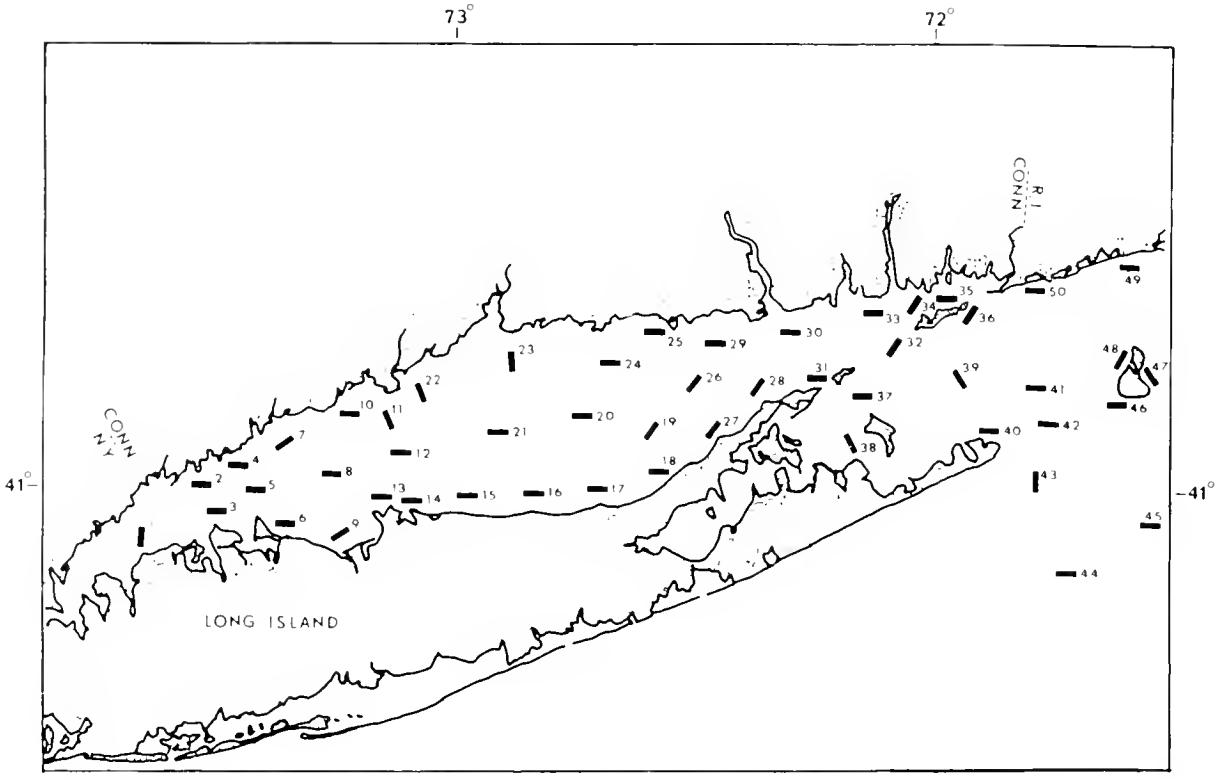

FIG. 5. *Inshore plankton stations sampled during 1968. Areas defined by current patterns are: West 1-15, 21-23; Middle 16-20, 24, 25; East 26-36; Block Island Sound 37-50.*

the bottom layer. Larvae are found in the surface layer (Templemen and Tibbo, 1945) and, based on current strength, lower concentrations would be expected in the western end. Riley (1952) presents what he terms a simplified and schematic current diagram of Long Island Sound. He points out that his diagram entails subjective judgements. These current patterns help to explain the distribution of lobster larvae. The direction of the currents in the western end tends to help contain larvae hatched in that area. The middle section could be relatively unproductive for lobster larvae, and the higher concentrations of stage III and IV larvae which have been in the surface layers the longest could be the result of gradual recruitment from the western end. The eastern end surface waters tend to flush the larvae out to sea and thus dilute their concentrations.

TABLE 3. *Average weekly catch/effort of lobster larvae taken in 1968 in three areas of Long Island Sound.*

	East					Middle					West				
Period covered	No. Tows	Stage I	II	III	IV	No. Tows	Stage I	II	III	IV	No. Tows	Stage I	II	III	IV
1-7 June	7	0.4	0	0	0	--	—	—	—	—	—	—	—	—	—
8-15	12	0.5	0.1	0	0	—	—	—	—	—	—	—	—	—	—
16-23	22	1.8	0.1	0	0	4	0.5	0.8	0.5	0.3	4	4.0	1.3	2.0	0.8
24-30	—	—	—	—	—	—	—	—	—	—	12	5.0	2.0	2.7	0.8
1-7 July	10	2.2	0.3	0.4	0.4	5	0.8	1.2	5.2	2.0	9	3.0	1.2	1.7	3.0
8-15	6	1.8	0.2	0	0.5	4	2.5	8.8	10.5	12.0	11	10.2	6.5	4.4	3.1
16-23	8	0.5	0.5	0.1	0.4	4	1.3	0.8	0	1.3	14	7.3	6.8	5.6	4.7
24-31	—	—	—	—	—	3	0	0	0.3	1.0	10	4.0	5.6	3.8	4.9
Total	65	1.4	0.1	0.1	0.2	20	1.1	2.2	3.6	3.4	60	6.0	4.4	3.7	3.1

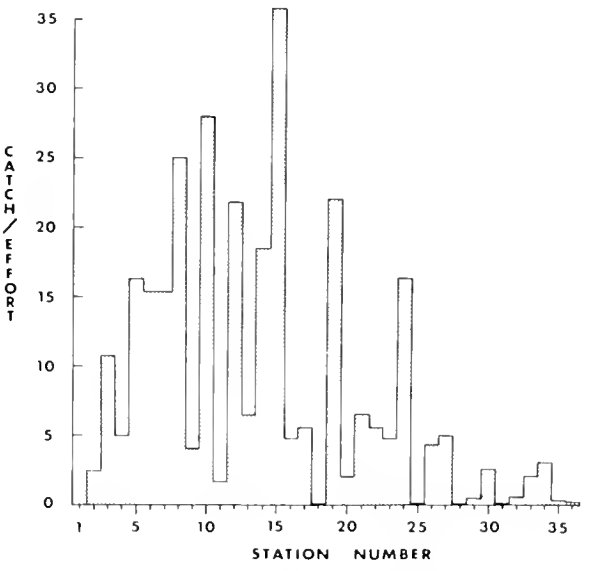

FIG. 6. *Total catch per effort of all larval stages for stations 1-36 in Long Island Sound, 1968.*

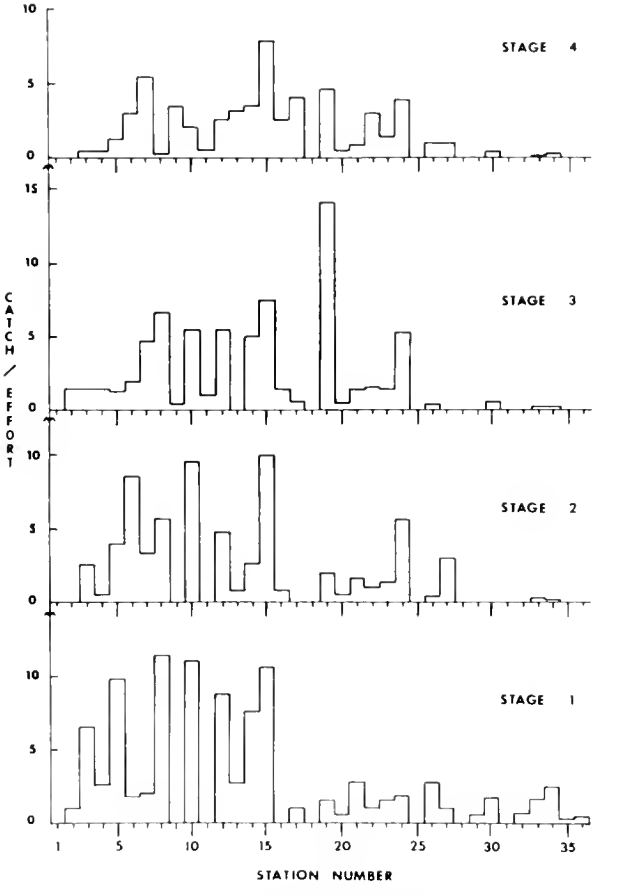

FIG. 7. *Catch per effort of individual lobster larvae stages for stations 1-36 in Long Island Sound, 1968.*

The 1966, 1967 and 1969 collections are compared with the 1968 data in Table 4. The relative abundance of lobster larvae in the eastern end of the Sound was consistent from year to year with lower concentrations. The middle section consistently had higher concentrations of stage III and stage IV larvae. The western end of Long Island Sound consistently had higher concentrations of larvae than the eastern end. Some consideration must be given to date of capture when comparisons between areas are made. The 1968 sampling program was the only one designed to determine areal differences in lobster larvae concentrations in Long Island Sound. The 1967 and 1968 collections do reflect these same differences between areas and also show a relative consistency between years of lobster larvae concentrations within areas.

Numbers of larvae collected throughout 1968 in Long Island and Fishers Island Sounds (Table 2) are used to estimate survival rates of larval lobsters. Recruitment from hatching should have been almost completed by the time the tows were terminated, and the summation of the total numbers collected should produce ratios which will give a good estimate of survival rate. Survival from stage I to stage IV was estimated to be 0.52. This is a rather high survival rate, but it can partly be attributed to the high survival estimate of 0.99 between stage II and stage III. These rates are much higher than anticipated. In fact, it can be argued that since sampling had to be terminated prior to the time that all larvae had settled to the bottom, an underestimate of survival rate was made as the proportion of stage IV larvae in the sample should be higher at the end of the season.

Thermal stratification does exist in Long Island Sound at the time when larvae are present in the surface waters. Thermal differences of 2 C within a 25-foot vertical column were noted in western Long Island Sound. Therefore, surface temperatures in this area can not be directly related to the bottom temperatures at which hatching occurs.

Larvae were most abundant in western Long Island Sound during July of 1968. Surface temperatures during the first week ranged from 18.5 to 22.5°C with a mean of 20.6°C; during the second week, 16.5 to 20.0 C with a mean of 19.1 C; and during the third week 22.0 to 28.5 C with a mean

TABLE 4. *Average weekly number of lobster larvae occurring in positive tows in 1966, 1967, 1968 and 1969 in three areas of Long Island Sound.*

Period covered	East					Middle					West				
	No. Tows	Stage I	Stage II	Stage III	Stage IV	No. Tows	Stage I	Stage II	Stage III	Stage IV	No. Tows	Stage I	Stage II	Stage III	Stage IV
1966															
16-23 June	5	4.0	0	0	0										
24-30	10	3.0	0.8	0.4	0.7										
1-7 July	9	1.8	0.9	0.6	0.2										
7-15	3	0.7	0.3	0.3	0.3										
Total	27	2.5	0.6	0.4	0.4										
1967															
24-30 June	8	4.3	0.5	0.1	0	—	—	—	—	—	—	—	—	—	—
1-7 July	4	2.8	1.3	0	0.3	—	—	—	—	—	—	—	—	—	—
8-15	2	0.5	0	0.5	0	1	0	3.0	14.0	7.0	—	—	—	—	—
16-23	—	—	—	—	—	—	—	—	—	—	5	12.6	4.4	2.2	2.2
Total	14	3.2	0.6	0.2	0.1										
1968															
1-7 June	2	1.5	0	0	0	—	—	—	—	—	—	—	—	—	—
8-15	7	3.3	0.1	0	0	—	—	—	—	—	—	—	—	—	—
16-23	11	3.3	0.1	0	0	2	1.0	1.5	1.0	0.5	4	4.0	1.3	2.0	0.8
24-30	—	—	—	—	—	—	—	—	—	—	12	5.0	2.0	2.7	0.8
1-7 July	8	2.8	0.4	0.5	0.5	5	0.8	1.2	5.2	2.0	8	3.4	1.4	1.9	3.4
8-15	4	2.8	0.3	0	1.3	4	2.5	8.8	10.5	12.0	11	10.2	6.5	4.4	3.1
16-23	2	2.0	2.0	0.5	0.7	3	1.7	1.0	0	1.7	13	7.8	7.4	6.1	5.1
24-31	—	—	—	—	—	3	0	0	0.3	1.0	8	5.0	7.0	4.8	6.1
Total	34	2.9	0.3	0.1	0.4	17	1.2	2.6	4.2	3.9	56	6.3	4.7	3.9	3.4
1969															
16-23 June	1	2	1	0	0	—	—	—	—	—	—	—	—	—	—
1-7 July	—	—	—	—	—	4	4.0	1.8	1.5	10.3	8	2.8	3.9	4.5	3.4
8-15	1	0	1	0	2	3	0	0.3	0.7	8.0	12	0.1	0.3	0.5	3.8
Total	2	1.0	1.0	0	1.0	7	2.3	1.1	1.1	9.3	20	1.2	1.7	2.1	3.6

of 24.2°C. The minimum temperature recorded when larvae were collected was 12.5°C and the maximum was 28.5°C. The surface water temperature when larvae were first collected, 12.5°C, and the temperature at peak hatching, approximately 20.0°C, for the waters of Long Island Sound agree with the hatchery data obtained by Hughes and Matthiessen (1962).

SUMMARY AND CONCLUSIONS

1. The relative abundance of lobster larvae in eastern Long Island Sound is shown to be much lower than that for middle and western Long Island Sound. Larval concentrations three to five times greater were obtained for the western and middle region. Low yields of lobster larvae from eastern Long Island Sound are comparable for all years in which significant sampling was conducted. Block Island Sound was the least productive of all areas sampled.

2. The relative paucity of lobster larvae in the offshore waters sampled in 1966 and 1967 does not contribute to the theory that a distinct offshore lobster population exists. The larvae that were collected were found to be widely distributed and "patchy" in occurrence.

3. Concentrations of larvae in western and middle Long Island Sound are believed to be caused by circular surface current patterns proposed by Riley (1952). The larvae are retained in two circulation masses rather than being diluted by seaward flushing as may be the case in eastern Long Island Sound.

More third and fourth stage larvae were collected in middle Long Island Sound and it is suggested that the overall transport of surface water from west to east is responsible for the gradual recruitment of stage III and IV larvae into this area.

4. The survival rate, computed as a proportion of each larval stage in the total collection, appeared to be exceptionally high for Long Island and Fishers Island Sounds in 1968. Survival from stage I to stage IV was estimated to be 0.52.

5. A bloom of the ctenophore, *M. leidyi*, at the time of peak larval concentrations caused a drastic change in the plankton composition. Lobster larvae were still hatching and abundant in all stages when ctenophore occurrence was 30% and less. When the occurrence of ctenophores exceeded 80%, lobster larvae ceased to be taken and plankton samples were practically devoid of all other associated plankton. This occurred in late July in 1966, 1967, 1969 and early August in 1968.

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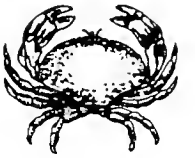

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RELATION BETWEEN MEAT WEIGHT AND SHELL HEIGHT OF THE GIANT PACIFIC SEA SCALLOP, *PATINOPECTEN CAURINUS*, FROM THE GULF OF ALASKA

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ABSTRACT

Meat weight-shell height relations were obtained for giant Pacific sea scallops, Patinopecten caurinus, *collected from two areas in the Gulf of Alaska. W is meat weight in g and L is shell height in mm.*

Ocean Cape $\hat{W} = 3.833 \times 10^{-6} L^{3.121}$
Kodiak Island $\hat{W} = 2.006 \times 10^{-5} L^{2.844}$

Over the range of shell heights examined, the mean weight of scallop meats differed significantly (1% level) between the areas. The 95% confidence limits for the meat weight-shell height equations and the number of meats per lb and per kg were computed for the two areas.

Explorations in the Gulf of Alaska by the Bureau of Commercial Fisheries research vessel *John R. Manning* in 1963 and by Kodiak Island fishermen in January 1968 indicated that giant Pacific sea scallops, *Patinopecten caurinus* (Gould), were commercially abundant in certain areas of the gulf. To explore the resource further, the Bureau of Commercial Fisheries and the Alaska Department of Fish and Game chartered the New England scallop vessel *Viking Queen* from 27 April — 6 June, 1968, to search for sea scallops from Cape Fairweather to Kodiak Island (Fig. 1). The large quantities of scallops found prompted several commercial fishermen to begin fishing for the species; by the end of 1968 their landings totaled about 1.6 million lb of scallop meats worth almost 1.5 million dollars.

The commercial catches were taken almost entirely from two areas — off Ocean Cape in the northeastern gulf and off Kodiak Island in the western gulf (Fig. 1). The data collected in these areas by the *Viking Queen* indicated that sea scallops from the Kodiak area grow faster and have heavier meats for their shell size than those from Ocean Cape.[1] We therefore analyzed these data to determine if the difference in the relation of the meat weight to the shell height of scallops between the two areas is statistically significant and to calculate the number of scallop meats per unit weight for each area. The scallop samples used in our analyses were taken from 59°39' N. Lat.; 141°32' W. Long. (Ocean Cape area) and 58°01' N. Lat.; 151°28' W. Long. (Kodiak area).

The scallops were collected from a trawler and processed ashore. They were captured with a standard New Bedford-type sea scallop dredge and kept alive on ice until they could be shucked ashore, about 2 hr later. The adductor muscle, the only part of the scallop kept by commercial fishermen, was weighed to an accuracy of ± 0.03 g. The weight of this muscle is usually 10-15% of the total weight of the scallop and about 30% of the total weight of the shell content. Shell height, the greatest distance between the umbo and the margin of the shell, was measured to the nearest mm. Table 1 summarizes the data on meat weight and shell height.

[1] Unpublished data on file, Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska

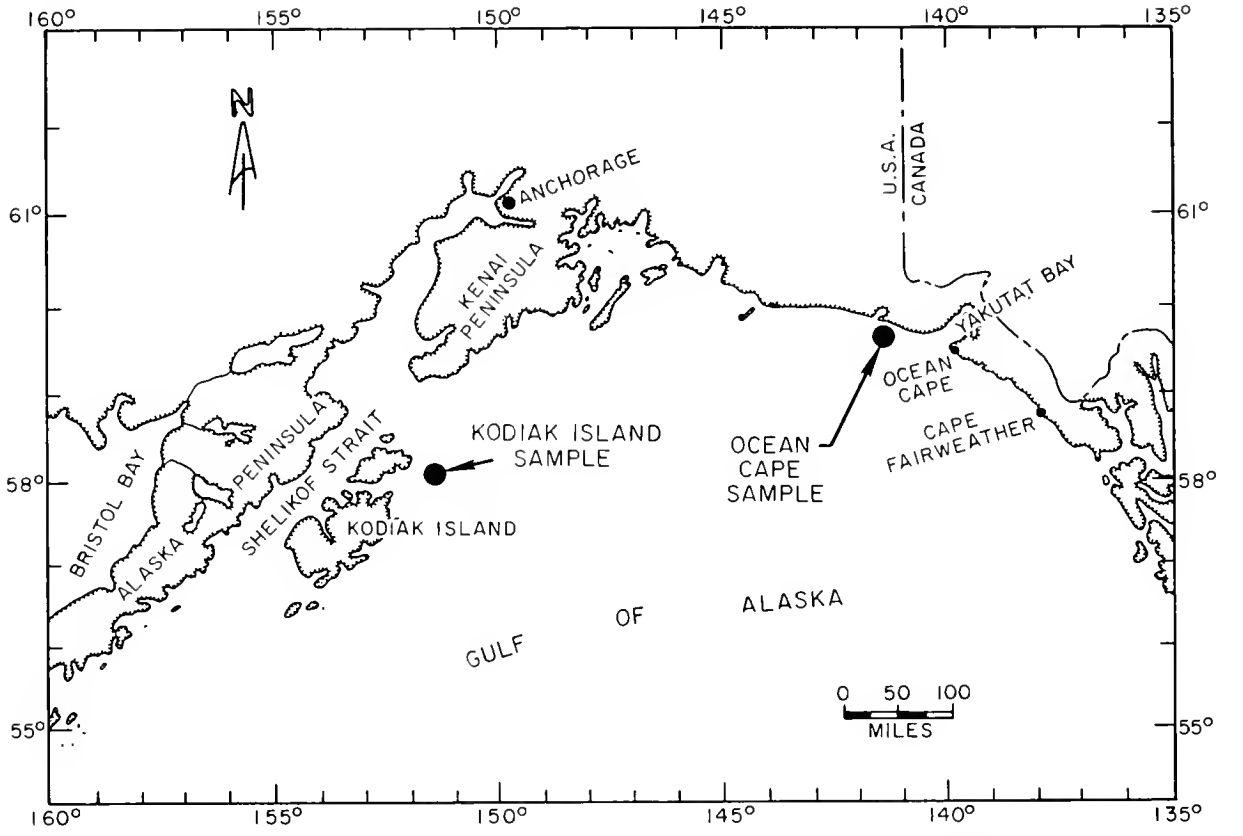

FIG. 1. *Gulf of Alaska, showing areas off Ocean Cape and Kodiak Island where samples of sea scallops were collected to determine meat weight-shell height relation.*

We related meat weight to shell height with the equation $W = cL^b$, in which W = weight in g, L = height in mm, and c and b are constants (Fig. 2). Values for c and b were obtained from least squares regressions of the logarithmic transformation, $\ln W = \ln c + b \ln L$. Logarithms of the individual weights and heights were used in the calculations. Notation of regression analysis followed Snedecor (1956).

We used analysis of covariance to compare the regression coefficient, b, and adjusted mean weights of the sample regressions. Only those lengths for which we had data for both areas, 105-161 mm, were used. The difference in regression coefficients at the 5% level was not significant ($F = 3.79$). Elevations of the curves (logarithms of adjusted mean weights) differed significantly, however, at the 1% level ($F = 271.54$). We rejected, therefore, the hypothesis of a common regression for the two samples and concluded that for any given shell height from 105-161 mm, the mean meat weights were significantly greater for scallops from Kodiak Island

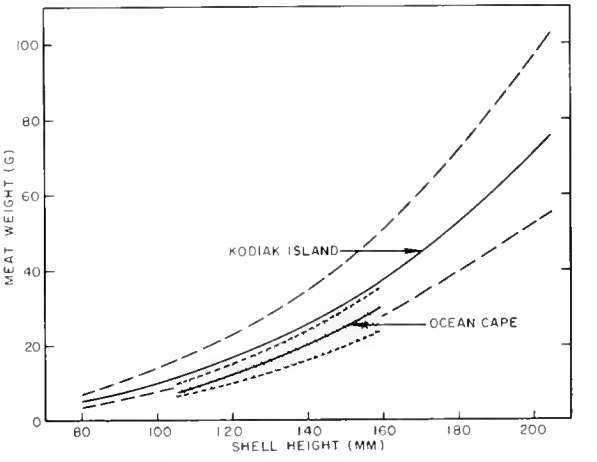

FIG. 2. *Regression lines of meat weight on shell height of sea scallops collected off Ocean Cape and Kodiak Island, Alaska. Widths of shaded and open areas show limits within which 95% of the meat weights may be expected to fall.*

TABLE 1. *Mean meat weights and standard deviations of meat weights by 5-mm classes of shell height of giant Pacific sea scallops collected off Ocean Cape and Kodiak Island, Alaska.*

	Ocean Cape			Kodiak Island		
Shell height (mm)	Number of scallops	Mean meat weight (g)	Standard deviation of meat weights (g)	Number of scallops	Mean meat weight (g)	Standard deviation of meat weights (g)
55- 59	0	—	—	1	1.7	—
60- 64	0	—	—	0	—	—
65- 69	0	—	—	0	—	—
70- 74	0	—	—	0	—	—
75- 79	0	—	—	0	—	—
80- 84	0	—	—	2	7.4	—
85- 89	0	—	—	1	7.0	—
90- 94	0	—	—	1	7.9	—
95- 99	0	—	—	3	9.0	—
100-104	0	—	—	1	11.5	—
105-109	1	8.0	—	1	13.1	—
110-114	4	9.1	1.45	2	11.8	—
115-119	5	10.9	1.51	2	13.5	—
120-124	16	12.6	2.05	8	15.9	1.08
125-129	23	14.6	1.70	6	18.8	1.87
130-134	48	16.2	1.57	2	18.2	—
135-139	54	18.2	1.82	3	23.6	—
140-144	57	20.0	1.70	8	25.2	4.24
145-149	16	21.3	2.40	3	31.0	—
150-154	14	24.6	2.62	5	34.0	3.71
155-159	12	28.0	2.28	10	38.8	4.56
160-164	2	27.2	—	12	43.2	5.20
165-169	0	—	—	7	43.3	4.19
170-174	0	—	—	11	45.7	7.94
175-179	0	—	—	4	50.7	—
180-184	0	—	—	1	62.0	—
185-189	0	—	—	11	57.0	12.51
190-194	0	—	—	6	60.1	6.68
195-199	0	—	—	3	60.4	—
200-204	0	—	—	3	72.7	—

than for those from Ocean Cape. Regression equations for estimating lnW from lnL for scallops 105-164 mm in height were as follows:

Kodiak Island $\widehat{\ln W} = -13.5939 + 3.406 \ln L$ (1)

Ocean Cape $\widehat{\ln W} = -12.4719 + 3.121 \ln L$ (2)

The regression for all scallops in the Kodiak Island sample (55-204 mm) was as follows:

$$\widehat{\ln W} = -10.8167 + 2.844 \ln L \quad (3)$$

In terms of original measurements equation (2) is $\hat{W} = 3.833 \times 10^{-6} L^{3.121}$ and equation (3) is $\hat{W} = 2.006 \times 10^{-5} L^{2.844}$

These equations were used to compute weight-height curves in terms of the original measurements. The computed curves and their 95% confidence limits of the individual observations are shown in Figure 2. Table 2 gives the ln values needed to calculate the limits.

The values calculated from the meat weight-shell height regression equations were used to determine the number of scallop meats per kilogram and per pound for scallops of various shell heights (Table 3). Such measurements are useful in estimating the average size (height) of scallops retained by fishermen.

This report contains the only published data on the meat weight-shell height relation of *P. caurinus*. Similarities exist, however, between our results and those of Haynes (1966) for the east coast sea scallop, *Placopecten magellanicus*. In both species, meat weights for any given shell

TABLE 2. *Values (ln) needed for calculating confidence limits of regression equations of meat weight on shell height for giant Pacific sea scallops off Ocean Cape and Kodiak Island, Alaska.*

Sample location	Number of scallops	Mean shell height ($\overline{\ln L}$)	Mean meat weight ($\overline{\ln W}$)	Sum of squares of deviations (Σx^2)	Standard error of estimate ($S_{y.x}$)
Ocean Cape	252	4.9176	2.8772	1.3406	0.1010
Kodiak Island	117	5.0124	3.4374	5.8417	0.1553

TABLE 3. *Estimated number of scallop meats per kilogram and per pound for various size scallops off Ocean Cape and Kodiak Island, Alaska.*

Shell height		Number of scallop meats			
		Ocean Cape		Kodiak Island	
mm	in	Per kg	Per lb	Per kg	Per lb
80- 84	3.1-3.3	—	—	178.6	81.0
85- 89	3.3-3.5	—	—	151.5	68.7
90- 94	3.5-3.7	—	—	129.9	58.9
95- 99	3.7-3.9	—	—	111.1	50.4
100-104	3.9-4.1	—	—	97.1	44.0
105-109	4.1-4.3	120.5	54.6	84.0	38.1
110-114	4.3-4.5	105.3	47.7	74.1	33.6
115-119	4.5-4.7	91.7	41.6	65.4	29.6
120-124	4.7-4.9	80.6	36.6	58.1	26.4
125-129	4.9-5.1	70.9	32.2	51.8	23.5
130-134	5.1-5.3	62.9	28.5	46.5	21.1
135-139	5.3-5.5	55.9	25.3	41.8	19.0
140-144	5.5-5.7	50.0	22.7	37.7	17.1
145-149	5.7-5.9	44.8	20.3	34.1	15.5
150-154	5.9-6.1	40.5	18.4	31.1	14.1
155-159	6.1-6.3	36.6	16.6	28.3	12.8
160-164	6.3-6.5	33.1	15.0	25.9	11.8
165-169	6.5-6.7	—	—	23.8	10.8
170-174	6.7-6.9	—	—	21.9	9.9
175-179	6.9-7.1	—	—	20.2	9.1
180-184	7.1-7.3	—	—	18.6	8.4
185-189	7.3-7.5	—	—	17.2	7.8
190-194	7.5-7.7	—	—	16.0	7.3
195-199	7.7-7.9	—	—	14.9	6.7
200-204	7.9-8.1	—	—	13.8	6.3

size varied widely. For certain areas, Haynes (1966) found significant differences in meat weights for any given shell height among sea scallops. These differences were related to gonadal condition. Our data do not permit such a comparison, but the possibility of such differences should be considered in future weight-height studies of *P. caurinus*.

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THE EFFECT OF TEMPERATURE ON THE FEEDING RATE OF THE ROUGH OYSTER DRILL, *EUPLEURA CAUDATA* (SAY) [1]

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ABSTRACT

Feeding rates of Eupleura caudata *(Say) were studied at a series of controlled water temperatures. The negligible consumption of young* Crassostrea virginica *and* Mulinia lateralis *at 10.0°C indicates that this temperature is near the lower limit for predatory activity. Feeding rates increased with increasing temperature from 10.0 to 27.5°C, and decreased when the temperature was increased from 27.5 to 30.0°C. Feeding rates were maximum at 25.0 and 27.5°C. Drills consumed more* M. lateralis *than* C. virginica *at all experimental temperatures although physical differences between the prey may account for this disparity. Drills were cannibalistic in the presence of alternative food sources throughout the range of temperature studied. Cannibalism increased as the temperature and feeding rates increased and the highest incidence of cannibalism was at optimum feeding temperatures (25.0 and 27.5°C). Ovipositing drills discriminated between the two prey organisms as substrata for capsular attachment; they deposited egg capsules readily on the valves of* C. virginica *but only infrequently on the valves of* M. lateralis.

INTRODUCTION

The marine prosobranch gastropods, *Eupleura caudata* (Say) and *Urosalpinx cinerea* (Say), are two of the more serious predators of the Eastern oyster, *Crassostrea virginica*. Economic losses caused by these muricid gastropods have led a number of investigators to study various aspects of the ability of the drills to consume prey organisms. Although numerous studies have been made of *U. cinerea*, very little attention has been given to the activities of *E. caudata* (Carriker, 1955), and no evaluation of the voracity of *E. caudata* under controlled laboratory conditions has been reported.

Much of what is known about the destructiveness of *E. caudata* came from field observations in several, separate geographical areas. Haskin (1935)[2], in his preliminary investigations at Barnegat Bay, New Jersey, found that *E. caudata* consumed prey at about the same rate as *U. cinerea*. Galtsoff, Prytherch and Engle (1937) reached the same conclusion with drills from Delaware Bay but suggested that *U. cinerea* was the more serious predator because of its greater abundance. MacKenzie (1961) reported that *E. caudata* collected from the York River, Virginia, began feeding at approximately 12.5°C. These authors, however, presented little quantitative information and almost no data on the effect of temperature on the feeding of *E. caudata*.

The present study was initiated to determine estimates of the feeding rates of *E. caudata* from Long Island Sound at a series of controlled water temperatures. Using an experimental procedure similar to that used by Hanks (1957) with *U. cinerea*, it was possible to determine the feeding rates of *E. caudata* at several temperatures and compare the feeding rates of the two drill species

[1] Adapted from portions of a thesis submitted to Southern Connecticut State College in partial fulfillment of the requirements for the degree of Master of Science.

[2] Haskin, H. H. 1935. Investigations on the boring and reproductive activities of the oyster drills, *Urosalpinx cinerea* (Say) and *Eupleura* sp. Unpub. Rep U. S. Bur. Fish.

indigenous to Long Island Sound. Observations on drill mortalities and on substrata used for egg capsule attachment were included.

METHODS

Oyster drills *(E. caudata)* and young oyster spat *(C. virginica)* were collected in Long Island Sound in the vicinity of the Norwalk Islands, Norwalk, Connecticut, an area extensively used for farming oysters. During July and August 1967, when the majority of animals were collected, the bottom salinities and temperatures averaged 27.0 ppt and 22.2°C. Coot clams *(Mulinia lateralis)* were collected from the intertidal area of Fort Trumbull Beach, Milford, Connecticut, in August and September 1967.

In the laboratory the drills were placed in 60-liter fiber glass aquaria, each supplied with a separate continuous flow of sea water at a temperature of 22.5°C and a salinity of 26.5 ppt. After 1 week of acclimatization the stock of drills was randomly divided, one group for each temperature to be studied, and placed in separate aquaria. The temperature of the water entering each aquarium was adjusted 1.0°C per day until one aquarium was maintained at each of the five temperatures to be studied. Drills were maintained for replacement stocks in these conditioning aquaria throughout the experiments. The young *C. virginica* and *M. lateralis* used as prey organisms were not temperature acclimated but were held in running water aquaria at 22.5°C and 26.5 ppt until used in the study.

Five temperature stations were established, each consisting of a polyethylene mixing cylinder held above the drain table on a wooden platform, and two fiber glass trays (35 cm x 48 cm x 11.5 cm) on the drain table. By adjusting the rate of flow from hot and cold sea-water outlets to the cylinders, the required temperature was maintained at each station (Loosanoff, 1949). The flow of water to the cylinders was adjusted so that overflow was continuous, thus keeping the water level and head pressure constant in all cylinders. A Y-tube at the bottom outlet of each cylinder supplied approximately 2 liters of water per minute to each of the two fiber glass trays.

Both trays at each station contained 20 adult *E. caudata* with a mean shell height of 24.4 mm, and either 60 oyster spat in 4 or 5 clusters (mean length 24.8 mm) or 70 clams (mean length 16.4 mm). By providing two species of bivalves as prey it was possible to compare the rates of prey consumption at different temperatures. *M. lateralis* was used as the secondary prey species on the basis of C. L. MacKenzie's (personal communication) field observations of heavy natural predation by *E. caudata* on the coot clam. The water temperatures at the five stations were maintained at 10.0, 15.0, 20.0, 25.0 and 30.0 $\pm$ 1.0°C. The salinity was maintained at 26.0 $\pm$ 1.5 ppt and probably did not have a significant influence on the feeding rates at the various temperatures. During the experiment the trays were covered with small-mesh nylon netting to prevent escape of the drills. The experiment consisted of five 10-day trials. The trays were examined at the end of each trial and the number of prey consumed and number of dead drills determined. After the trays were cleaned, the original number of drills and prey was restored by replacements from the aquarium stocks.

A second experiment was conducted to determine more accurately the optimum feeding temperature of *E. caudata*. Four stations were established and maintained at 22.5, 25.0, 27.5 and 30.0 $\pm$ 1.0°C. This study also consisted of five 10-day trials in which the same experimental procedures described above were used.

RESULTS AND DISCUSSION

Relation of feeding rate to temperature

The first experiment showed that the rates at which *E. caudata* consumed *C. virginica* and *M. lateralis* varied with changes in temperature (Table 1). At 10.0°C, drills fed very little (0.02 oyster or 0.05 coot clam per drill per trial), and attacked (attempted perforation) prey organisms only occasionally. Locomotor activity was limited; the drills generally remained stationary and firmly attached to a substratum. Movement was relatively slow (approximately 0.35 cm/min) and entailed limited podial extension. No copulation or oviposition was seen. These observations seemed to indicate that 10.0°C may be near the lower temperature limit for normal activities of *E. caudata* indigenous to Long Island Sound.

The feeding rate gradually increased with each increase in temperature from 10.0 to 25.0°C. At 25.0°C the largest number of both prey species (1.34 oysters and 2.23 clams per drill per trial) was consumed and the highest percentage of drills feeding (55%) was observed. At 30.0°C, however, the feeding rate decreased noticeably, and the drills were relatively immobile and weakly attached to the trays. Egg deposition also was reduced considerably. Although feeding was still moderate at 30.0°C, this temperature may be near the upper limit for some activities of the drills.

The optimum feeding temperature for *E. caudata* was more accurately determined in the second experiment (Table 2). The rates at which both prey organisms were consumed increased as the water temperature increased from 22.5 to 25.0°C. At 25.0 and 27.5°C the feeding rates were similar; *E. caudata* consumed an average of ap-

TABLE 1. Average number of *Crassostrea virginica* and *Mulinia lateralis* consumed by *Eupleura caudata* per 10-day trial and the number consumed per drill per trial at a series of controlled water temperatures. [a]

Temperature °C	*C. virginica*		*M. lateralis*	
	Average per trial	Average per drill	Average per trial	Average per drill
10.0	0.40	0.02	1.00	0.05
15.0	5.20	0.26	11.20	0.56
20.0	13.80	0.69	29.80	1.49
25.0	26.80	1.34	48.60	2.23
30.0	17.80	0.89	20.80	1.04

[a] Twenty *E. caudata* were placed in trays at each temperature with either 60 oyster spat or 70 clams. See text for details.

proximately 1.54 oysters and 2.08 coot clams per drill per trial. At 30.0°C feeding had again declined to a rate below that observed for 22.5°C. Thus, the optimum temperature for prey consumption was between 25.0 and 27.5°C.

A comparison of the feeding of oyster drills on each prey species showed that more coot clams than oysters were consumed at all temperatures studied (Fig. 1). At the lower temperatures the

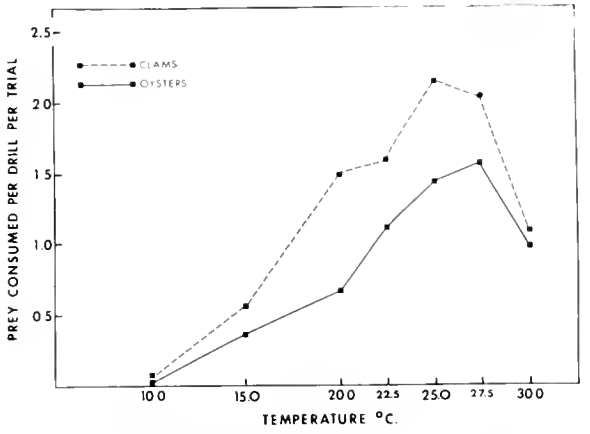

FIG. 1. *Feeding rates of* Eupleura caudata *on two prey species at a series of controlled water temperatures.*

drills consumed approximately twice as many clams as oysters, but this difference gradually decreased as the temperature and feeding rates increased. At the optimum feeding temperature the number of clams consumed was only 40% higher and at 30.0°C the disparity was reduced to about 10% (Experiments 1 and 2 combined).

Statistical evaluation (Student's t-test) revealed that all differences between the means of the feeding rates at progressively increasing temperature levels were significant at the 99% confidence level ($t>4.604$ with d.f. = 4) in Experiment 1 and (except for those at 25.0 and 27.5°C) at the 95% confidence level ($t>2.776$ with d.f. = 4) in Experiment 2.

Hanks (1957) reported a progressive increase in feeding of *U. cinerea* similar to that shown here for *E. caudata* and suggested that the optimum feeding temperature for this species was 25.0°C (27.5°C was not tested). He stated, however, that since water temperatures in Long Island Sound seldom reach 25.0°C or higher, oyster drills probably do not feed at the observed maximum rates in their natural environment. His results showed that *U. cinerea* consumed a larger number of oyster spat at all temperatures than the *E. caudata* observed in the present study. Although this difference could indicate that *U. cinerea* is the more voracious of the two drills, it is possible that *C. virginica* is a less attractive prey organism to *E. caudata*.

Relation of feeding rate to species of prey

The disparity between the rates at which the two prey organisms were consumed by *E. caudata* (Tables 1 and 2) could be considered evidence of a preference for the coot clam over the oyster. More clams than oysters were consumed at each temperature, but possibly certain physical factors were responsible for the disparity. Because of its larger size, *C. virginica* provided the attacking drill more food per kill than *M. lateralis*. Moreover, the greater ease with which the thinner shell of the clam can be penetrated may result in a higher frequency of successful attacks. Regardless of the effect of these factors it seems reasonably certain that *E. caudata* feeds on *M. lateralis* at least as readily as it does on *C. virginica*.

TABLE 2. Average number of *Crassostrea virginica* and *Mulinia lateralis* consumed by *Eupleura caudata* per 10-day trial and the number consumed per drill per trial at a series of controlled water temperatures.[a]

Temperature °C	*C. virginica*		*M. lateralis*	
	Average per trial	Average per drill	Average per trial	Average per drill
22.5	22.20	1.11	30.80	1.54
25.0	30.00	1.50	42.40	2.12
27.5	31.80	1.59	40.80	2.04
30.0	20.80	1.04	21.20	1.06

[a] Twenty *E. caudata* were placed in trays at each temperature with either 60 oyster spat or 70 clams. See text for details.

Relation of cannibalism and mortality to temperature

Cannibalism among *E. caudata* occurred in many of the experimental trays and may have had a significant bearing on the results. The rate of cannibalism, like the rate of feeding, increased with temperature. The incidence of cannibalism was highest at 25.0 and 27.5°C, where maximum feeding on the prey species also occurred. Although cannibalism has been observed previously for *E. caudata* (Flower, 1954; C. L. MacKenzie, personal communication), this was the first instance where cannibalism was observed throughout the drill's thermal feeding range in the presence of alternative food sources. In all observations of active cannibalism, the predators were female drills. Probably the rate of cannibalism in the comparatively high drill population densities in these experiments does not occur frequently in the natural environment; thus, the cannibalism rates observed may be valid only in comparable population densities in nature.

The survival of *E. caudata* also appeared to be temperature-dependent. The range of temperatures studied was not sufficient to establish the thermal limits for drill survival, but the experiments did show that mortalities can occur at temperatures comparable with those occurring in natural waters. Drill mortalities were not appreciable below 20.0°C within the experimental period; the total average mortality ($\bar{x}$ mortality of the five trials) was only 3.0% during the five 10-day experimental periods at 20.0°C. The percentage mortality increased as the temperature increased and reached a peak of approximately 17.0% at 30.0°C. In most experiments cannibalism accounted for a relatively large part of the mortalities (20.0-66.0% of the recorded mortalities), especially at the optimum feeding temperatures, 25.0 and 27.5°C. Unknown causes, however, contributed to the observed mortalities, particularly at 30.0°C. It seems reasonable to conclude, therefore, that natural mortalities probably increase at 30.0°C and above

Substrata used for capsular attachment

MacKenzie (1961), in his study of drills from the York River, Virginia, reported that *E. caudata* showed little preference in substratum for capsular attachment. He stated that the only apparent criteria for these substrata were that they be hard and free of fouling. In the present study the rates of egg-capsule deposition of *E. caudata* confined with two different prey organisms were not significantly different, although the substrata used for capsule attachment were markedly dissimilar. The *E. caudata* confined with *C. virginica* attached capsule clusters, almost exclusively, to the valves of the oyster spat. Drills confined with *M. lateralis*, however, rarely attached capsules to the shell surface; most capsules were attached to the sides and bottom of the tray, or on other drills. The ability of the drills to discriminate between substrata for attachment of egg capsules is worthy of further study.

SUMMARY AND CONCLUSIONS

1. The small number of attacks by *E. caudata* from Long Island Sound on prey organisms at 10.0°C indicates that this temperature is near the lower limit for feeding.

2. Feeding rates increased with each increase in temperature from 10.0-27.5°C, but decreased when the temperature was increased to 30.0°C.

3. Maximum feeding rates on both prey organisms (*C. virginica* and *M. lateralis*) were at 25.0 and 27.5°C.

4. Drills consumed more *M. lateralis* than *C. virginica* at all temperatures. Physical differences between the prey may account for some of this disparity.

5. Drills were cannibalistic in the presence of alternative food sources throughout the range of experimental temperatures. Cannibalism increased as feeding rate increased and was greatest at the optimum feeding temperatures. All cannibalistic drills observed were females.

6. *E. caudata* discriminated between the two prey organisms as substrata for capsular attachment. Ovipositing drills deposited egg capsules readily on the valves of *C. virginica* but only infrequently on the valves of *M. lateralis*.

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CAUSES OF OYSTER SPAT MORTALITY, CONDITIONS OF OYSTER SETTING BEDS, AND RECOMMENDATIONS FOR OYSTER BED MANAGEMENT

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ABSTRACT

As part of a study of mortalities of American oysters, Crassostrea virginica, *I identified the causes of mortality of oyster spat between setting and age of 6 months and compared their relative importance. The causes were complex and varied widely from bed to bed. They were a result of predation by various species, overgrowth by others, mechanical breakage during transplanting, suffocation by silt, early post-setting mortality (cause unknown), and deaths apparently from starvation and, in one location, from poisoning by a bryozoan.*

Two factors prevented much larger sets of oysters on commercial beds: (1) a small supply of clean oyster shells available for commercial oyster companies to plant and (2) layers of fouling organisms and silt that accumulate on shells planted for any length of time.

Between 1966-68, nevertheless, the total quantity of oysters in Connecticut was greatly increased by additional care given to seed oysters. From the mid-1950's through the mid-1960's the quantity had been no more than 35,000 hl (hectoliters) (100,000 bushels). By the spring of 1968 it had increased to about 350,000 hl. The additional care consisted of overcoming, to a large extent, the 3 main causes of mortality of seed oysters, namely, predation by starfish, predation by oyster drills and smothering by silt.

INTRODUCTION

The identification and relative importance of causes of mortality of American oyster spat *Crassostrea virginica*, on commercial beds in Connecticut have received scant attention. Galtsoff and Loosanoff (1939), Engle (1940) and Loosanoff and Engle (1940) made preliminary studies on mortality caused by starfish, *Asterias forbesi*, and oyster drills, *Urosalpinx cinerea*, and Loosanoff and Engle (1941) indicated that overgrowth by other molluscan species may cause mortality.

In other areas it has been reported that crabs destroy oyster spat (Ryder, 1884; Lunz, 1947; McDermott and Flower, 1952; McDermott, 1960) and that silt interferes with either setting or survival of oysters (Lunz, 1955; Engle, 1956; Galtsoff, 1964).

As part of a long-overdue study that was begun in 1966 to determine the causes and patterns of mortalities of oysters throughout their life span on commercial beds, I identified the causes of mortality of oyster spat between setting and 6 months of age and compared their relative importance. The objectives of this study were to identify significant factors which limit production of oysters, find and develop methods to reduce their limiting effects, and help companies incorporate these methods into their system of oyster culture. In this article I list and compare the relative importance of the causes of oyster spat mortality, describe the conditions of oyster setting beds, and recommend methods for reducing mortalities and for preparation of setting beds.

METHODS

I made a number of preliminary observations on mortality of oyster spat in 1966 and 1967 which aided in identifying the causes of mortality and also provided data on causes of mortality that did not occur in 1968. In the laboratory I examined dead spat collected from setting beds and studied the characteristic markings of the valves of oysters killed by various predators. I confirmed them by noting markings made by various predators isolated in aquaria. Extensive, detailed observations were made from late July to mid-October, 1968 (during a period of intense setting), when I examined commercial beds visually twice a week between Norwalk and New Haven. During that time observations of spat mortality were made about once a week, and until January 1969, an overall period of 6 months.

A day of diving consisted of detailed visual inspections of 5 to 10 oyster beds, which ranged from 8 to 40 ha (20 to 100 acres) in size. Visibility of the water ranged from 0.10 to 8 m, average about 2 m (6 feet). Inspections were made by slowly swimming over the bottom, noting: (1) condition of spat, (2) occurrence and behavior of any possible predators and competitors, and (3) degree of siltation. Once every 2 weeks I gently collected about 30 shells randomly from each bed without breaking off the top valves of any dead spat. Later I examined them in the laboratory to determine the number of live and dead spat, the cause of mortality of each dead spat, and the average number of spat killed by each cause for each bed.

The identification of causes of mortality was usually certain. It was determined by knowledge of the condition of a bed when shells were collected, by markings on valves left by predators, by position of spat in relation to competitors or to some physical characteristic, such as under a deposit of silt, and by knowledge of commercial oyster culture operations. In some instances, when the valve markings were common to more than one cause of mortality, a cause could be established by knowledge that only one of them was present on the bed. In a few instances, mortality of spat was apparently due to a specific cause, but the cause could not be definitely established.

CAUSES OF OYSTER SPAT MORTALITY

Mortalities of oyster spat during their first 6 months are nearly always high, and many heavy oyster sets can be reduced by predation or other causes to non-commercial levels during this period. I began observing small spat within 1 or 2 days after they had set to record all possible causes of mortalities. The causes were complex and they varied widely from bed to bed (Table 1). Many years of observation would be necessary to understand them thoroughly, but I believe that this short study has yielded valuable information.

Causes of mortality of oyster spat will be discussed in 2 sections: I. Established causes of mortality in which I shall discuss only those mortalities for which the cause could be definitely established, and II. Apparent causes of mortality

TABLE 1. *Percentages of oyster spat alive and dead from various causes on 4 beds at different dates during 1968-69. Lots 152, 143, and 1-C are in New Haven Harbor and lot 50 is at Norwalk, Connecticut. Characteristics of each mortality are discussed in text.*

	Lot, date, and percentage of oysters alive and dead			
	Lot 152 26 Sept.	Lot 143 27 Sept.	Lot 50 15 Nov.	Lot 1-C 30 Jan.
Live spat	28.0	60.0	86.5	70.8
Established causes of mortality				
Predation by:				
Adult starfish	0.0	17.0	0.5	0.0
Oyster drills	0.2	14.0	13.0	8.3
Overgrowth by:				
Slipper shells	58.0	0.0	0.0	4.1
Calcareous bryozoans	0.1	1.0	0.0	1.2
Other spat	0.2	0.5	0.0	0.0
Suffocation by silt	0.0	0.0	0.0	1.0
Apparent causes of mortality				
Post-setting mortality	6.3	5.0	?	9.0
Predation by mud crabs	7.2	2.5	0.0	5.6

in which I shall discuss mortalities which, at present, could be assigned only to probable causes.

I. Established Causes of Mortality

Predation by starfish

Predation of spat by young-of-year and adult starfish will be considered separately because the 2 groups behave differently and for this reason present different control problems. When spat and older oysters have been killed by either young-of-year or older starfish the valves gape and the top one appears to be filed to a blunt edge for at least a part of its circumference (Mead, 1901). No other predator leaves a similar mark.

Predation by young-of-year starfish. Young-of-year starfish were abundant on planted oyster beds from Norwalk to New Haven in 1966, but scarce in 1967 and 1968. They did not appear to be migratory; they remained on or close to the bed on which they set at least until the following spring.

I learned from laboratory and field studies that young-of-year starfish are very sensitive to light. In running water aquaria in a dark room, young starfish were on top of clusters of oysters, but when the room was lightened they crawled underneath the clusters. On Connecticut oyster beds under 2 to 7 m of water, they were on the bottom of shells and clusters of oysters and thus not visible from a position directly above. In contrast, in the dark turbid waters of Northport Harbor, Long Island, young starfish were on top of such clusters. Divers have not yet examined oyster beds at night to determine whether young starfish are on top of clusters at that time.

In 1966 young-of-year starfish killed significant numbers of oyster spat. For instance, in late November, on lot 152, New Haven, in a section where their uneven density was 50/m², these starfish killed 66% of spat which had once numbered about 40 per shell. I estimated the average mortality of spat over the entire bed at 28%. On lot 13, New Haven, each young starfish consumed an estimated 23 spat on various shells from 27 September to 9 November, a period of 6 weeks.

From 1968 to 1969 young-of-year starfish killed spat during the entire 6 months of this study, but they occurred in small numbers on only a few beds and caused small mortalities (Tables 2 and 3).

Predation by adult starfish. Adult starfish were numerous in all areas between Norwalk and New Haven. They migrate to some extent and appear able to travel several hundred meters within a few weeks.

TABLE 2. *Causes of mortality of oyster spat which set 1 August 1968, on 30 beds during different months. Approximate percentages of beds on which mortality occurred are shown under each month. Dashes indicate no mortality.*

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Established causes of mortality						
Predation by:						
Young-of-year starfish	5	5	5	5	5	5
Adult starfish	a	a	a	a	a	a
Oyster drills	30	30	25	25	—	—
Overgrowth by:						
Slipper shells	20	20	—	—	—	—
Calcareous bryozoans	85	—	—	—	—	—
Barnacles	30	—	—	—	—	—
Other spat	30	30	30	30	—	—
Jingle shells	5	5	—	—	—	—
Mechanical breakage during transplanting	—	—	5	5	5	—
Suffocation by silt	—	70	70	70	—	—
Sinking into soft bottoms	5	5	5	—	—	—
Apparent causes of mortality						
Post-setting mortality	85	—	—	—	—	—
Predation by mud crabs	70	—	—	—	—	—
Starvation	—	15	15	—	—	—
Poisoning by fleshy bryozoans	5	—	—	—	—	—

a Approximately 80% of beds were invaded by random movements of starfish at least once during the 6-month period. Starfish caused most damage to spat along the borders of beds.

TABLE 3. *Approximate percentages of spat dead from various causes, between setting in 1968 and age of 6 months, on 15 commercial beds in Connecticut.*

	Percentage dead	
	Average	Range
Established causes of mortality		
Predation by:		
Young-of-year starfish	1	0 - 5
Adult starfish	25	0 - 90
Oyster drills	5	0 - 25
Overgrowth by:		
Slipper shells	5	0 - 58
Calcareous bryozoans	3	0 - 5
Barnacles	1	0 - 5
Other spat	1	0 - 2.5
Jingle shells	0	0 - 1
Mechanical breakage during transplanting	3	0 - 15
Suffocation by silt	1	0 - 5
Sinking into soft bottoms	1	0 - 1
Apparent causes of mortality		
Post-setting mortality	10	5 - 15
Predation by mud crabs	12	0 - 50
Starvation	8	0 - 50
Poisoning by fleshy bryozoans	1	0 -100

Oyster spat killed by adult starfish have the top valves with the same filed appearance as those killed by young-of-year starfish. Thus, mortality of spat by either of these groups of starfish can be distinguished only if the other group is absent. This was no real problem in my study because young starfish were scarce in 1968.

Oyster companies remove adult starfish from setting and growing beds before they spread shells or seed oysters. Starfish destroyed most spat, however, along the edges of setting beds when they invaded them from adjoining unplanted areas. For instance, they killed 77 and 94% of spat in a 5 to 7 m band along the edges of 2 beds.

Starfish consumed spat during the entire 6 months of this study (Table 2). They killed from 0 to 90%, or an average of about 25% of the spat on various setting beds (Table 3).

Predation by oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*

In 1968 oyster drills were scarce on nearly all planted oyster beds between Norwalk and New Haven. Their densities averaged less than 1/m^2. On a few unplanted beds in Norwalk and New Haven, however, densities were as high as 20/m^2 (MacKenzie, in press). A small round hole through the top valve of a dead spat easily identifies an oyster drill as the predator.

In 1968 those oyster drills present consumed spat from the time of oyster setting until the water temperature fell below 10°C in late November (Table 2). Most planted beds, because of the very low densities of drill populations, showed virtually no mortality of spat by drills, but on one bed it reached about 25% (Table 3).

Overgrowth by slipper shells, *Crepidula plana* and *Crepidula fornicata*

Slipper shells were common on shells, oysters and other surfaces between Norwalk and New Haven. Their numbers varied widely from bed to bed, but lot 152 in New Haven, an excellent bed for collecting oyster sets, also received consistently heavier sets of slipper shells than most other beds. On 26 September 1969, shells which had been spread on this bed in late July had an average of 44 *C. plana* and 8 *C. fornicata* on their inner faces. By October the slipper shells covered three-fourths of these inner faces. Other setting on beds in New Haven Harbor ranged from 5 to 10 per shell; however, slipper shells were even less abundant on beds in Bridgeport.

Larvae of slipper shells and oysters set at about the same time on shells which companies spread on setting beds. Until the age of 2 months, slipper shells grow much faster than oyster spat, and can kill large numbers of spat by overgrowth. For example, on 8 August 1969 the largest slipper shells on lot 152 were 7 to 10 mm (1/4 to 1/3 inch), but the largest spat were only 1.5 mm, although both were about the same age. After about

2 months, growth of slipper shells becomes much slower. Dead spat or their scars (bottom valves) were observed under slipper shells.

Slipper shells killed spat from late July to late September (Table 2). I estimated the number of spat killed by the 2 species of slipper shells on lot 152 by determining the reduction in number of live spat on shells at regular dates. On 15 August the average number of spat per shell (both sides) was 143. Possibly, they had already killed many spat because shells in test setting bags on the bed had accumulated 233 by that time. These test bags with clean shells were placed on the bottom and recovered twice a week; hence, slipper shells did not have time to overgrow and kill spat. By 26 September the number of spat on shells on the bed had decreased to 36, whereas the number on shells in the test bags had accumulated an average of 453 (Table 4). Overgrowth by slipper shells was responsible for about three-fourths, or 80, of the 107 spat killed. Slipper shells killed more spat on the inner face of shells, where they were more abundant, than on the outer face. After 15 August it seemed possible that the large number of attached filter feeders, such as slipper shells, barnacles and spat themselves growing on cultch shells, may have prevented some setting of oyster larvae. Slipper shells did not kill significant numbers of spat on other beds (Table 3). A light set of oyster spat occurred on shells of both *C. plana* and *C. fornicata*, but I did not determine what percentage survived.

Overgrowth by a calcareous bryozoan, *Schizoporella unicornis*

Calcareous bryozoans were extremely common on shells, oysters and other hard surfaces between Norwalk and New Haven. They kill spat by growing either between their 2 open valves or completely over both valves and sealing them. Calcareous bryozoans killed only those spat that were less than a month old (Table 2), or 5 mm long. In 1968 they killed only 0 to 5% of spat (Table 3), and in a group of bagged shells, about 8%.

Overgrowth by barnacles (species not identified)

Barnacles were extremely abundant in New Haven but not as common in other areas. Barnacles kill adjacent spat by pushing up the top valve and growing over the bottom one, as the shell grows in diameter. Barnacles killed only those spat that were less than a month old (Table 2), or about 5 mm long. In 1968 they killed only 0 to 5% of spat (Table 3).

Overgrowth by other spat

Spat may be killed by overgrowth by larger spat especially when more than 25 spat are attached to one side of a shell. I saw dead spat, obviously killed by this cause, under shells of larger spat.

Mortalities from overgrowth of older spat took place mostly during the first 4 months (Table 2). In 1968 such mortalities were only 0 to 2.5% (Table

TABLE 4. *Average numbers of spat per shell on bottom and in test bag, lot 152, New Haven Harbor. Test bag was replaced twice weekly.*

Date (1968)		Setting bed	Test bag (per half-week)	Cumulative total in test bag
July	29	—	5	5
Aug.	1	26	50	55
	5	—	40	95
	8	94	14	109
	12	—	21	130
	15	143	103	233
	19	—	124	357
	22	112	31	388
	26	—	27	415
	29	77	8	423
Sept.	3	—	6	429
	6	44	6	435
	9	—	10	445
	13	—	4	449
	16	—	3	452
	19	—	0	452
	23	—	0	452
	26	36	1	453

3). Overgrowth might have been greater had not spat settled uniformly over a shell, thereby providing space between each spat for growth.

Overgrowth by jingle shells, *Anomia simplex*

During 1966-68 the setting intensity of jingle shells was extremely light, and thus they caused little mortality of oyster spat (Tables 2 and 3). Jingle shells kill spat by overgrowth as do slipper shells. Scars of dead spat were observed under jingle shells. In one instance, 7 dead spat, all less than 5 mm long, were found under a single live jingle.

Mechanical breakage during transplanting

Oyster companies use the same heavy dredge for transplanting spat as employed for harvesting market oysters. Divers observed that this dredge collects only 10 to 20% of spat in its path during a drag and that it is very destructive. Many spat are broken and killed when the dredge passes over them, when they are tumbled about as they are picked up by the dredge, when they are dumped on deck, when they are walked on by deck workers, and when they are tumbled about while being washed overboard and planted on another bed.

Many spat killed during transplanting operations have broken top valves, but in others only the bottom valve remains. The mechanical handling of oysters destroys the markings on valves left by other causes of mortality, and thus I could not distinguish the spat killed by transplanting from those killed by other causes. Instead, I estimated the percentage of spat killed by comparing the number of live spat per shell before and after a transplanting operation.

Transplanting of spat was usually done in October, November or December, when they were 3 to 5 months old and 25 to 35 mm long (Table 2). In one transplanting operation, I determined the percentage of spat killed when they were transplanted during November from lot 804, Bridgeport, to lot 455, New Haven. The spat were 3 months old. In early October before being transplanted 79% of the spat were alive, while in early December, after transplanting, only 67% were still alive. Thus, as many as 15% of the transplanted spat may have been killed by the transplanting (Table 3). Nearly all this mortality seemed to be a result of mechanical breakage because the other causes were virtually absent. In addition to this mortality, counts of the number of live spat per unit area on lot 804 before and after the transplanting showed that about 20% of the spat, most of them attached to small fragments of shells which cannot be harvested by the standard oyster dredge, were left behind. Oyster companies rarely protect spat left behind on a bed after a transplanting operation, thus these spat are frequently lost to predation by starfish or destroyed by storms.

Suffocation as a result of siltation

Silt begins to accumulate on some setting beds after shells are spread. Besides interfering with the setting of oyster larvae, continuing siltation may suffocate spat, especially those at the bottom of a crevice between 2 shells.

Mortalities from suffocation can be identified by a covering of silt over the spat which have black, complete valves. This cause of mortality was distinguished from the post-setting mortality (see *Apparent Causes of Mortality)* if the dead spat had shown signs of growth. Suffocation of spat took place when they were 2 to 4 months old (Table 2). Mortalities of spat from this cause were 2.5 and 5% on 2 beds, but less on most beds (Table 3).

Sinking into soft bottoms

Spat were killed on a few beds when the shells to which they were attached sunk into soft mud. I listed buried spat with complete valves which had grown slightly (to distinguish the cause of death from post-setting mortality) in this category. In 1966 a company planted shells on 3 beds with soft bottoms in Stony Creek, Branford. By 23 September 1966, 17% of the spat were buried on one of these beds. The mortality may eventually have been much greater because the spat were not transplanted and shells may have sunk deeper into the soft bottom. In 1968, however, this cause of mortality was very low because companies planted almost all their shells on beds with hard bottoms (Tables 2 and 3).

II. Apparent Causes of Mortality

Post-setting Mortality

In this type of mortality the spat died within a few days after they had set and before displaying any growth (Table 2). The dead spat or scar which remained could be identified because it displayed no growth and the top valve was always complete. From 5 to 15% of spat on most beds died in this manner (Table 3).

Predation by mud crabs, *Neopanope texana*

Mud crabs are extremely common on most oyster beds. *Neopanope texana* was the only species I recognized, though other species of xanthid crabs probably occur. At first, the identity of mud crabs as the cause of mortality was not certain because they usually leave no characteristic mark. In most instances, I found only a clean scar, but in others, a jagged top valve. After observing in laboratory aquaria that mud crabs do prey on spat, I listed them as the cause of mortality when they were present and when there was no other apparent cause for the mortality.

In laboratory aquaria mud crabs did not kill spat much larger than 10 mm, or after about 1 month of age, when the spat were attached to shells (Table 2). In contrast, they preyed on unattached spat up to about 25 mm long. On most beds mud crabs appeared to kill from 0 to 20% of spat. On lot 827, Fairfield, however, they apparently killed about 50% of the spat (Table 3).

Starvation

In 1968 I observed a mortality of spat apparently due to starvation or, possibly, to disease. This type of mortality occurred only on beds under 10 to 12 m of water in New Haven. About 50% of the spat that survived the early post-setting mortality became gradually pale and after about 2 weeks showed no further growth. The spat became increasingly pale until they died when 1 to 2-1/2 months old (Table 2). The remaining survivors were dark in appearance, however, and they lived and grew, but more slowly than spat on beds under shallow water. Mortalities due to this cause did not occur on any inshore beds; the average mortality from this cause on all beds was about 8% (Table 3).

Poisoning by a fleshly bryozoan, *Bowerbankia* sp.

In Bridgeport, fleshy bryozoans grew abundantly on shells on beds that had lain idle for 10 or more years. The few spat that had set on these shells grew only slightly and eventually all died. The bryozoans did not kill spat by overgrowth, as did calcareous bryozoans; instead, the strong acrid secretions they produce appeared to kill them, although confirmation was not made in the laboratory. The spat died before they were a month old, or 8 mm long (Table 2). The average mortality from this cause on all beds was about 1% (Table 3).

Undetermined causes of mortality

Doubtless, oyster spat are killed by other, still unrecognized causes. In laboratory aquaria rock crabs, *Cancer irroratus*, destroyed spat at least 25 mm long. I did not investigate mortalities of oyster spat by several other possible predators which are common in Connecticut, including: the tautog, *Tautoga onitis;* the summer flounder, *Paralichthys dentatus;* the hermit crabs, *Pagurus pollicaris* or *P. longicarpis*; the young-of-year mud crab; and the spider crab, *Libinia emarginata*. Field studies are needed to determine the importance of these fish and crabs as predators of oyster spat. The blue crab, *Callinectes sapidus*, which preys on spat in other areas, has been scarce in Connecticut in recent years.

CONDITIONS OF OYSTER SETTING BEDS

While studying setting beds in 1968, an excellent year for oyster setting, I observed that only a small percentage of available oyster beds in Connecticut were in condition to receive the many billions of eyed oyster larvae in the water. Clean shells in test bags placed in many areas by the Milford Laboratory staff indicated that thousands of acres of bottom would have received a set of oysters had they been properly prepared. Oyster companies spread clean shells on only a small number of beds with a total area of about 150 to 200 acres, or about 2% of the available seed beds, and they obtained heavy sets of oysters on them. On a smaller number of beds, whose area totaled about 100 acres, companies dredged up and immediately respread old shells, but because these shells were heavily fouled they collected only light sets. The remaining beds which received no preparation collected insignificant sets.

Shells on the unprepared beds were covered with live fouling organisms, consisting mostly of bryozoans and algae, and silt, which prevented oyster larvae from setting. The few shells and stones on the once-famous 1,800 ha public seed bed off Bridgeport and Fairfield which, until 1948, produced large quantities of seed oysters, were completely covered with live fouling organisms. While each clean shell in test bags placed on this bed by the Milford Laboratory staff accumulated an average of 150 spat during the setting season, each shell on the bed accumulated less than 1 spat, an insignificant number.

Deposits of silt on shells decreased the intensity of setting of oyster larvae. For instance, on lot 25M in Milford each clean shell in test bags placed by the Milford Laboratory staff had a cumulative average of about 1,000 spat, but silt-covered shells, that were otherwise virtually clean of fouling organisms, on the bottom collected an average of only 1 spat per shell. On lot 804, Bridgeport, shells at the north end where silting was negligible collected an average of 20 spat per shell, but those at the south end where silting was substantial had an average of only 5 spat.

It had always been difficult to explain the discrepancy between setting of oysters on shells planted by oyster companies and on clean shells in test bags placed in the same areas by the Milford Laboratory staff. Spread shells always had much lower sets than shells in test bags. The observation that spread shells become covered by live organisms and silt explains why they caught fewer spat.

In 1968 I compared the value of the following 3 types of oyster shells as cultch for setting oyster larvae: (1) shells cleaned by storage on land; (2) black shells obtained from muddy bottoms; and (3) shells "reconditioned" by being dredged up and respread immediately. This latter method of preparing shells has been used extensively in recent years by oyster companies, but it is not effec-

tive because it exposes only small clean areas of shells that were against the bottom. I placed bags of these 3 groups of shells together on a number of setting beds and also collected shells that had been spread on the bottom. Shells of the first 2 types were about equal as cultch, collecting from 3-1/2 to 12 times as many spat as the "reconditioned" shells.

RECOMMENDATIONS FOR OYSTER BED MANAGEMENT

Control of mortalities of spat

In 1968 oyster companies controlled several causes of mortality of oyster spat to various degrees. Adult starfish and oyster drills were under reasonably adequate control, but the former still caused significant mortalities. Competitors for space on shells, such as slipper shells, calcareous bryozoans and barnacles, which cause mortalities of oyster spat, were partially controlled by delaying the spreading of dock-stored shells on setting beds until eyed oyster larvae appeared in the water. From 1966 to 1968 the total quantity of oysters in Connecticut was increased at least 10 times because companies gave much more care to seed oysters. By the spring of 1968 the quantity of oysters, which had been no more than 35,000 hl (100,000 bushels) from the mid-1950's through the mid-1960's, increased to about 350,000 hl. The additional care consisted of controlling the 3 main causes of mortality of oyster seed, namely, predation by starfish, predation by oyster drills and smothering by silt in April and May.

Mortalities of spat caused by: (1) competition for space on shells (except by slipper shells); (2) siltation; and (3) poisoning by fleshy bryozoans are not large enough to warrant attempts to control them. Oyster companies reduced mechanical damage of spat during transplanting to some degree by postponing this operation until late fall or the following spring when spat had larger and thicker shells. Nevertheless, mortalities from this cause were still too great. Suffocation after sinking into soft bottoms has been avoided on occasion by early transplanting.

What causes of mortality would be the most profitable to control? At present, the ones that appear to hold the most promise, in order of importance, are predation by (1) adult and (2) young-of-year starfish, (3) mud crabs, (4) mechanical breakage during harvesting, (5) starvation, and (6) overgrowth by slipper shells. Adult starfish can be controlled more effectively by checking oyster beds more frequently to determine their presence and by applying lime without delay. It may be that young-of-year starfish would be controlled most effectively by treatments with lime at night, if they are not protected beneath shells at that time. Mud crabs can be controlled before shells are planted on a bed by use of suction dredges, as recommended by McDermott and Flower (1952).

An improved system for transplanting spat is obviously needed. The present system in which a heavy oyster dredge is towed over the bottom, filled with oysters, pulled to the surface, emptied, and lowered to the bottom, is extremely destructive and inefficient. I estimate that employment of an ideal system, one which would harvest all spat and older seed from the bottom with negligible breakage, would bring an ultimate increase of about 50% in production of market oysters. Such a system would also remove pests from the bottom. The Bailey hydraulic-escalator oyster harvester or the Chesapeake Bay escalator clam harvester used on shallow beds in Canada (Medcof, 1961; Quayle, 1969) might satisfy these requirements, if they were modified to retain small predators and operate on beds under deeper water. The use of either harvester might permit spat to be transplanted earlier in the summer. This would avoid several causes of spat mortality, i.e., predation by starfish in some instances, starvation on beds under deep water, suffocation by sinking into soft bottom and destruction by storms.

Slipper shells can be controlled by treating shells with Polystream [1], as recommended by MacKenzie, Loosanoff and Gnewuch (1961).

Preparation of oyster setting beds

Oyster companies could obtain many times more spat on their setting beds in a number of inexpensive ways: (1) by preparing larger stocks of clean oyster shells; (2) by spreading shells only when and where setting size oyster larvae are present in the water (they would have to take plankton samples to determine this); (3) by spreading shells dredged from under the bottom on setting beds after the supply of clean shells is exhausted; (4) by keeping the setting beds free of silt by using devices such as starfish mops or cutting boards (vanes); and (5) by dipping fouled shells in hot water as they are harvested, making them suitable as cultch for oyster larvae.

CONCLUSION

Apparently, the 2 major limitations to oyster production in Connecticut are: (1) lack of sufficient shells in good condition for setting oyster larvae; and (2) very high mortality of young spat and older seed by various causes. The waters of Connecticut contained enough oyster larvae in the years of 1958, 1959, 1962, 1966 and 1968 (un-

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

published data, Biological Laboratory, Milford, Conn.) to support an annual production of several million bushels of market oysters if enough of the set had been caught and saved.

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ACUTE TEMPERATURE INCREASE AS A STIMULUS TO SETTING IN THE AMERICAN OYSTER, *CRASSOSTREA VIRGINICA* (GMELIN)

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ABSTRACT

Field work in Delaware Bay has indicated that a rapid increase in temperature such as experienced in the intertidal zone might stimulate setting in oysters (Crassostrea virginica). *To test this possibility, "eyed" setting larvae were kept at a constant temperature (approximately 24°C) for 8 hr while experimental cultures were at 24°C for 4 hr, after which the temperature was rapidly increased to 29°C and held for 4 hr. A significant increase in larval setting rate was apparent with the initial temperature rise and persisted for 3 subsequent hours. The very high setting rates experienced when all cultures were initiated indicated that factors other than temperature increase may also stimulate setting.*

INTRODUCTION

Setting of oyster larvae may be affected by many factors including light (Nelson, 1926; Medcof, 1955; Ritchie and Menzel, 1969), type of cultch (Butler, 1955) and possibly waterborne chemicals from previously set oysters (Cole and Knight Jones, 1949; Hidu, 1969).

Thorson (1964) reviewed literature which indicated to him that temperature changes such as those encountered in the intertidal zone might stimulate setting in many marine invertebrates including oysters. Bayne (1969), however, found that temperature changes between 19°C and 23°C had no significant effect on setting of European oyster larvae, *Ostrea edulis*. In Delaware Bay, working with several invertebrate species, Hidu (1967)[2] found that the American oyster, *Crassostrea virginica*, was the only species there having heavy inshore intertidal setting. Moreover, the inshore setting was associated with only a tenth of the larval density observed in offshore setting areas, indicating that stimulatory factors were affecting inshore set. Regularly occurring intertidal temperature increases of 5-6°C over flood tide indicated that temperature increases may be a factor in the stimulation of oyster set at Cape May. These experiments test, under laboratory conditions, the effect of abrupt temperature increases on the setting of the oyster, *C. virginica*.

MATERIALS AND METHODS

The oyster larvae used in this study were reared in the laboratory to the "eyed" stage of development by the techniques described by Loosanoff and Davis (1963). Six experiments tested the effect of an acute temperature increase on setting of oyster larvae. Larvae were kept at 24°C for an initial 4-hour period after which the temperature was rapidly increased 5°C in half of the cultures. New cultch shells were added and removed at hourly intervals throughout the six experiments using three broods of larvae; one for experiment 1, one for experiments 2 and 3, and one for experiments 4, 5 and 6. More specific details and modifications for separate experiments are as follows:

Experiment 1

In preparation for the experiments, the larvae were allowed to stand overnight at approximate-

[1] NSF Undergraduate Research Participant, 1969.

[2] Hidu, H. 1967. Inshore settlement of several marine invertebrates at the Cape May shore of Delaware Bay, New Jersey, with special reference to the American oyster, *Crassostrea virginica* Gmelin. Ph.D. Thesis. Rutgers, The State University, New Brunswick, N. J. 233 p.

ly 24°C in a number of the 15-liter cultures that contained scrubbed and washed oyster shells placed to catch any larvae that were ready to set. In the morning, culture water with algal food was renewed to insure adequate nutrition. A new batch of cleaned shells was added to catch additional set and the larvae were then aliquoted to the test cultures by constant stirring and repeated serial transferral using a 250 ml beaker. Eight 15-liter polyethylene containers were used, four experimental and four control. The total number of larvae in each culture exceeded 10,000. An electric CRC heater, equipped with a Teflon heating coil and stirrer, was then inserted in each of eight cultures. Ten new scrubbed and washed shells of approximately equal size and shape were distributed evenly over the bottom of each container. The stirrers were turned on low speed and the temperature kept at 24°C (± .5°C) in each container for 4 hours. At hourly intervals, the ten shells in each container were removed for counting and were replaced with ten new shells. At the end of the fourth hour, the temperature was raised 5°C to approximately 29°C, shells being replaced hourly. Temperature readings were taken at 15-minute intervals throughout the experiments.

Experiments 2-6

Experiments 2 through 6 were run in a manner similar to experiment 1, with the exception that water baths were used to eliminate direct contact of the larvae with the heaters. Three-liter plastic containers were used in place of the 15-liter ones, and five shells placed in each container instead of ten. Again, each culture held more than 10,000 larvae. All temperature increases were effected within 15 minutes in all experiments.

Spat on all shells were counted under a stereomicroscope to give a total number of spat per hour for both the controls and the experimental oysters in each experiment. Culture containers were scrutinized for set at the end of each experiment to assure that the shell counts were an accurate measure of set per time unit.

Data were analyzed by subjecting the 4-hour initial control period and the later 4-hour experimental period to separate analyses of variance using the split-plot design (Snedecor, 1956). Sources of variability were: "temperature rise" vs. "control" cultures (note that the temperature rise cultures were kept under constant temperature in the first four hours); time (four hourly set measurement periods); and replicate experiments (6). Differences in set in "experimental" vs. "control" cultures were further analysed by calculating the percentage contribution of total set in each within each of the hourly set measurement periods. Since "experimental" and "control" cultures each contained half the larvae, with no experimental effect each should have produced 50% of the set. Calculation of percentage contribution for the six replicate experiments permitted a calculation of confidence limits ± 2.45 $s_{\bar{x}}$ for the percentages.

RESULTS

During the first 4 hours, when all cultures were kept at a uniform 24°C, there were no statistically significant differences in setting rates between the "experimental" vs. the "control" cultures as revealed by the analysis of variance (Table 1).

Setting rates were relatively high in the first hour in all six replications (Fig. 1). Thereafter, setting rates fell off sharply in all cultures until the fourth hour and remained at the relatively low rate until termination of the experiment at 8 hours. The analysis of variance attributed significance to the effect of time in both the 4-hour preliminary measurement period and during the

TABLE 1. *Significance of effect of experimental factors in stimulating oyster set as revealed by the split-plot analysis of variance.*

Source of Variation	df	Mean Square	F
Preliminary Control Period (Hours 1-4)			
Main effects			
Experimental treatment (None)	1	12,065	4.43 N.S.
Replicate experiments	5	435,919	159.97[b]
Main effect error	5	2,725	
Sub-effects			
Time	3	324,679	12.22[b]
Time X experimental treatment	3	6,766	.25 N.S.
Sub-effect error	30	26,562	
Experimental Period (Hours 5-8)			
Main effects			
Temperature rise	1	13,549	20.94[b]
Replicate experiments	5	76,317	117.95[b]
Main effect error	5	647	
Sub effects			
Time	3	12,597	6.11[a]
Time X temperature rise	3	1,467	.71 N.S.
Sub-effect error	30	2,060	

[a] Significant effect to the .05 level.

[b] Significant effect to the .01 level.

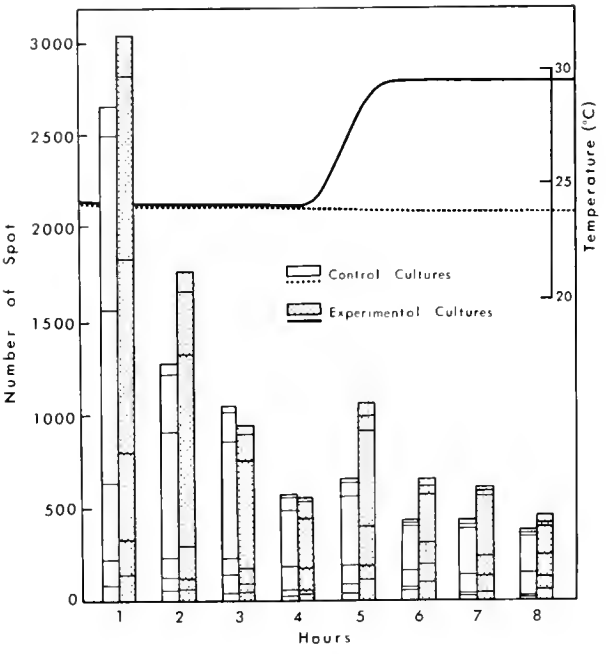

FIG. 1. *The effect of a 5°C temperature increase on setting of* C. virginica. *The total number of spat received in all experiments (6) for control (C) and experimental (E) cultures is shown for each hour.*

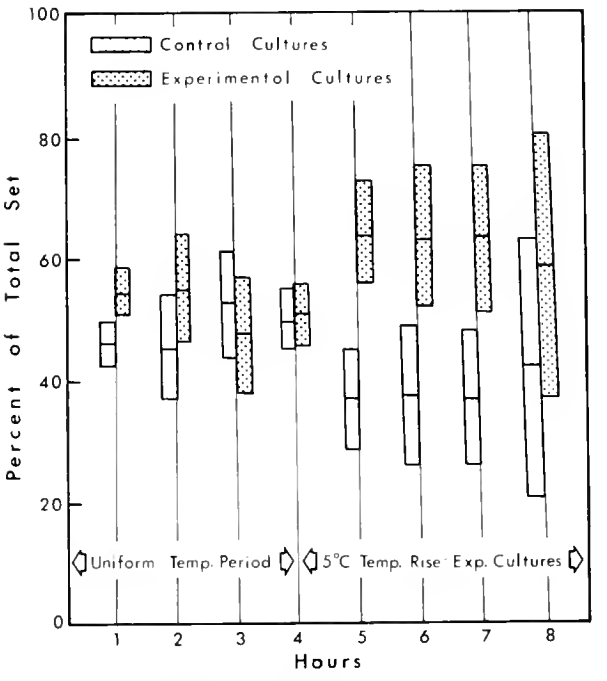

FIG. 2. *Percentage contribution to total set from "experimental" and "control" cultures. Horizontal lines represent mean percentage contribution from 6 replicate experiments while vertical bars show 95% confidence limits (± 2.45 $s_{\bar{x}}$).*

final 4 hours when temperatures were raised (Table 1).

Setting rates were significantly increased (p-0.99) at the fifth hour in cultures receiving the temperature increase (Table 1, Fig. 1). Moreover, the increased rates were apparent for at least 3 hours after the temperature rise. Setting rates in experimental cultures from the fifth to eighth hours were 58%, 39%, 38% and 13% higher than those in control cultures. The increases during hours 5-7 but not hour 8 appeared to be statistically significant as revealed by an analysis of the percentage contribution of total set in experimental and control cultures (Fig. 2).

DISCUSSION

It is apparent that mature oyster larvae may have ability to "delay" setting and metamorphosis, at least up to 7 hours (Hidu, 1969). Thus, it is possible that they may exercise some "choice" of setting substrate in response to environmental stimuli. Abrupt temperature increase was shown here to be a significant factor in stimulating setting. This response, if operative in nature, may have adaptive value for the species since in the southern part of its range (below the Chesapeake) oysters are unusually prominent and successful in the intertidal zone. Here apparently they have advantage by being away from some of their principal predators such as oyster drills. The warmer intertidal waters may thus function to stimulate setting into the favorable intertidal zone.

These laboratory observations on the effects of temperature rise on setting have some support in field observations. The high intertidal setting at Cape May, Delaware Bay, associated with high temperatures has been mentioned previously. Landers (personal communication) has noted that in outdoor hatchery setting tanks the heaviest sets occurred in midmorning hours at the time of increasing water temperature. New Jersey oyster biologists (Haskin, personal communication) have also noticed heavy oyster sets characteristically associated with river mouths on Delaware Bay. They have speculated that these areas may become "larval traps" due to the lowering of salinity. Haskin's laboratory work (1964) indicates a decreased larval swimming activity in response to lowered salinity. It is also possible that oyster larvae in estuarine waters mixing with the warmer river water may be subjected to

rapidly increasing temperatures, which may stimulate setting.

The increasing use of estuaries by the electric power generating industry has created some interesting temperature considerations in the ecology of oysters. On the Patuxent River, Mihursky (1969) noted measurable temperature increases to 5 miles upstream and downstream from the Chalk Point power plant effluent, and pointed out that such changes may have detrimental effects on estuarine biota. It would he interesting to determine whether the warming of great acreages by power plants in some proximity of oyster producing areas may in fact enhance setting in these areas or change setting patterns in more remote established seed bed areas.

Other factors in addition to temperature changes may stimulate setting of oyster larvae. In these experiments, obviously some factor associated with setting up the cultures was effective in stimulating set for the first 2-3 hours of the experiment despite the fact that temperatures were held at a constant 24°C. These factors may include mechanical disturbance, increased O_2 supply and increased food supply. The decreasing set rates with the first 4 hours were not due to a depletion of setting larvae in the cultures since the number that set were only a small percentage of those introduced into the cultures.

In summary, an understanding of the stimuli which may affect oyster setting appears to he important in a full understanding of recruitment of the American oyster in both the laboratory and the natural environment. These experiments indicate that rapidly rising temperatures can be significant. However, additional factors may be equally important, including stimuli from established adult populations to produce the "gregarious setting response" and other environmental factors.

ACKNOWLEDGMENT

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ADVANTAGES OF ELECTRONIC POSITIONING AND PROFILING IN SURVEYING BURIED OYSTER SHELL DEPOSITS [1]

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ABSTRACT

The cost of surveying buried oyster shell deposits was reduced about 90% by using an electronic positioning system and an electronic profiler in conjunction with conventional probing. An Autotape Electronic Positioning System provided accurate positioning under all visibility conditions, which eliminated the need for visual triangulation positioning. Electronic positioning reduced conventional survey costs over 85%. An Elac Echograph bottom profiler was used to detect hard substances such as clay, sand, or shell below mud bottom which eliminated unnecessary probes and further reduced the cost. Cost was reduced by surveying more acres per day with the electronic equipment than was possible with conventional methods.

INTRODUCTION

As a part of a comprehensive survey of the oyster resources and buried oyster shell deposits in Alabama, electronic positioning and profiling equipment were used during part of the study (May, in press). The systems have been used extensively by the junior author in shell surveys in Florida, Alabama and Louisiana. Costs and operations of conventional and electronic surveying were compared. Cross-sectional profiles of shell deposits were compared using an electronic profiler and standard probing.

A standard systematic survey for buried shells consists of traversing the area along a grid pattern and taking probes at predetermined intervals. The location is determined at each station by triangulation from known points using transits or electronic instruments.

Among the disadvantages inherent in conventional methods of surveying for buried shell deposits is the extensive physical examination required in both probing and positioning. Probes and positions must be obtained at each grid intersection irrespective of the presence of shell. If visual positioning is used, operations must be limited to daylight and almost ideal weather conditions.

EQUIPMENT AND METHODS

A self propelled spud barge, 52 by 20 feet, equipped with a 40-foot by 3/4-inch water-jet probe was used to take shell soundings. Probing consisted of stationing the barge by lowering the spuds and measuring the overburden and shell depth by pushing the calibrated water-jet pipe into the bottom.

A DM-40 Autotape Electronic Positioning System [2] was used which provided direct distance readout from two known points. The system operates on 12 vdc and consists of two portable responders which transmit ranges at 1-second intervals, and a 2-range interrogator which displays distances from two known points. The system employs microwaves to establish ranges to fixed or moving vehicles along a radio line of sight. The system automatically measures the slope distance between the two responders and the interrogator

[1] This study was conducted in cooperation with the U. S. Department of the Interior, Bureau of Commercial Fisheries under PL-88-309 (Project No. 2-34-R) and with Radcliff Materials, Inc., Mobile, Alabama.

[2] Use of trade names does not constitute an endorsement.

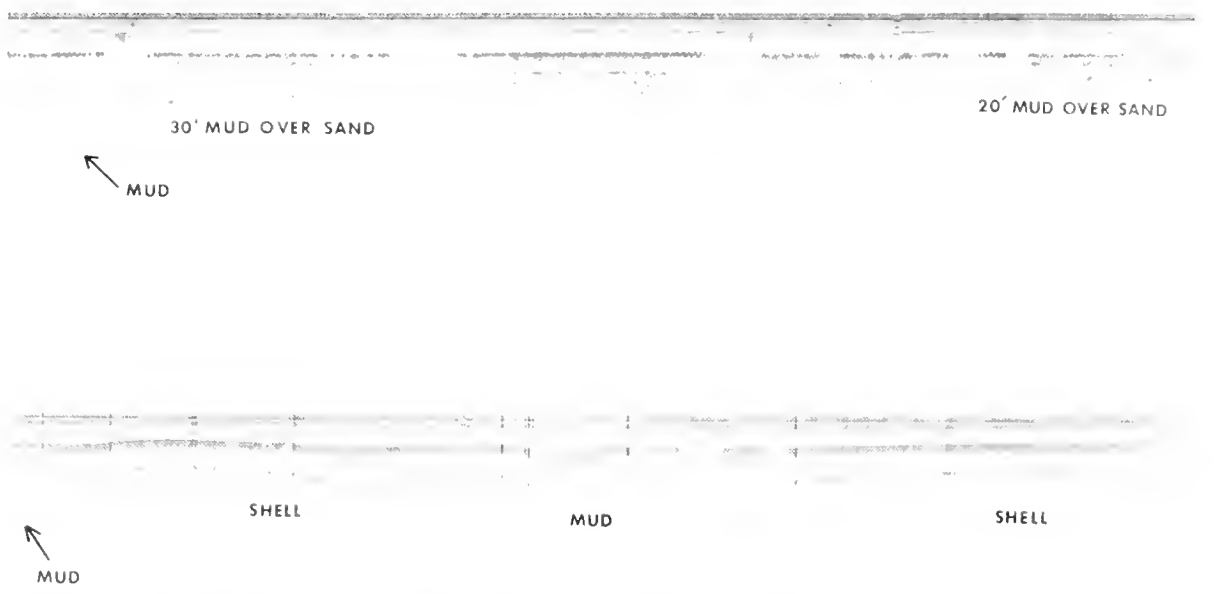

FIG. 1. *Bottom profile chart showing distinction between mud and hard materials below bottom in Bon Secour Bay, Alabama. Shell under the mud appears identical to mud over sand.*

and visually displays those ranges in meters. The manufacturers report the accuracy of the system to be within 1.5 m (4.9 ft) at 50 km (31 miles). Readings are converted to state grid coordinates by computer. The system is simple to operate and includes integral two-way radio communications from interrogator to both responders.

An Elac Echograph LAZ 17[2] bottom profiler adapted for top-strata, shallow water profiling was used to detect hard substances such as clay, sand or shell below mud bottom. The depth of the deposit below bottom was measurable with the profiler although the character had to be determined by probing. When hard material was indicated by the instrument, the depth of overburden was confirmed by measuring with the probe. When the deposit was shell, the thickness was determined with the probe.

VALUE OF THE SYSTEMS

Positioning problems resulting from poor visibility were eliminated by using the electronic positioning system which enabled operation to be conducted 24 hr a day under all visibility conditions. Cost per acre surveyed was reduced 85-91% using electronic positioning by increasing the number of acres surveyed per day 91-95% (Table 1).

Unnecessary probes were eliminated by using the bottom profiler. Deposits of hard materials below bottom such as sand or shell were distinguishable with the profiler (Fig. 1).

A combination of the two systems enables areas to be systematically surveyed by proceeding along arcs at known distances from two fixed points and probing only when hard materials below bottom are shown on the profiler. Cost using the position-

TABLE 1. *Cost and time comparison of conventional and electronic horizontal control under field conditions in Choctawhatchee Bay, Florida and Atchafalaya Bay, Louisiana.*

	Florida (100 M Grid)		Louisiana (200 M Grid)	
	Conventional	Electronic	Conventional	Electronic
Days surveying	22	32	180	51
Acres surveyed	937	25,540	40,748	130,854
Acres/day	43	798	226	2,566
Cost/day	$400 (12 hr)	$700 (24 hr)	$400 (12 hr)	$700 (24 hr)
Cost/acre	$9.39	$0.88	$1.77	$0.27

TABLE 2. *Comparison of cost and time using electronic postioning with physical probing and electronic profiling in Lake Borgne, Louisiana.*

	Positioner and probing (200 M Grid)	Positioner and profiler (200 M Grid)
Days surveying	5	5
Acres surveyed	12,000	21,956
Acres/day	2,420	4,391
Cost/day	$700 (24 hr)	$775 (24 hr)
Cost/acre	$0.29	$0.18

er was reduced an additional 38% by using the profiler (Table 2). The average cost/acre conventionally surveyed (Table 1) was reduced 90% using the two electronic systems together. The cost was reduced because the electronic equipment enabled more acres to be surveyed/day. In Atchafalaya Bay, 226 acres/day were conventionally surveyed. Electronic positioning and profiling were used in Lake Borgne, and 4,391 acres/day were surveyed.

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AN ENGINEERING STUDY OF THE CHESAPEAKE BAY AREA OYSTER INDUSTRY [1, 2]

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ABSTRACT

Information collected from personal interviews with oyster processors, time study work and on-site observations are used to construct an operations-process chart of the Chesapeake Bay area oyster industry. Time study and economic information presented show that an average shucker can shuck about 7.7 oysters per minute. As an annual average a shucker can shuck about 1.7 gallons per hour. Under the assumptions made in this paper, an oyster processing plant could economically invest $33,000 in a machine which could shuck 60 oysters per minute.

INTRODUCTION

The oyster has been used as food by man since before Roman times. Initially the use of oysters was limited, but as population expanded and new areas were discovered men began to realize that oysters are very widely distributed over the world. In fact they have been found to inhabit coastal waters anywhere between latitudes of 64° North to 44° South (Galtsoff, 1964). Today large quantities of oysters are harvested each year. In 1966 the worldwide landings of oysters were 761,000 metric tons (live weight) with the United States accounting for 356,400 metric tons (live weight) of this (Food and Agriculture Organization of the United Nations, 1968). In the same year the Chesapeake Bay area landings were 9,630 metric tons of oyster meats valued at $14,633,000 (Suttor, Corrigan and Wuhrman, 1968).

The Chesapeake Bay oyster industry has not benefited fully from this age of mechanization. The basic methods used in the oyster industry have not changed greatly since Colonial days. For example, the oyster dredge, one of the latest major changes in oyster harvesting techniques, has been in use for over 80 years. Hand shucking, a method used in Roman times, is the dominant shucking method used today. However, economic forces today are rapidly forcing the oyster industry to find new answers to its economic problems. Rapidly rising labor cost, shortage of skilled shuckers and inability of the industry to attract young people are major problems facing the oyster industry today. Mechanization appears to provide the most promising solution to some of the problems.

Engineering work which has been done in the Chesapeake Bay area oyster industry is quite limited. Basic engineering information necessary to any research on mechanization does not appear to be available. In order to develop this information the study described in this paper was conducted. The objective of this study was to develop an engineering analysis of the oyster industry with emphasis on processing.

PROCEDURE

Operational research techniques were used to develop an engineering analysis of the oyster industry. Visits to harvesting, handling and processing facilities provided first hand information for construction of an operations-process chart. Information collected during personal interviews

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[2] Scientific Article Number A1533, Contribution Number 4225, of the Maryland Agricultural Experiment Station, Department of Agricultural Engineering.

with oyster processing plant operators and biologists, time-study work and other economic information were combined with the operations-process chart to identify areas where mechanization would be most beneficial. The first step was to use the data collected to estimate the investment which an oyster processing plant could economically make for various pieces of equipment.

RESULTS

The operations-process chart (Figs. 1 A - 1 H) details all operations which an oyster undergoes from the time of set until the processed meat reaches a retail market. Standard symbols used in industrial engineering were used to develop the chart; circles represent operations done on the product, triangles represent storages, the D-shaped objects represent delays and the arrows indicate transports. Squares are normally used to designate inspections, but in this chart squares are used for various purposes which are evident from the chart.

Harvesting

The first part of the operations-process chart (Figs. 1 A - 1 C) is concerned with the production and movement of the oysters to the processing site. The upper one-half of these figures (shown with solid lines connecting the symbols) represents the present method of growing, harvesting and handling oysters. All growth in this section of the chart is done in natural waters. The chart begins with the fall or set of spat. The second symbol entitled "growth to seed size" denotes a delay (a D-shaped symbol) while the oysters grow to seed size. Following this symbol is a parallel path showing that oysters may be taken up by any one of three methods, i.e., tongs, patent tongs or a dredge. The circles denote that an operation is taking place on the oysters and the triangular symbols indicate that the oysters are stored on a harvesting boat. The arrow symbolizes transportation aboard a harvesting boat to a freight boat or barge. From this point the oysters are planted, allowed to grow to market size, harvested and transported to the processing site.

The lower part of Figures 1 A and 1 B (shown with dotted lines connecting the symbols) shows a possible method of growing oysters in a controlled environment. The spat would be grown without cultch in hatcheries while growth would take place in controlled environment tanks or ponds. The controlled environment tanks and/or ponds would permit food supply (both particle size and amount), water temperature, waste disposal and other factors to be held at optimum growth levels for the oysters. The dotted lines connecting the operations-process chart for the proposed method with the present method indicate points where a transfer could be made from the proposed to the present system. These points of transfer should make the practical transfer from one system to the other easier and more economical. These connecting points would also provide flexibility in the system.

The controlled environment method of growing oysters has many advantages. Some advantages are: (1) eliminate blind hunting for oysters and thereby increase harvesting efficiency, (2) increase growth rate of the oysters, (3) allow top quality oysters to be available all year long as opposed to the seasonal nature of today's methods, (4) allow use of more efficient harvesting and handling techniques, (5) eliminate or minimize the effects of weather on oysters and on the harvesting of oysters, (6) greatly reduce the mortality rate of oysters between egg and harvestable crop, and (7) increase the number and regularity of the supply of oysters.

At the present time economic and some technical problems limit application of the controlled environment method of producing oysters. On the biological side problems include such questions as: What is the most desirable food supply for oysters in every stage of development? What food concentration in the water is best for oyster growth? How much water must be supplied to the oysters and what are the filtering requirements to remove toxic materials from the water?

On the engineering side of the controlled environment problem are such questions as: What population densities can be tolerated? What water velocities are most desirable? What are the cheapest nontoxic materials to use for growing chambers? How can the water be filtered for closed loop operation or how can undesirable elements of natural waters be removed for a flow-through system using natural waters? How can oysters be handled mechanically or automatically? What equipment must be developed to make closed loop systems economically feasible? These and other questions must be answered before oysters can be economically produced in a controlled environment. Mechanization will be required to make the controlled environment system economical.

Processing

The point where processing of the oysters starts is shown in Figure 1 C. The points A, B, C and D appearing near the center of Figure 1 C mark, respectively, the beginning of the four widely used processing methods for oysters. Point A is the beginning of the traditional method of producing raw shucked oysters for market. The beginning of the hot-dip method for producing raw shucked oysters is indicated by point B. Steamed oysters

(cooked oysters) for soup and other uses are produced by the process beginning at point C, while point D is the origin of the process by which shell stock reaches the retail market. Almost all of the east coast oysters reach the retail market by one of these four paths.

Traditional method: In the traditional method a shucker picks up one oyster at a time from a pile on a table in front of him, inserts a knife or other instrument into the interior of the oyster, cuts the connection between the adductor muscle and each half of the shell, and removes the body of the oyster. Upon removal from the shell the meat is visually inspected by the shucker and graded into three or occasionally four sizes. When a shucker fills a shucking pail he carries it to the weighing station where it is drained and weighed. Since the shuckers are paid on a piece rate, a tally sheet is kept for each shucker.

After weighing the oysters are transferred to blowing tanks. These tanks, 30-50 gal in size, usually have fresh water and compressed air flowing into them continuously. The compressed air is pumped into the bottom of the blowing tanks and provides agitation and improved cleaning of the oysters. The oysters are normally left in blowing tanks until the water clears, a maximum contact time with fresh water of 30 min is allowed by the health regulations (U.S. Food and Drug Administration, 1969), indicating the dirt and shell fragments have been removed from the oysters. The volume of water entering the tank influences the amount of time necessary for clearing the tank and hence, the amount of time the oysters are in the blowing tank. Since the water in the blowing tanks is fresh, there is an osmotic exchange between water in the tank and the salt water in the oyster's body. The longer the oysters remain in the blowing tanks the more water they absorb and the greater their weight and volume. However, salt and flavor are lost in proportion to the length of time the oysters remain in the blowing tanks. Management must decide how much flavor to sacrifice to increase body weight of the oysters.

After removal from the blowing tanks the oysters are drained and packed by hand, usually into tin cans. Most of the oysters are sold as a refrigerated fresh product. However, the 10 day shelf life of the fresh product has increased the attractiveness of freezing which greatly extends shelf life. Frozen and breaded oyster meats account for a relatively small but increasing portion of the total market. For example, breaded oyster meats produced in the Chesapeake Bay area have had an annual value of about $750,000 (Suttor *et al.*, 1968).

Hot-dip method: The second method of producing fresh raw oysters is called the hot-dip method. The diagram of the process begins at point B in Figure 1C. The essential difference between this process and the traditional process is the hot water dip. Before the oysters are shucked they are placed in 1/2 bu wire baskets, washed with a water spray from a hose and placed in a tank of water heated to 145 to 150°F (U.S. Public Health Service, 1965). The time the oysters are in the hot-dip tank cannot legally exceed 3 min. The hot water makes the oysters gape or at least relax somewhat so it is easier to get a knife into the shell. After removal from the hot-dip tanks the oysters are placed on shucking tables, and from this point onward are treated the same as in the traditional method.

Good management becomes very important when a processing plant is using the hot-dip method. If the oysters are left in the hot water too long, they tend to acquire a cooked flavor which is very undesirable since these oysters are being sold as a raw product. Sanitation becomes more of a problem with the hot-dip tanks, because the meat and the outside of the oyster shells are both in contact with the same water. Frequent changes of water in the hot-dip tanks help but requires more fuel for heating the water. Cooling the oyster meats to below 40°F immediately after shucking is very important with the hot-dip process. This may be accomplished by placing ice in the bottom of the shucking container and by shucking directly into small (2 quart) containers.

Steaming method: The start of the operations-process chart describing the steaming method of shucking oysters is indicated by point C in Figure 1 C. This method produces cooked oysters and is the only shucking method which is presently mechanized. Cooked oysters are used mainly to make soup and oyster stew so nearly all the output of the steaming plants goes to companies which make oyster soup or stew. The key to mechanization of the steaming process is the tumblers. These are large rotating cylinders ranging from 4-8 ft in diameter and from 4-12 ft long with a sloping axis. The slope causes the oysters to move continuously through the tumbler as it rotates.

As the oysters enter the steaming plant they are conveyed to a tumbler and tumbled under a water spray. From the first tumble wash they are conveyed to a second tumbler for a second wash. A conveyor takes the oysters from the second wash to batch-type retorts where the oysters are steamed at 250°F for about 3 min. This heating cooks the oysters and releases or weakens the attachments between the shell and the adductor muscle. Juices removed from the oysters during steaming are collected from the retort and packed. Later this juice is added to the stew or soup as a flavor-

ing ingredient. Since the volume of the oyster meat is reduced from 40-60% in the retort, these juices are of great importance and constitute a significant proportion of the total volume of the steamed oysters.

From the retort the oysters are conveyed to a large tumbler with perforated cylindrical walls. Tumbling action in this tumbler shakes the oyster meats out of their shells. Perforations in the tumbler wall act as a separating mechanism since they are large enough to allow the meats to pass through but retain the shells and force them to pass out the end of the tumbler to be discarded. Final separation of the meats and shell fragments is accomplished by a brine tank located directly below the separating tumbler. The brine, containing 80-90 ppt of sodium chloride, is dense enough to float the oyster meats but not the shell fragments. Some osmotic exchange undoubtedly takes place between the brine and the oyster meats, but since the oysters are cooked and the exposure time of the oysters to the brine is short, this has not presented a flavor problem.

Final preparation of steamed oysters requires cleaning and packing. Cleaning begins by placing the oysters in blowing tanks to remove dirt and embedded shell fragments. This is followed by a final tumble wash. From the tumble wash the oysters are conveyed in front of inspectors who remove damaged or diseased meats. Following inspection the oysters are packaged usually in one or five gallon containers.

Shell stock method: The fourth method of processing, the shell stock trade, produces raw oysters for the half-shell trade. These oysters must be well shaped and possess high quality meats. The processor receives a much higher price for half-shell oysters than for shucked oysters, sometimes as high as four or five times as much. The operations-process chart for processing the half-shell oysters begins at point D in Figure 1 C. This is the simplest of the four processing methods and consists of washing, sorting and packing the oysters in barrels.

DISCUSSION OF TIME STUDY

Two things are emphasized by the operations-process chart shown in Figure 1. First, the large number of times an oyster is handled between the time the spat set and the oyster reaches market. Second, the great amount of hand labor involved in harvesting, processing and marketing oysters.

A third point which occurs but is not evident from the operations-process chart is the skill which is required for a person to be a productive oyster shucker. Even the most adept people take at least two years of practice before they can rapidly shuck oysters. After about two to six weeks of practice most people can learn to shuck oysters without cutting the meats and at a pace of about 1 gal/hr. Since the shuckers are paid $1.60 to $1.75/gal for shucking, a 1/gal/hr shucker is not an economic liability to the plant operator, but below the 1/gal/hr level a shucker is a liability to the processing plant due to minimum wage laws. Unfortunately, shucking oysters is a dirty, smelly, laborious and often dangerous job which few people are willing to do for $1.60 to $2.00/hr. The supply of skilled shuckers is critically low and getting worse. For example, in Maryland the average age of the shuckers has been estimated at over 50 years old (Sieling, personal communication). Since between 60 and 90%, depending on the shucking plant, of the labor in the oyster processing plants using the traditional method is expended on shucking, the shucker-shortage is a critical problem.

The problem of the oyster industry today is familiar to anyone who has worked in agriculture. The rapidly rising labor costs, the shortage of labor and the onerous requirements for hand labor which characterize the oyster industry today are the identifying marks of an industry in need of mechanization. The problem of the oyster industry is not whether to mechanize or not, but rather what process to mechanize first.

Labor demand and labor shortage are greatest in the shucking process. However, mechanization of other areas in the processing plant would be helpful and could be done at much less expense and effort. Materials handling and storage techniques definitely could be greatly improved by use of fairly low cost equipment and/or "relative minor changes". However, if the economic conditions faced by the processors are considered, one must justify any equipment expenditures in an oyster processing plant on the basis of expected recovery of costs in three years or less. The reasons for this are very basic. About 90% of the physical facilities now used for processing oysters in Maryland are outdated and very unsatisfactory for mechanized equipment. The present rate of decrease in the number of shuckers available for hire indicates that many processing plants in operation today will be out of business in three to five years because they will not be able to hire shuckers. The outdated facilities and lack of shuckers make a plant owner very hesitant to invest money in his present operation, except for a shucking machine, unless he can get his money back in three years or less. Thus, without a shucking machine mechanization will be very slow in coming to the oyster industry.

Mechanization of any industry must be at a cost which the industry can afford. The small size of the oyster processing plants and the variation in

TABLE 1. *Time study data for shucking oysters by hand* [g].

Speed of shuckers [a]	Reaching and grasping [b] (sec)	Inserting knife [c] (sec)	Cutting lower muscle [d] (sec)	Cutting upper muscle [e] (sec)	Total shucking process [f] (sec)
Average shuckers	1.0	2.4	1.5	1.2	5.9
	0.7	1.4	1.8	1.5	6.0
	1.0	1.0	1.5	1.4	5.7
	0.8	1.7	1.3	—	—
	0.9	1.6	1.0	1.6	6.5
	1.0	1.9	2.5	1.9	6.6
	0.8	1.3	1.7	1.3	5.2
	0.7	1.4	2.3	1.9	7.4
	1.2	1.6	2.5	1.7	7.4
Average of all of above	0.9	1.6	1.8	1.6	6.3
Learning shucker	1.0	1.5	2.2	1.7	8.1
Fastest shucker	—	—	—	—	4.2

[a] The "speed of the shucker" was the plant management's classification. An average shucker was a person who shucked at a rate about average for the plant. The learning shucker was one who was just learning how to shuck, and the fastest shucker was the fastest shucker in the house.

[b] "Reaching and grasping" included the time spent reaching for an oyster, grasping it and returning it to the shucking block. Orienting the oyster also was included in this period.

[c] "Inserting the knife" was the period starting when the knife approached the oyster until the knife was between the shells to the necessary depth.

[d] "Cutting the lower muscle" (i.e., muscle attachment of cupped half of shell) began when the oyster was picked up after inserting the knife and ended when the lower muscle was detached, the lower half shell discarded and the oyster turned over so that the flat shell rested in the shucker's hand with the meat facing upward.

[e] "Cutting the upper muscle" began where "cutting the lower muscle" stopped and ended when the meat was placed in the shucking can.

[f] "Total shucking process" started when shucker began reaching for one oyster and ended when the shucker began reaching for the next oyster.

[g] All values shown, except those shown horizontally across from the entry entitled "average of all of above", were averaged over ten observations. The horizontal entry entitled "average of all of above" is the average of all preceding values in the respective column.

their operations made it necessary to conduct some time study work to supplement the operations-process chart. The time study data collected on oyster shucking together with the operations-process chart were used to make an estimate of the initial price which a processor could afford to pay for a machine to shuck oysters.

Time study data taken on the shucking process are shown in Table 1. Data in the bottom three horizontal rows of the table which give a comparison between an average shucker, a person learning to shuck (this person had been shucking nearly five months when the data were taken) and the fastest shucker in one house are of particular interest. The data for the learning shucker and for the fastest shucker in Table 1 are averages of ten observations on one shucker only. Thus, data in these horizontal rows are of limited value and are presented only to give a rough indication of the range of shucking speeds.

Table 2 gives the summary of the time study and necessary time allowances for delays, personal time and fatigue. Since an average shucker can shuck one oyster in 7.8 sec he should be able to shuck 7.7 oysters min. Assuming this rate, the productivity of an average shucker shucking only one grade of oysters at a rate of $1.60/gal is presented in Table 3.

TABLE 2. *Summary of time study.*

	sec/oyster
Shucking time per oyster	6.3
Unavoidable delays [a] (approximately 5 min/hr)	0.6
Personal and fatigue time (15% of shucking time) [b]	0.9
Total	7.8

[a] Unavoidable delay time includes time required to place oysters on the shucking table and time shucker spends carrying his shucked oysters to the weighing station.

[b] Results of survey of 42 industrial plants (Niebel, 1962). Smallest average total allowance was 10% of working time. Highest allowance time was 35% and the average was 17.7% of the working time.

The information developed above and the numbered assumptions stated below make it possible to estimate the price an oyster processing business could afford to pay for a machine to shuck oysters. The assumptions which must be made are:

1. The hand shuckers and any shucking machine developed would work 6 hr/day, 4 days/week, 30 weeks/year for a total of 720 hr/year. (This is based on present operating procedure in the industry).
2. Shuckers are paid $1.60/gal for shucking oysters.
3. Any machine developed would shuck about 60 oysters/min (i.e., the same as 7-1/2 hand shuckers).
4. Quality of hand and machine shucked oysters would be similar.

Using the data from Table 3 an average number can be determined for the gal/hr an average shucker can shuck. Since a shucker will shuck more standards and selects than extra selects or counts during a season, standards and selects must be weighed more heavily than the other grades when calculating an average rate of shucking. If it is assumed that 50% of the oysters shucked are standards, 40% are selects, 5% are extra selects and 5% counts [3], the calculated average shucking rate is 1.7 gal/hr as shown below:

$$\text{Average shucking rate} = \sum_{1}^{4} [(\% \text{ of each grade}) (\text{gal/hr/shucker for respective grade})]$$

$$\text{Average shucking rate} = (.50)\ (1.16) + (.40)\ (2.05) + (.05)\ (2.49) + (.05)\ (3.30)$$

$$\text{Average shucking rate} = 1.7 \text{ gal/hr/shucker}$$

A shucker producing 1.7 gal/hr of shucked oysters will earn $2.72/hr. On the basis of the assumed 720 hr of work per year, the shucker's yearly wages would be $1958.40. The 7-1/2 shuckers, which could shuck the same amount as the assumed machine, would have a yearly wage of $14,688 and produce 9,180 gallons of shucked oysters.

Assuming fixed costs (i.e., depreciation, taxes, insurance, etc.) at 1/3 of the initial cost, a five year life and an operating cost of $5.00/hr, an oyster processing plant could hold expenses at the current level if the initial cost of a shucking

[3] These percentages are averages of estimates given by Mr. Fred Sieling, Chief of Natural Resources Management, Maryland Department of Chesapeake Bay Affairs, Annapolis, Maryland, Mr. Frank McGinnis of Virginia Seafoods, Inc., Irvington, Virginia and Mr. Woodfield of Woodfield Oyster Company, Galesville, Maryland.

TABLE 3. *Productivity of an average oyster shucker.*

Oyster grade	Oyster/gal [a] (averages)	Gal/hr per shucker	Shucker's hourly wage
All standard	400	1.16	$1.86
All selects	225	2.05	3.28
All extra selects	185	2.49	3.98
All counts	140	3.30	5.28

[a] Average number taken from Code of Federal Regulations, 1969.

machine with a capability of 60 oysters/min did not exceed $33,000. If operating costs exceed $5.00/hr of operation, the initial cost of the shucking machine would have to be lower than $33,000. If the operating costs were less than $5.00/hr, the oyster processing plant may be able to invest more for a shucking machine.

SUMMARY

Rising labor costs, shortage of skilled shuckers and onerous labor requirements make it necessary for the oyster industry to consider mechanization for lowering costs and solving labor shortage problems. Since very little operations research has been done in the oyster industry, a study was conducted to identify operations that might be mechanized. Information collected from literature review, oyster processing plant visits, time study data and personal contacts with oyster processors and biologists were used to construct an operations-process chart of the oyster industry and to identify several processes where mechanization is needed. Since shucking is a major problem, data necessary for estimating the initial cost a processor could afford to pay for a shucking machine were assembled. Under the assumptions made in this paper, an oyster processing plant could afford to pay about $33,000 for a shucking machine capable of shucking 60 oysters/min.

ACKNOWLEDGMENTS

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The author is indebted to Dr. R. L. Green, Head of the Agricultural Engineering Department, University of Maryland and to the Maryland Agricultural Experiment Station for the use of their facilities and for continued support and assistance.

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FIGS. 1A-1H. *Operations process chart for the oyster industry.*

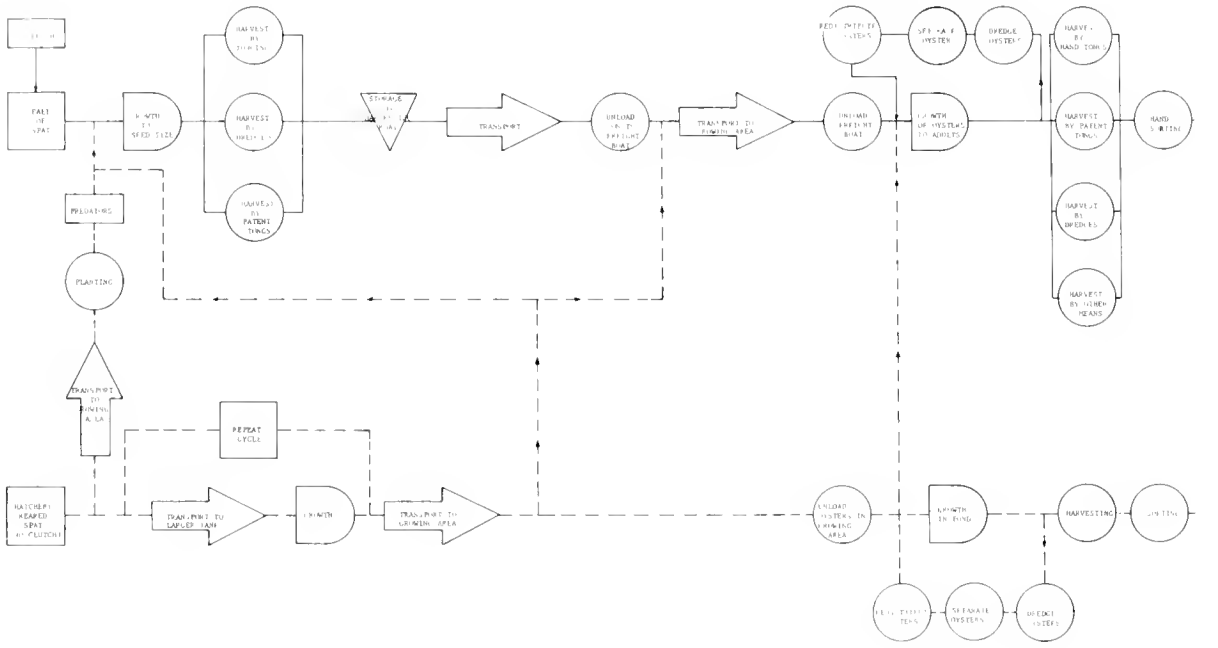

FIG. 1A

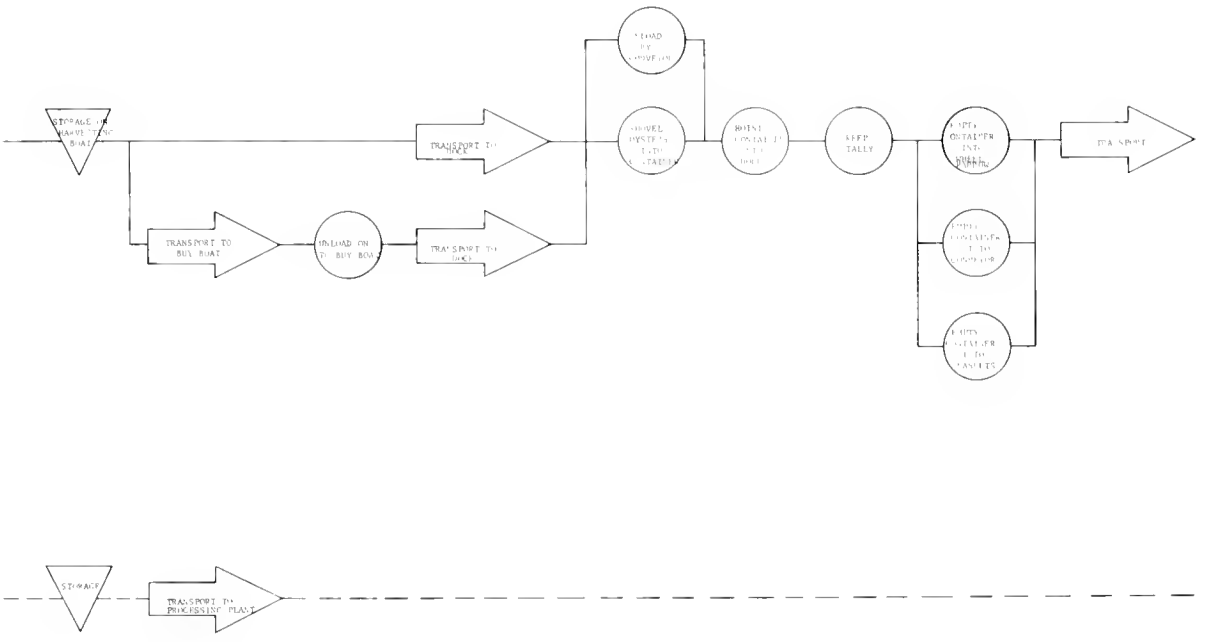

FIG. 1B

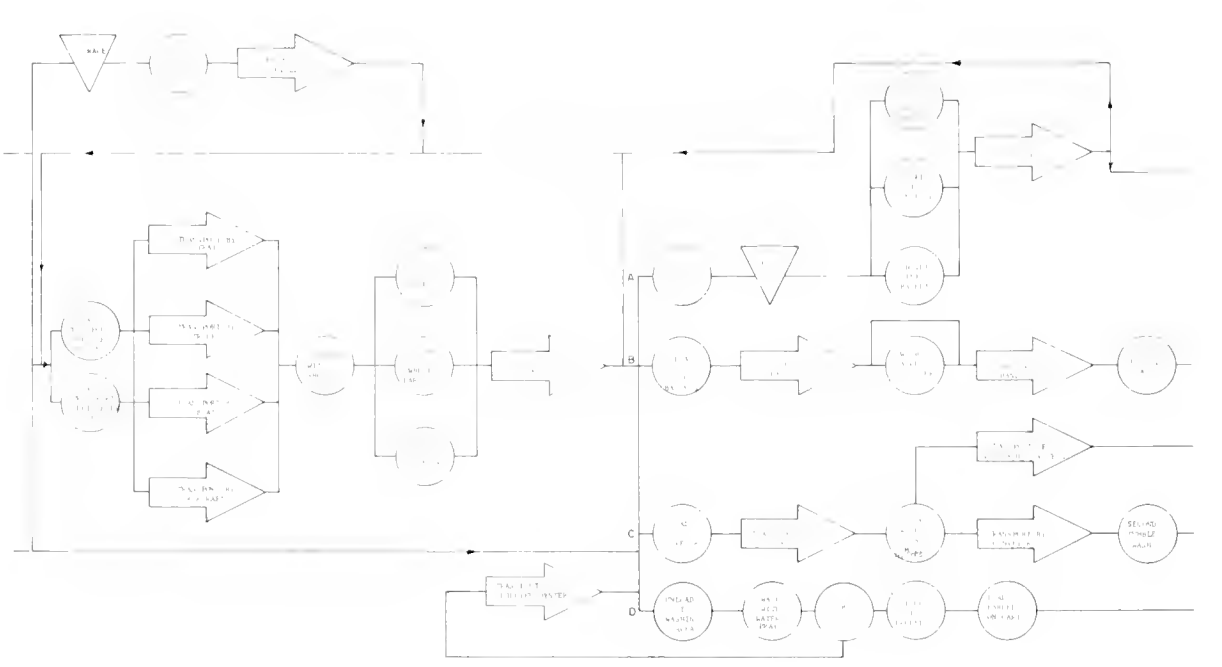

FIG. 1C

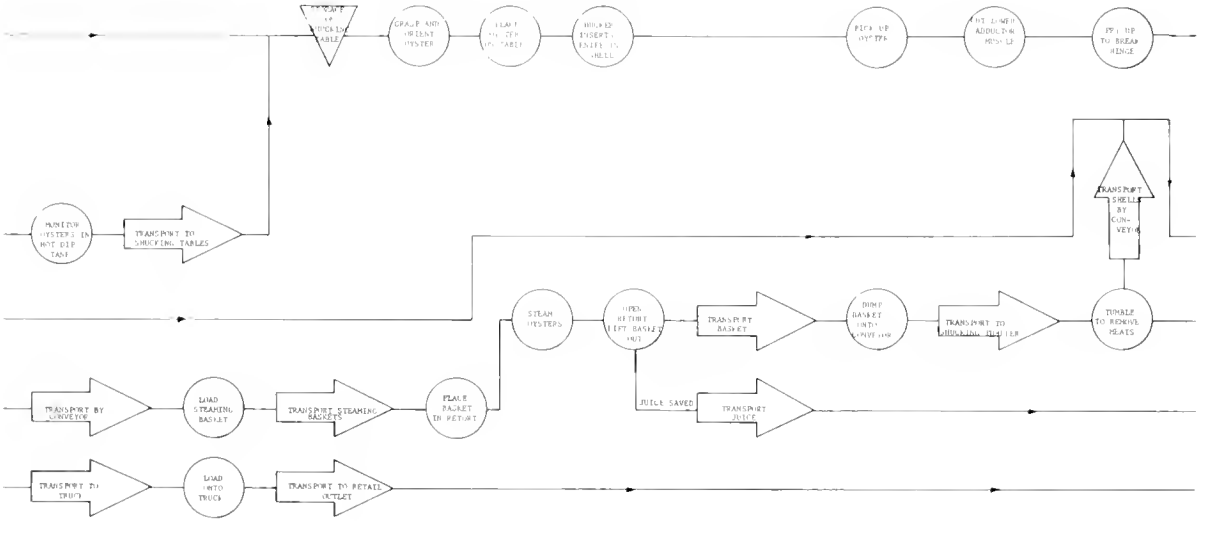
TRANSPORT TO SHUCKING TABLES
STEAM OYSTERS
TRANSPORT BASKET
TRANSPORT SHELLS BY CONVEYOR
TUMBLE TO REMOVE MEATS
TRANSPORT BY CONVEYOR
LOAD STEAMING BASKET
TRANSPORT STEAMING BASKETS
PLACE BASKET IN RETORT
JUICE SAVED
TRANSPORT JUICE
TRANSPORT TO TRUCK
LOAD INTO TRUCK
TRANSPORT TO RETAIL OUTLET

FIG. 1D

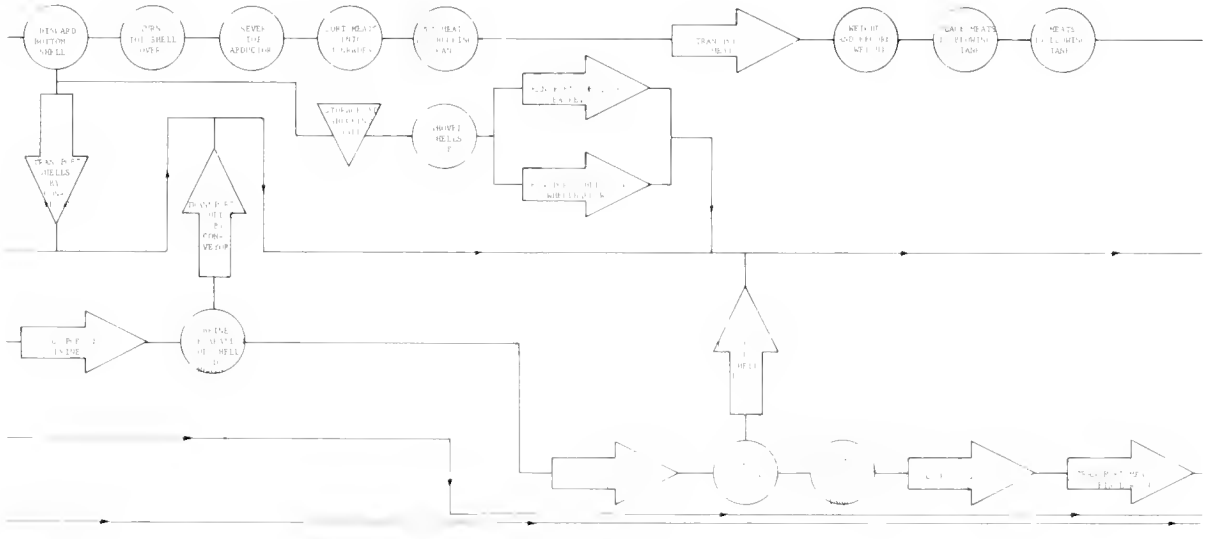

FIG. 1E

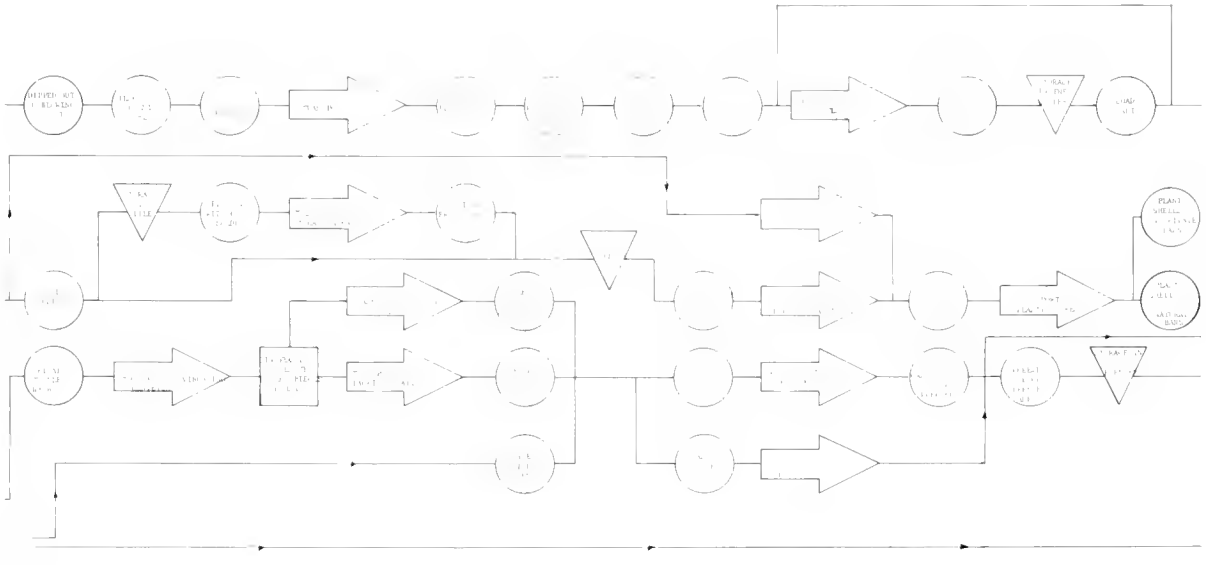

FIG. 1F

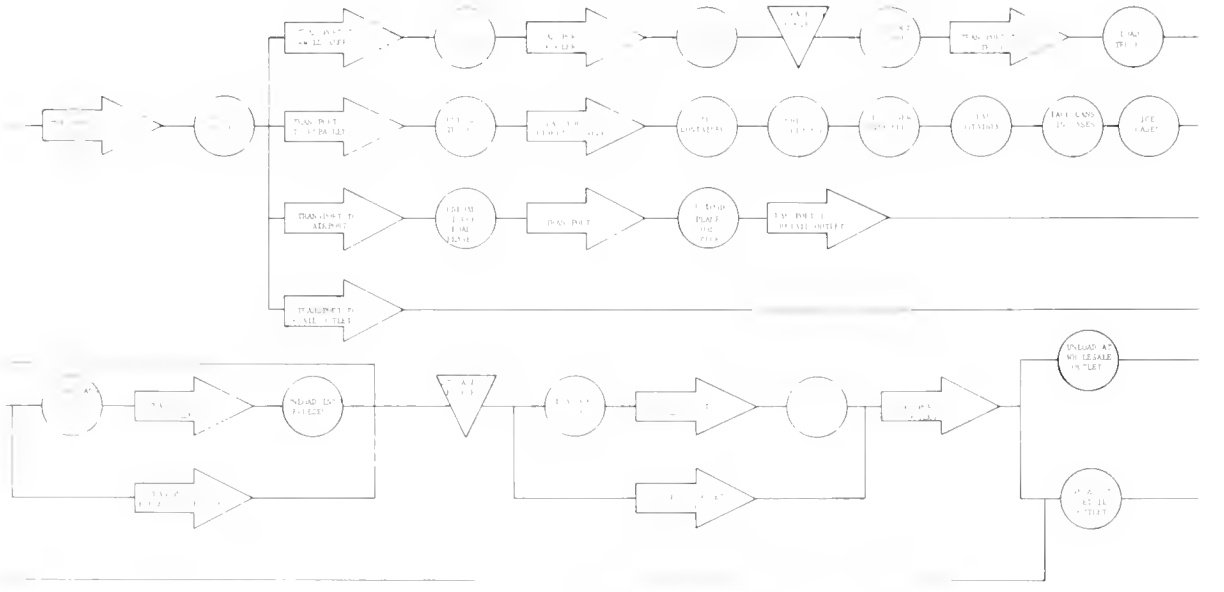

FIG. 1G

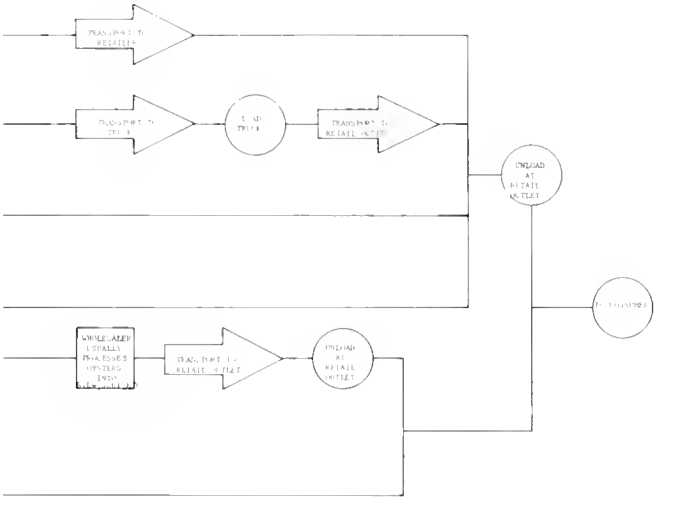

FIG. 1H

Proceedings of the National Shellfisheries Association
Volume 60 — June 1970

LARVAL DEVELOPMENT OF THE HOOKED MUSSEL, *BRACHIDONTES RECURVUS* RAFINESQUE (BIVALVIA: MYTILIDAE) INCLUDING A LITERATURE REVIEW OF LARVAL CHARACTERISTICS OF THE MYTILIDAE [1]

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ABSTRACT

Brachidontes recurvus *larvae were reared from eggs in the laboratory. Larval length increased from 90-220 μ during shelled stages with straight-hinge stage from 90-165 μ, umbo stage from 135-220 μ, and pediveliger stage from 165-220 μ. Height was 23 ± 10 μ less than length. Depth was 54 ± 15 μ less than length. The hinge line increased with growth and ranged from 68-84 μ. Hinge structure consisted of small taxodont hinge teeth over the entire hinge line with teeth becoming larger at both ends. Larvae are typical D-shaped mytilid larvae during straight-hinge stages but develop a conspicuous, broadly rounded umbo and steeply sloping shoulders. Ends are blunt and the ventral margin flattened. The eyespot appears at a length of about 165 μ.*

Larvae are more likely to be confused with larvae of Modiolus demissus *than those of other bivalves.*

INTRODUCTION

Brachidontes recurvus, the hooked mussel, reportedly occurs from Cape Cod to the West Indies (Abbott, 1954). Truly indigenous populations are likely to have a much more limited distribution. Hooked mussels north of New Jersey probably were imported with commercial shipments of oysters and do not represent permanent populations.

B. recurvus is the most common subtidal mussel in the brackish waters of Chesapeake Bay, sometimes so abundant it becomes a serious fouling problem on oyster beds. Because of this, the hooked mussel has been the subject of more studies than most bivalves that are not commercially harvested (Chanley, 1958; Allen, 1960; Nagabhushanam, 1965).

In upper Chesapeake Bay *B. recurvus* spawns from June until November with peaks of spawning activity in June, late July and in November (Allen, 1962). Larvae taken in plankton samples by Allen were classified as "pre-hinge" and "post-hinge." No more detailed description of larval *B. recurvus* has been found in the literature.

The purpose of this report is to describe the larval development of the hooked mussel and to compare its larvae to those of other mytilids by means of a comprehensive literature review of larval development in the Mytilidae.

MATERIALS AND METHODS

Mussels from Horsehead Shoals in the James River were kept in the laboratory in heated, running sea water at 23-25°C from mid-March until 2 May at a salinity of about 20 ppt. Several mussels spawned in less than an hour when placed in Pyrex baking dishes containing filtered sea water fluctuating between 20 and 32°C. Previous attempts to spawn *B. recurvus* by rapidly fluctuating water temperature, adding stripped gametes to the water and stretching or injuring adductor muscles were unsuccessful though the mussels were apparently sexually mature.

Fertilized eggs were first poured through a stainless steel screen to remove debris, and

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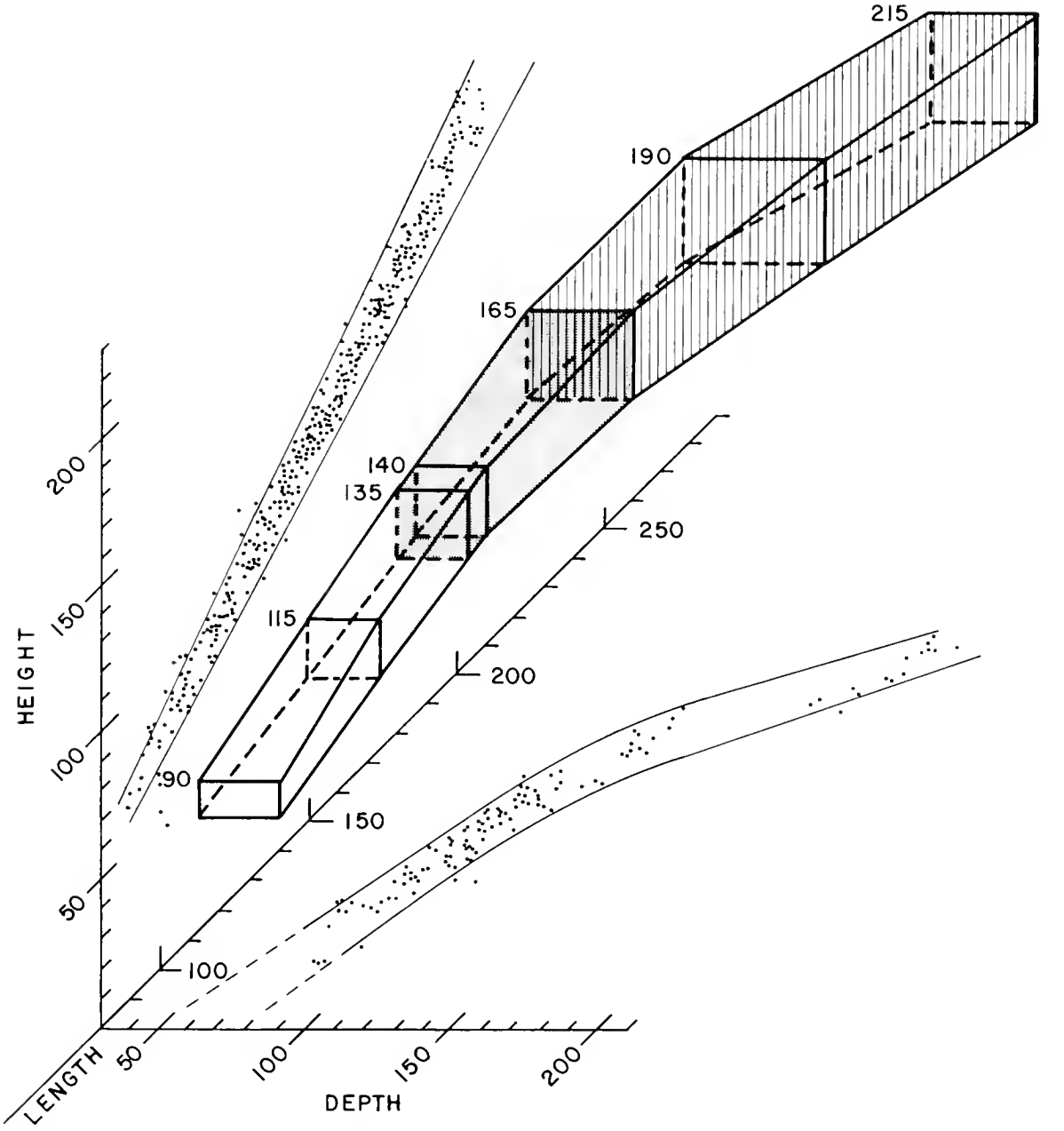

FIG. 1. *Larval dimensions of* Brachidontes recurvus. *Height and depth coordinates run parallel to the length axis. Dots represent observed length-height, or length-depth measurements. Lines enclosing the dots were fitted by eye and represent probable maximum and minimum dimensions. The 3-dimensional figure encompasses all possible length-depth-height combinations of* B. recurvus *larvae (Chanley and Van Engel, 1969). The clear area represents straight hinge stages, the lined area, umbo stages and the darkest area, intermediate stages.*

then cultured at concentrations of about 30/cc in polyethylene garbage pails containing filtered sea water. Larval concentrations were adjusted to 15/cc after two days. Three times a week water was changed by siphoning it through a stainless steel screen of appropriate mesh size to collect the larvae. Larvae were maintained at about 25°C in water of 18-22 ppt and were fed daily at the rate of one liter of a unialgal culture of *Mocochrysis lutheri* for each 70 liters of larval culture. Periodically larvae were examined microscopically and preserved in Carriker's (1950) fixative. A minimum of 10 were measured at each 5 μ length interval. Measurements, using a filar micrometer, were made of hinge-line length, total length, height and depth.

In this report dimensions are given in microns: L = length, the maximum anterior-posterior dimension; H = height, the maximum dorsal-ventral dimension, and D = depth, the maximum left-right dimension. Descriptive terminology is that used by Chanley and Andrews (in press).

RESULTS

Spawned eggs of *B. recurvus* were greenish tan to brown. They ranged from 62-68 μ and averaged 65 μ in diameter.

Larval dimensions (Fig. 1)

Straight-hinge stage: L = 90-165 μ; H = 60-150 μ; D = 67-115 μ, generally increasing more slowly

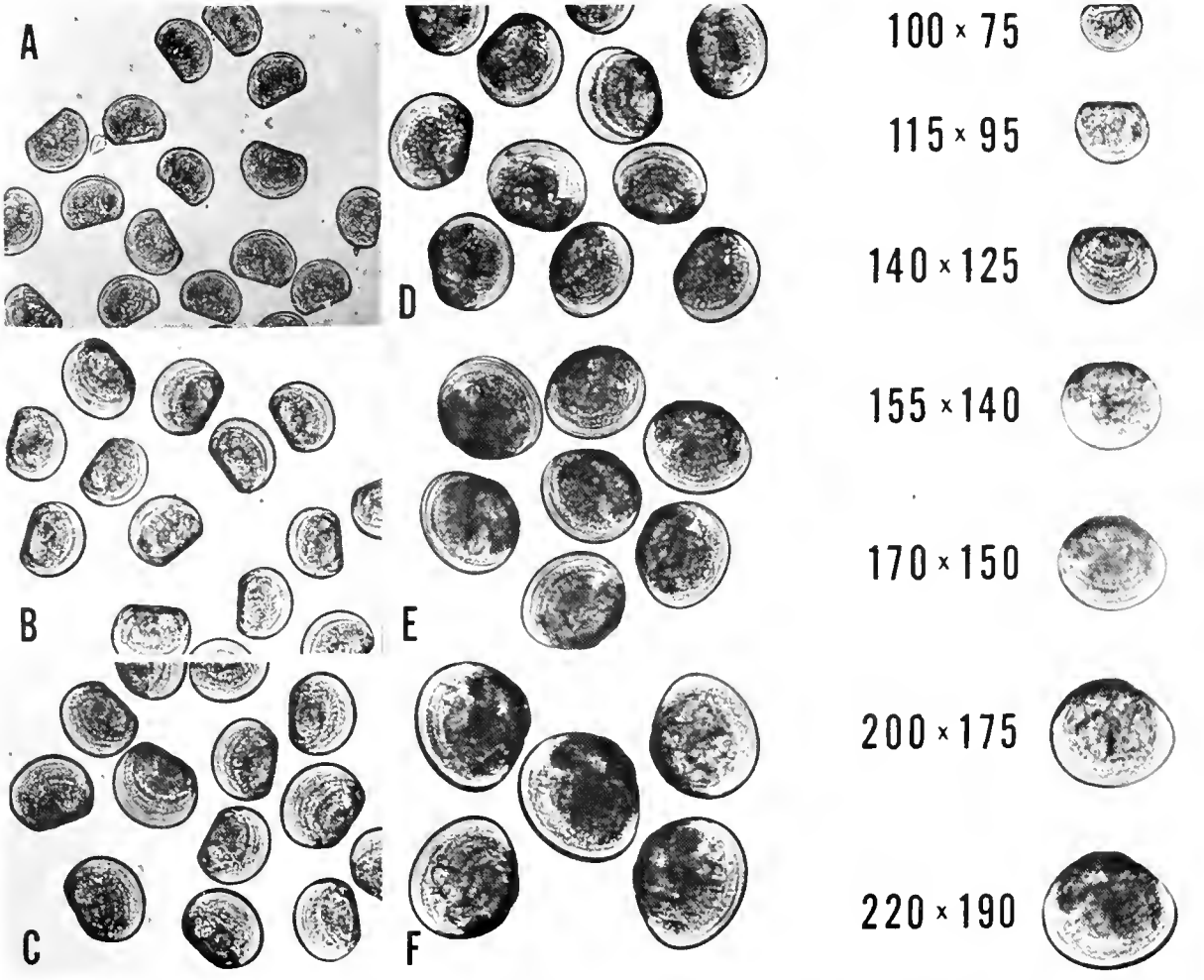

FIG. 2. *Photomicrographs of* B. recurvus *larvae. Length x height measurements are given in microns under larvae at right. These larvae are arranged with anterior end right. A. One-day old larvae about 100-110 μ long. B. Four-day old larvae about 115-125 μ long. C. Five-day old larvae about 130-140 μ long. D. Larvae about 140-160 μ long. E. Larvae about 165-175 μ long. F. Larvae about 195-215 μ long.*

than length; L—23 μ = H $\pm$ 9; L—52 μ = D $\pm$ 13 μ. Hinge line initially 68-76 μ, increasing to 72-84 μ at L = 120 μ.

Umbo stage: L = 135-220 μ; H = 101-199 μ; D = 81-184 μ; L—23 μ = H $\pm$ 11 μ; L—56 μ = D $\pm$ 12 μ.

Pediveliger stage: Minimum length with functional foot = 165 μ. Maximum length with functional velum = 220 μ.

Larval shape (Fig. 2)

Straight-hinge stage: Larvae D-shaped; hinge line proportionately long; shoulders almost straight, sloping steeply, posterior shoulder shorter and sloping more steeply than anterior; ends blunt, posterior higher and more pointed than anterior; anterior slightly longer than posterior in late straight-hinge stages; ventral margin rounded, but elongated, not hemispherical.

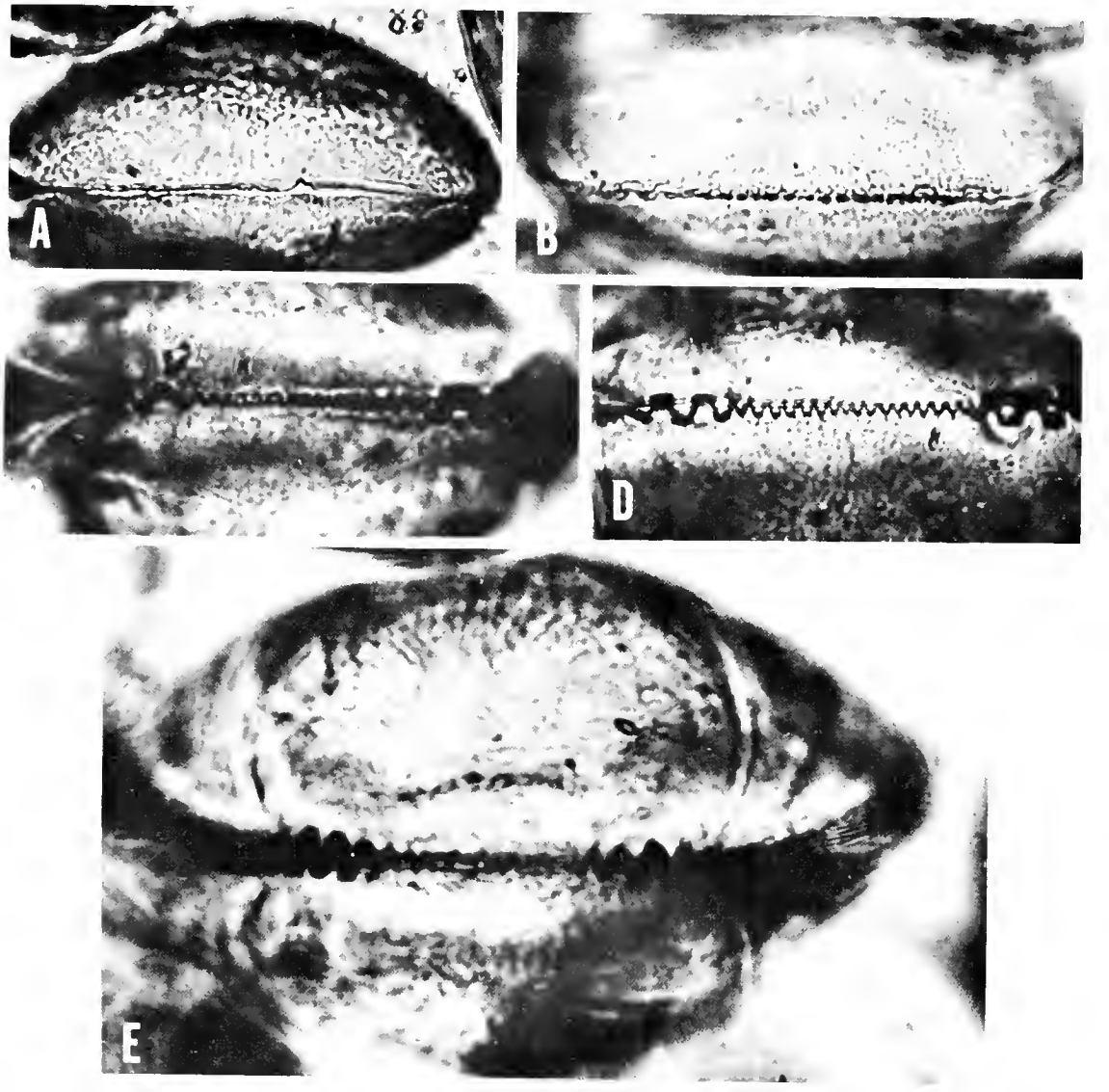

FIG. 3. *Hinge structure of larval* B. recurvus. *Anterior end is left. A. Dorsal view of hinge of larvae 105 μ long. B. Ventral view of hinge of larva 105 μ long. C. Dorsal view of hinge of larva 120 μ long. D. Dorsal view of hinge of larva 135 μ long E. Dorsal view of hinge of larva 180 μ long.*

Umbo and pediveliger stages: Umbo appearing as rounding of hinge line at about 150 μ, becoming more conspicuous and broadly rounded in late stages; shoulders almost straight, anterior longer than posterior and not sloping as steeply; posterior end blunt, anterior end longer and more sharply pointed; ventral margin markedly elongated, but still rounded, not hemispherical.

Anatomy

Shell appearing heavy and thick; apical flagellum present, but rarely displayed; velar cilia about 25 μ long; larvae dark, brown, antero-ventral margin frequently darker and reddish brown in larvae over 165 μ; eyespot appearing at 165 μ, small, indistinct but becoming conspicuous at about 180 μ, eventually 10 μ in diameter; pediveligers first appearing in 11 days.

Hinge structure (Fig. 3)

Hinge originally undifferentiated (Fig. 3A); within one or two days many small taxodont central teeth and two larger teeth develop at both ends of hinge line in each valve (Fig. 3B), increasing to 3 or 4 large teeth with growth (Figs. 3C, 3D, 3E). No ligament evident.

DISCUSSION

Larvae of many mytilid species have been described (Table 1). Some have non-pelagic development (Thorson, 1935); others differ widely in shape. However, most pelagic larval Mytilidae have many common characteristics. The hinge line is long, in relation to other dimensions, and increases in length with larval growth. Hinge-line length does not increase with growth in larvae of most bivalves. Dentition, in mytilid larvae, usually consists of a series of taxodont teeth over the entire hinge line, but with larger teeth near the ends. The umbo is usually late in developing and remains low, rounded, and inconspicuous. The larval umbo is more pronounced in the genus *Modiolus*. The anterior end is rounded but not nearly as blunt as the posterior. This and the inconspicuous umbo give larvae a decided egg shape. The color is usually "dark" or some shade of brown. Mytilid larvae attain a comparatively large pelagic size, frequently in excess of 300 μ. Juveniles remaining pelagic by means of entrapped air, byssus floats or drifting algal substrates (Nelson, 1928; Bayne, 1964) have been taken in plankton samples and have undoubtedly led to some reports of extremely large larvae. Nonetheless, larvae of mytilids generally set at larger sizes than do larvae of most other bivalves. There is frequently much variation in setting size among larvae of the same species (Nelson, 1928; Bayne, 1965).

Larvae of *B. recurvus* have many characteristics common to larval Mytilidae. For example, the hinge line is long and has a typical mytilid dentition, larvae appear dark or coarse and thick shelled and the ends are rounded, with the anterior more pointed than the posterior. When they first develop a shell, *B. recurvus* larvae are not appreciably smaller than most mytilid larvae. However, they set at a smaller size (165-220 μ) and develop a broader, more conspicuous umbo at a smaller size than most mytilid larvae.

Other species of Mytilidae that occur in the same geographic range as *B. recurvus* include *Mytilus edulis*, *Modiolus demissus* and *Amygdalum papyria*. Larvae of *M. edulis* can be readily differentiated by their more rounded ventral margin and less conspicuous umbo, which is no more than a rounding of the hinge line below L = 220 μ. The hinge structure of larval *M. edulis* is also much weaker. Teeth are lacking in the central portion of the hinge and are small at the ends.

Larval *M. demissus* are similar to *B. recurvus* in appearance and are virtually indistinguishable from L = 150 to 200 μ. In earlier stages the straight hinge line of larval *M. demissus* is longer (85 μ) and the umbo appears somewhat later. *M. demissus* larvae have a minimum length of about 105 μ and a maximum of about 300 μ. Their hinge structure has not been described.

A. papyria larvae have a more pointed anterior end, and a shorter hinge line (50-70 μ) than larval *B. recurvus*. They develop a broad knobby umbo at only 110-125 μ.

Larvae of *B. recurvus* can be distinguished from most other bivalve larvae by their hinge, heavy appearance and dimensions. They resemble larval *M. mercenaria* and other venerid larvae in shape and dimensions but have a much flatter ventral margin and entirely different hinge structure.

ACKNOWLEDGMENTS

I am grateful to Mrs. Juanita Tutt, Miss Judy Ward and Mrs. Phyllis Howard of the Microbiology Department of the Virginia Institute of Marine Science for providing the algal food and helping culture and measure the larvae. I am also indebted to Mrs. Jane Davis, also at the Virginia Institute of Marine Science, for preparing the illustrations.

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TABLE 1. *A Summary of Published Descriptions of Larval Mytilidae*

Nominal Taxa	Reference	Descriptions
Adula simpsoni (Marshall)	Rees (1950)	Large (figured specimen over 300 μ) rich brown larvae. Length considerably greater than height.
Brachidontes senhausi (Reeve)	Yoshida (1937; 1953)	Length to at least 240 μ. Height about 30 μ less. Pediveligers 230 to 290 μ with pigmented eyespot. Many minute teeth along hinge.
Crenella decussata (Montagu)	Jørgensen (1946)	Prodissoconch is 750 μ.
Lithophaga bisulcata (Orbigny)	Culliney (in press)	Length 92-400 μ. Hinge line 66μ. Umbo develops at 140-160 μ. Pediveliger 300-400 μ.
Modiola adriatica (Lamarck)	Jørgensen (1946)	Development probably non-pelagic. Prodissoconch about 1 mm.
	Zakhvatkina (1959)	Length to 378 μ. Anterior end longer and narrower than posterior. Umbo low, wide and distinct. Hinge with taxodont dentition. Teeth at ends larger than distinct central teeth.
Modiola modiolus (L.)	Jørgensen (1946)	Prodissoconch about 400 μ.
Modiolaria discors (L.)	Thorson (1935)	Non-pelagic larvae.
Modiolaria marmorata (Forbes)	Lovén (1848) Jørgensen (1946)	Minimum size 80 μ. Larvae set at 320-400 μ. Shells orange with purple flat umbo. Anterior end more pointed and shorter than posterior. Eyespot and statocyst evident. Hinge with taxodont dentition and central ligament. Teeth larger at both ends of hinge.
Modiolaria nigra (Gray)	Thorson (1935)	Non-pelagic. Lengths 112 to 205 μ. Height 20-25 μ.
Modiolus demissus (Dillwyn)	Sullivan (1948)	Length 112-205 μ. Height 20-25 μ less. Bulky thick shell with dark outline. Heavy yellow brown. Posterior shoulder higher and steeper than anterior. Umbones project prominently.
	Loosanoff and Davis (1963)	Length 105-305 μ. Pediveligers with eyespots 220-305 μ. Most set at 275 μ.
	Loosanoff, Davis and Chanley (1966)	Length 105-305 μ. Height 20-60 μ less; difference increasing with growth. Dark brown. Long hinge line becomes rounded at 160 μ and knobby at about 220 μ. Pediveliger 200-305 μ. Most set at 275 μ.
Modiolus modiolus (L.)	Rees (1950)	Length to 315 μ. One end pointed. Knobby umbo in late stages. Blunt end droops ventrally.
	Newell and Newell (1963)	Umbo more pronounced and shell more massive than *M. edulis*.

Musculus marmoratus (Forbes)	Rees (1950)	One end pointed, other blunt and drooping ventrally. Umbo knobby but inconspicuous at 260 μ.
Mytilacea	Rees (1950)	Distinctive hinge with minute taxodont teeth over entire hinge line. Teeth larger near ends. Ligament posterior.
Mytilaster lineatus (Gmelin)	Zakhvatkina (1959)	Length 105-312 μ. Height 96-290 μ. Hinge line 95 μ. Anterior end longer and narrower than posterior. Hinge taxodont with larger teeth at both ends.
Mytilidae	Odhner (1914)	Characterized by medium umbo, taxodont hinge and eyed stage.
	Hayashi and Terai (1964)	Three types of larvae shown. Lengths 283-413 μ. Height 10-45 μ less. One type with small umbo. Pediveliger over 400 μ had large umbo and straight ventral margin. All with anterior more pointed than posterior.
Mytilus californianus (Conrad)	Breese, Williamson and Dimick (1963)	Length of straight-hinge larvae much longer than height. Hinge line long.
Mytilus crassitesta (Lischke)	Miyazaki (1935)	Length 95-203 μ. Height 23-33 μ less. Hinge line 71 μ increasing to 85 μ. Umbo small, yellow, inconspicuous. Anterior end more pointed than posterior. Eyespots and statocyst present in pediveliger.
	Yoshida (1936; 1953)	Larvae set at 280-320 μ. Height about 30 μ less than length. Umbo small. Anterior end more pointed than posterior.
Mytilus edulis (Linné)	Borisiak (1909)	Taxodont hinge teeth, long hinge line. Anterior end more pointed than posterior.
	Stafford (1912)	Length to 400 μ. Hinge line long. Length much greater than height. Umbo appears at about 140 μ. Posterior much deeper than anterior at 172 μ as foot and gills appear. At 275 μ pediveligers have byssus gland, statocysts and eyespots.
	Mathews (1913)	Set from 210-380 μ. Height 20-60 μ less than length. Cockle-shaped.
	Field (1923)	Figures straight hinge stage at 60 hours.
	Kändler (1926)	Recognizable at 225 μ. Have statocyst with multiple statoliths and eyespot. Pediveligers at 290 μ.
	Wells (1927)	Long hinge line; low, rounded umbo. Anterior end more pointed than posterior. Umbones small; color, horn yellow.

	Nelson (1928)	Length to 376 μ. Height 20-40 μ less. Vary considerably in size at setting. Anterior end more pointed than posterior. Umbones small. Color, horn yellow.
	Werner (1939)	Length proportionately long, about 113-299 μ. Height 30-40 μ less. Hinge line 93 μ. Multiple statoliths. Eyespot. Taxodont hinge with larger teeth at both ends. Anterior end more pointed than posterior.
	Jørgensen (1946)	Length 90-400 μ. Egg-shaped with anterior end more pointed than posterior. Umbo low indistinct. Deep orange, almost opaque. Variable in shape, color and development. Hinge taxodont. Weak teeth in center with 6-8 stronger teeth at both ends.
	Sullivan (1948)	Length 155-320 μ. Height 35-65 μ less. Umbo low and rounded. Statocyst in foot. Anterior end more pointed than posterior.
	Rees (1950)	Umbo inconspicuous. Photomicrographs.
	Newell and Newell (1963)	Ovoid shape. Taxodont hinge with posterior ligament.
	Loosanoff and Davis (1963)	Length 93-300 μ. Height 14-30 μ less. Eyespot appears at about 215 μ. Larvae set from 215-300 μ.
	Loosanoff *et al.* (1966)	Length 80-348 μ. Height 65-304 μ Eyespot appears at 215 μ. Pediveligers from 210 μ. Photomicrographs.
Mytilus galloprovincialis (Lamarck)	Zakhvatkina (1959)	Length 80-348 μ. Height 65-304 μ Hinge line 71-91 μ. Pediveligers with numerous statoliths. Taxodont dentition with 7-8 large teeth at each end of hinge line. Umbo low, broad. Anterior end more pointed than posterior.

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SOME OBSERVATIONS ON THE SPAWNING AND EARLY DEVELOPMENT OF THE BUTTER CLAM, *SAXIDOMUS GIGANTEUS* (DESHAYES) [1]

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ABSTRACT

Successful spawning and rearing of the butter clam, Saxidomus giganteus *(Deshayes), has been demonstrated. Spawning of ripe adults was induced by thermal stimulation and the addition of KCl to the sea water in the holding tanks. The larvae were free swimming for 20 to 30 days and grew an average of 7 μ per day. A byssal thread attachment was formed by metamorphosed larvae and subsequent juvenile growth accelerated to about 18 μ per day for the next 150 days.*

INTRODUCTION

The butter clam, *Saxidomus giganteus*, which is found from Sitka, Alaska, to San Francisco Bay, California, is a valuable recreational and food resource (Fitch, 1953). This clam is also known as the Washington clam, quahog, Coney Island clam, beefsteak clam and great Oregon clam (Marriage, 1958). It is important to both the commercial and sports digger, and knowledge of its early life history will contribute to sound management practices.

The only report that we have found on the larval life history of the butter clam is that of Fraser (1929) who described the free-swimming larvae from plankton samples. He stated, "Evidently it takes about 2 weeks from time of spawning for the larvae of this species to reach the veliger stage (.16mm) and 4 weeks to pass through this stage to settle on the gravel." We find the veliger stage (116 μ) is reached in 2 days, apparently he did not find the smaller larvae in the plankton.

During the past 4 years we have reared several groups of butter clam larvae through their free-swimming stages using methods adapted and modified for culture of bivalve molluscs from those described by Loosanoff and Davis (1963). Our observations on early developmental stages of the butter clam are summarized here.

SPAWNING

Groups of 12 mature clams were conditioned in 18 liters of standing sea water at a salinity of 25 ppt or greater and at 16 to 18° C for 7 to 14 days. The water was changed daily to avoid accumulation of harmful metabolites. Conditioned clams transferred to continuously recirculated sea water at 21° C usually spawned within 8 hr. If elevated temperature alone failed to induce spawning, the clams usually spawned after the addition of stripped sex products or 1-2 g of KCl to each liter of recirculated water. This method has been used to spawn the bay mussel, *Mytilus edulis*, (Breese, Millemann and Dimick, 1963). After being induced to spawn, the clams continued to release gametes for 2 hr; and if returned to cold water (<15° C) to prevent further spawning, they could be induced to spawn again at a later date.

DEVELOPMENT

The round egg is 80 to 90 μ in diameter and is

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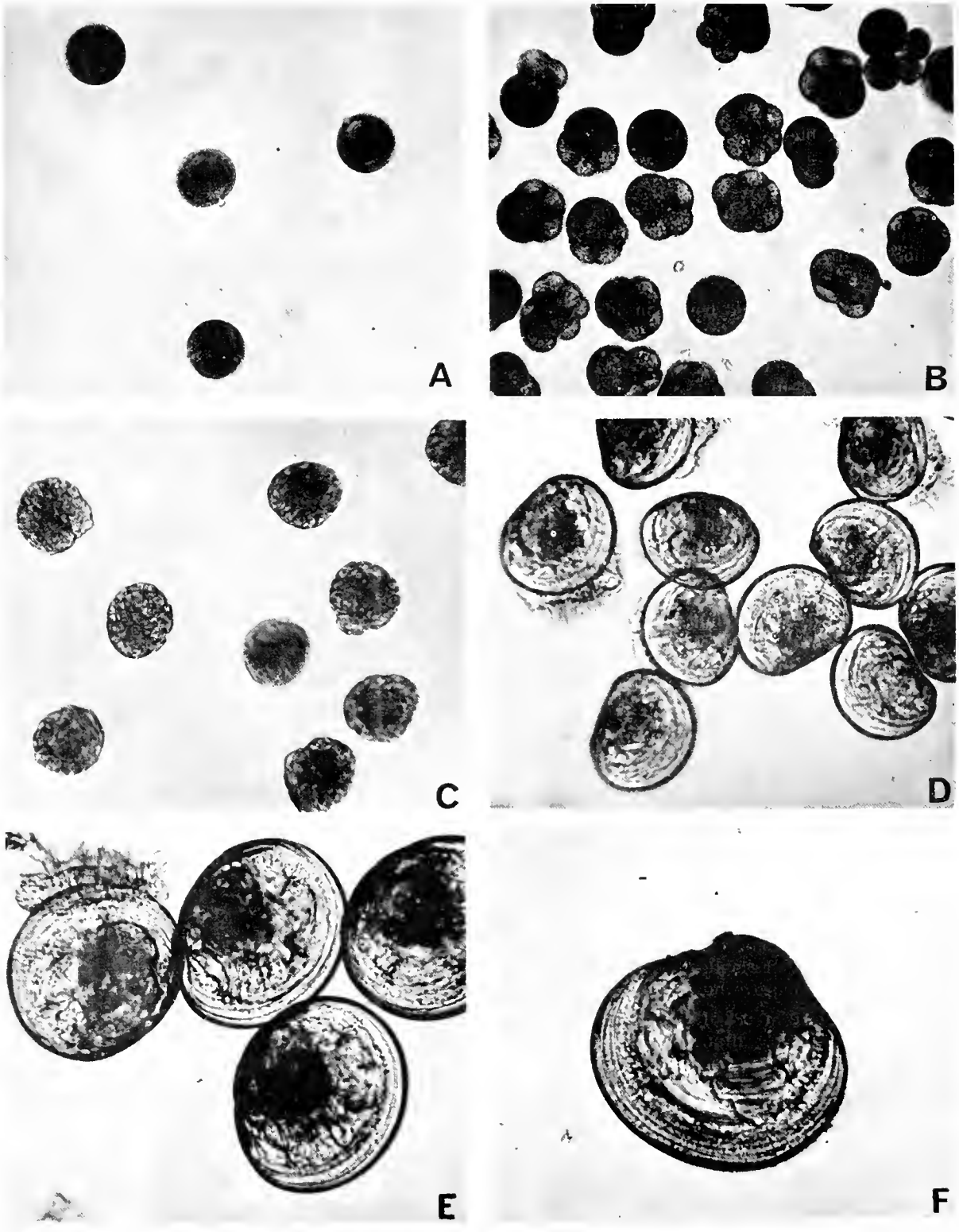
A
B
C
D
E
F

FIG. 1. *Fertilized eggs of the butter clam showing "halo" and polar bodies (A); one, two and four cell stage of the butter clams (B); 44 hr trochophore of the butter clam (C); six-day veliger averaging 142 μ (D); sixteen-day veliger averaging 224 μ (E); metamorphosed juvenile butter clams with bysus thread, 30 days after fertilization, measuring 311 μ (F). 390 X.*

enclosed within a halo-like membrane which is approximately 230 μ in diameter (Fig. 1A). The membrane is absent at the time of egg cleavage and its function is not known. At 18° C, polar bodies (Fig. 1A) form within 60 min after fertilization and cleavage begins within 90 min (Fig. 1B). Trochophore larvae (Fig. 1C) first appear 24 hr after fertilization and develop into veliger larvae 48 hr (Fig. 1D) after fertilization.

The 48-hour-old veliger larvae were held in 19-liter glass jars or 700-liter plastic tanks containing sea water at 18° C and at a salinity ranging from 25 to 31 ppt. The concentration of larvae in each rearing container was approximately 1/ml of water. Larvae were fed 3 times a week with equal quantities of the algae *Monochrysis lutheri* and *Isochrysis galbana* at which time the water was changed. Each feeding consisted of 20,000 algal cells/ml of rearing water. The larvae grew approximately 7 μ each day under these conditions (Figs. 1E, 2). Larval metamorphosis began on culture day 22 and was completed by day 30. The

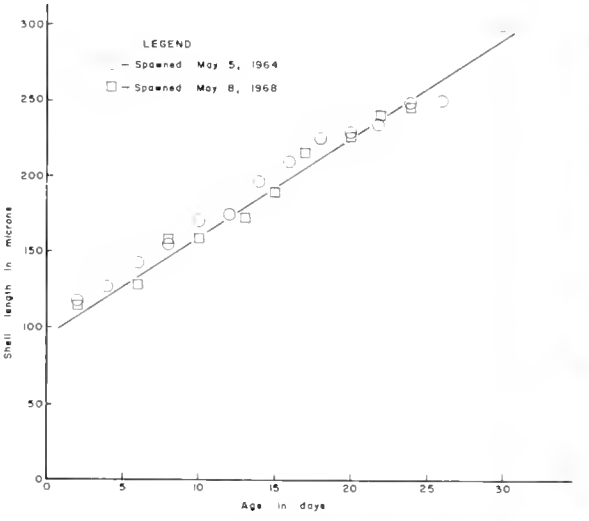

FIG. 2. *Growth of butter clam larvae spawned in May 1964 and May 1968. Rearing temperatures were 17-18° C. Points are mean lengths of 19 and 20 larvae from 1964 and 1968 cultures respectively.*

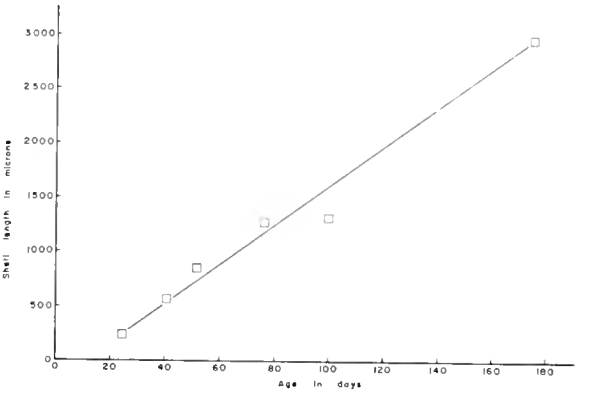

FIG. 3. *Post larval growth of butter clams spawned in May 1968. Points are mean lengths of 20 clams. Lines were fitted by inspection.*

juvenile clams were found attached to the sides and bottom of the rearing tanks by a byssus thread (Fig. 1F).

The attached juveniles were transferred from the 700-liter plastic tanks to 45-liter plastic trays, held in either running sea water or in standing water, and were fed *M. lutheri* and *I. galbana*. They grew approximately 18 μ a day during the 146 days of observation (Fig. 3).

We are now rearing juvenile butter clams for subsequent experimental plantings in different

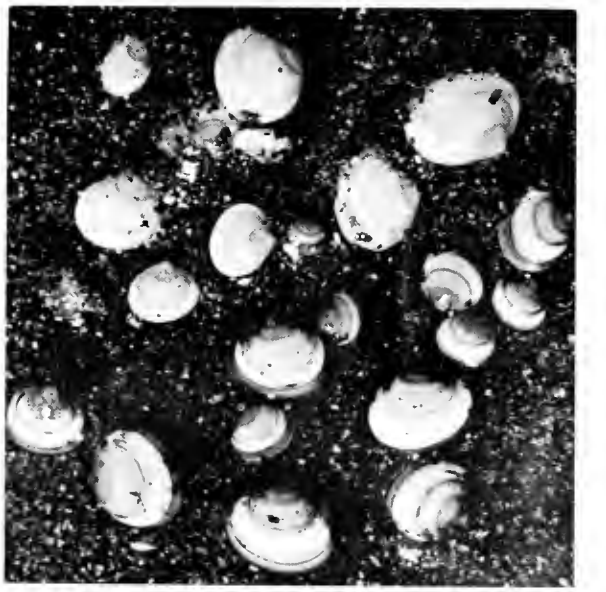

FIG. 4. *Juvenile butter clams stained with alizarin sodium monosulfonate dye. Note the dark rings near the umbo.*

habitats. The clams are being marked with alizarin sodium monosulfonate dye (Hidu and Hanks, 1968) prior to planting to facilitate later identification (Fig. 4). This treatment causes the clams to produce a purple shell ring that persists throughout life.

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MARKING SURF CLAMS

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ABSTRACT

Rapid and distinctive methods of marking surf clams, Spisula solidissima *(Dillwyn), were sought since large numbers must be released in the ocean to insure sufficient returns for analysis in studies of growth and population dynamics. Colored inks and paints either were not retained on the shells or faded as the clam grew. The attachment of a conspicuous tape to the shells with a sealant, combined with notching of the shell margin, proved satisfactory for use on shore and at sea. Recovered marked clams yielded information on growth during the release period, as well as the identification of the time and place of release. Tape attached to the shell by the sealant caused no injury to the clam, and notching the shell margin had no serious effects on growth.*

INTRODUCTION

Tests of methods of permanently marking and tagging large numbers of surf clams were begun in 1964 because a good means of identifying them in studies of growth or population dynamics was not available. Routine marking of surf clams was not mentioned by Westman and Bidwell (1946 [1]) — they relied on length frequency measurements and "ridges" on the shells to determine growth. Westman (1948 [2]) apparently marked some surf clams with red ink and recovered one after it had been in the ocean for 2½ years. He reported that "no perceptible fading of the ink had taken place."

Materials to color the shells of bivalves have been used in the past. Hidu and Hanks (1968) marked the shells of several species of clams with a vital stain, but the technique is impractical for use in a large-scale fishery study because the marked individuals are difficult to identify in the field. For studies of growth, various inks, paints, and lacquers have been applied to bivalves, such as the soft-shelled clam, *Mya arenaria* (Spear and Glude, 1957), and the quahog, *Mercenaria mercenaria* (Gustafson, 1954). We tested inks and paints on surf clams because they can be rapidly applied.

Marks filed or bored on the outer shell surfaces and through the shells have been used to identify individual bivalves in some studies. A code system of holes bored in the shell of fresh-water mussels, *Lampsilus ventricosa*, by Thoma, Swanson and Dowell (1959), however, seemed impractical for surf clams because the marks would not be easily seen by fishermen and shuckers. Posgay (1953) bored holes in the "ears" near the byssal notch of sea scallops, *Placopecten magellanicus*, to attach Petersen disks with wire, but surf clams have no "ears," and holes bored in the shells often caused injuries and shell breakage. Notching the shell margin of bivalve mollusks has been used to show subsequent growth of soft-shelled clams (Mead and Barnes, 1904), quahogs (Belding, 1912), oysters, *Crassostrea virginica* (Loosanoff and Nomejko, 1949) and sea scallops (Stevenson and Dickie, 1954; Merrill, Posgay and Nichy, 1966). Since notching clearly delimited new shell growth

[1] Westman, J. R. and M. H. Bidwell. 1946. The surf clam. Economics and biology of a New York marine resource. Unpublished manuscript. In files of Bureau of Commercial Fisheries Biological Laboratory, Oxford, Md.

[2] Westman, J. R. 1948. Recapture of a marked "skimmer" clam *(Mactra)* after two and one-half years in ocean. Bur. Mar. Fish., Conserv. Dep., N. Y., January, 1 p. (mimeo).

of these bivalves, we tested the method on surf clams.

The importance of a conspicuous tag was shown by Posgay (1963). When he attached a 6-inch strip of yellow plastic tape to sea scallops, he increased the recovery more than sevenfold (from 3 to 23%) over that of Petersen disks alone. Conover and Pierce (1956) successfully attached paper labels to oysters with an adhesive. We also attached disks and tapes by adhesives to surf clams under laboratory and field conditions.

COLLECTING CLAMS

Middle Atlantic beaches were searched for a source of large numbers of small surf clams to mark. Windrows of surf clams found on beaches after storms (Ropes, Chamberlin and Merrill, 1969) are evidence that they are abundant in some inshore areas. A dense population of surf clams, averaging 21.1 mm in shell length, was found in October 1964 on an intertidal bar at Wallops Island, Chincoteague Inlet, Va. (Fig. 1, area A); clams were collected there by hand digging. Although the majority of clams used in this study were from Wallops Island, some larger clams were collected from New Jersey beaches and some were taken with a hydraulic surf clam dredge off the New Jersey coast.

MARKING MATERIALS AND METHODS

Notching

Rapid methods of making notches on the clam shells developed into a coding system to separate plantings of clams. A single notch extending up the shell surface from the posterior ventral margin was made, first with small triangular files which frequently crushed the thin, fragile shells of the smallest clams (about 13 mm long), and later with a fast turning, thin carborundum disk on a Moto-Tool (Dremel Manufacturing Co.).[3] The Moto-Tool cut a distinctive notch with a single stroke and injured very few clams. During one tagging operation 4,803 clams were notched in 16 man-hours — an average of 5 clams/min. Another distinctive mark was made by using two carborundum disks separated by a 1/8-inch spacer to produce parallel grooves. Other types of marks were developed to separate groups of clams planted on the same date or marked in some other way. For example, in a test of adhesives, six groups of clams were distinguished by grinding a single or double notch up the shell surface from the ventral margin and crossing some of these obliquely with one or two grooves.

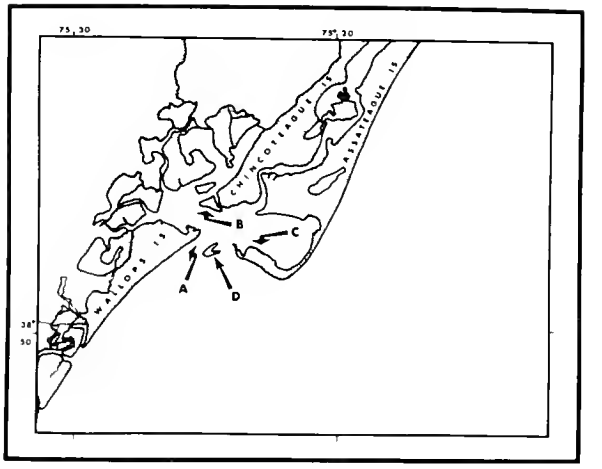

FIG. 1. *Collecting and planting sites of surf clams used in marking experiments at Chincoteague Inlet, Va.: (A) Wallops Island, (B) Chincoteague Point, (C) Assateague Cove, and (D) barrier beach.*

Although all of the clams released at Chincoteague Inlet during the study were notched, a total of 17,519 was used in tests of notching alone (Table 1). One group of clams, planted at a shifting sand island (not named on any charts) which we called the barrier beach site (Fig. 1, area D), was put in a 3-foot-square, ½-inch mesh hardware cloth cage in an attempt to hold them in the turbulent area. The site was chosen because it was near the open ocean, the usual habitat of the surf clam. All other notched clams were planted at Chincoteague Point (Fig. 1, area B). The clams were distributed at low tide over the sand bottom in about 1 foot of water. Stakes placed 100 feet apart and parallel to the beach marked the planting site.

Colored Liquids

Five colored liquids were applied directly to the shells of 6,197 surf clams planted in late 1964 (Table 2). The liquids were: (1) black printing ink from the Burroughs Corporation; (2) black Marks-A-Lot ink from the Carter's Ink Company; (3) red Mark-Tex Tech-Pen enamel from the Mark-Tex Corporation; (4) red Sapolin spray enamel from Sapolin Paints, Incorporated; and (5) red Cutex "Cute Tomata" fingernail polish from the Northam Warren Corporation. In applying the colored liquids, the shells were wiped clean with an alcohol-soaked rag, the shell surfaces were dried in air for ½ to 1 hr, marking liquid was ap-

[3] References to trade names in this publication do not imply endorsement of commercial products.

TABLE 1. *Surf clams notched and planted in Chincoteague Inlet, Va., 1964-66. (Unless specifically noted, all of the clams were collected from Wallops Island and planted at the Chincoteague Point site.)*

Type of mark, and date of planting	Release			Recovery					
	Number planted	Shell length (mm)		Days after planting	Number recovered	Shell length (mm)		Length increment (mm)	
		Average	Range			Average	Range	Average	Range
Single file notch, right valve 9, 16 and 20 Nov. 1964 [a]	5,117	22.5	13-21	4	6	25.0	19.7-29.1	2.2	0.1- 4.9
				65	10	26.9	19.8-37.4	3.4	0.2- 6.4
				95	4	27.4	23.9-33.7	2.7	1.1- 5.5
				123	47	31.0	23.3-41.0	8.6	3.4-13.1
				228	45	42.8	32.5-50.5	19.0	8.0-25.0
				401	6	61.1	57.0-65.6	37.7	32.4-42.2
				481	27	65.8	60.3-74.5	42.1	33.7-50.6
				612	1	70.3	-	44.6	-
Single ground notch, right valve 11 Dec. 1964 [b]	2,074	24.2	15-36	None	None	None	None	None	None
Single ground notch, left valve, and oblique groove 9 March 1965 [c]	500	68.3	50-100	318	2	85.0	82-88	17.0	14.0-19.5
				394	5	85.2	79-90	33.8	20.5-57.9
Double ground notch, left valve 9 Jan. 1966	2,037	54.7	39-84	85	54	63.1	46-80	2.4	0.0- 7.3
				170	17	72.8	65-85	10.1	6.5-18.5
				190	2	75.0	70-79	14.7	8.9-20.5
				219	10	72.2	62-83	12.9	8.9-19.2
				276	7	62.4	66-85	13.1	11.0-15.5
				277	1	86.0	-	11.5	-
Double ground notch, left valve, and oblique groove 16 Feb. 1966.	2,766	65.1	51-84	47	5	59.5	59-60	0.5	0.2- 0.8
				132	34	74.3	62-89	9.0	3.5-14.5
				152	5	70.0	60-82	9.7	8.0-11.8
				183	19	74.8	68-86	9.9	3.1-14.6
				238	29	76.9	66-86	11.5	0.5-16.5
				239	12	76.5	69-90	12.2	7.5-21.0
Single ground notch, left valve, and oblique groove 21 April 1966 [d]	5,025	100.1	72-133	174	22	105.8	80-131	1.0	0.0- 4.5
				175	4	103.8	91-125	0.0	0.0

[a] To determine the number of days after planting, 12 December was used as the day of planting.

[b] The clams were planted at the barrier beach site.

[c] The clams were collected from dredging by the M/V Delaware.

[d] The clams were collected from dredgings by a commercial surf clam vessel.

plied to the shells, and the shells were again dried for ½ to 1 hr.

A total of 5,283 clams was planted at the Assateague Cove site (Fig. 1, area C) and 914 clams at the barrier beach site (Fig. 1, area D) by distributing them on the sand bottom in 1 foot of water at low tide. Stakes were used to mark the planting sites.

Sealant and Adhesives

Plastic disks, 12 mm in diameter, were attached to 250 clams with Thiokol LP Base: T-13-P polysulfide sealant (Thiokol Chemical Corporation), mixed to the manufacturer's recommended proportions (139:15). After the disks were attached near the umbo of the clean and dried shells, the clams were exposed to the air for 3 hr and then returned to running sea water in the laboratory. The sealant remained soft during the 3 hr period and was still slightly flexible 18 hr after application. Nevertheless, Thiokol held the disks to the shells. After making the laboratory observations, the clams were planted at the staked barrier beach site (Fig. 1, area D and Table 3).

In a test of two adhesives during 1966, two types of colored plastic materials were bonded to the clam shells (Table 3). Petersen disks were attached to 102 clams and yellow vinyl tape (15 cm long x 12 mm wide) to 90 clams with Thermogrip adhesive (United Shoe Machinery Corporation). Drying the shell surface, grinding off a portion of the periostracum, and cutting a slot through the shell near the umbo with a carborundum disk were preliminary treatments. A hole about 1 mm wide and 2 mm long was made at the bottom of the slot. Hot adhesive, applied with an electric applicator, was forced into the slot and through the hole in the shell by pressing on a disk or tape. Petersen disks were also attached to 103 clams and vinyl tape to 50 clams with Thiokol sealant. Drying the shell surface and grinding off the layer of periostracum were the only preliminary treatments. Twice as much catalyst as recommended was used to hasten

TABLE 2. *Surf clams marked with colored liquids and planted at Assateague Cove, 1964. (All of the clams were collected from the barrier beach site.)*

Type of mark, and date of planting	Release			Recovery					
	Number planted	Shell length (mm)		Days after planting	Number recovered	Shell length (mm)		Length increment (mm)	
		Average	Range			Average	Range	Average	Range
Burroughs [a] and Marks-A-Lot black ink 30 Oct. 1964	1,652	30.4	19-46	47	2	35.5	35-36	1.1	1.0- 1.2
				138	2	28.0	25-32	0.5	0.5- 0.5
				167	21	33.6	26-38	2.8	0.0- 0.8
				270	14	43.6	37-47	12.7	5.5-19.0
				523	13	57.2	51-64	25.5	18.1-32.9
				624	6	56.5	52-64	27.6	23.9-31.6
Cutex "Cute Tomata" red 5 and 13 Nov. 1964 [b]	1,575	31.4	21-56	37	2	29.6	29-30	0.9	0.7- 1.2
				128	2	28.5	25-33	0.5	0.5- 0.5
				157	12	36.3	26-39	4.6	1.5- 8.0
				260	23	44.5	39-54	12.1	7.5-16.5
				482	9	55.1	51-60	22.8	18.2-26.9
				614	2	67.0	66-68	32.9	30.6-35.2
Sapolin spray enamel red 16 Nov. 1964	1,556	30.1	21-47	150	10	29.6	26-37	2.4	0.5- 5.0
				253	10	28.5	38-49	13.2	9.0-16.5
				506	10	52.5	49-56	21.4	16.3-24.9
				638	1	56.0		36.0	
Mark-Tex Tech Pen red numbers 16 Nov. 1964	500	30.1	21-47	91	4	31.5	28-34	1.4	0.0- 2.7
				253	3	44.7	41-48	12.5	10.5-14.5
				506	37	52.7	45-61	21.9	15.7-32.1
				638	7	57.8	53-63	24.3	18.7-28.3
Cutex "Cute Tomata" red 10 and 11 Nov. 1964 [c]	914	31.4	21-56	None	None	None	None	None	None

[a] Volger's Ink used by Westman (see footnote 1) was no longer in production. The manufacturer supplied an ink with similar characteristics.

[b] To determine the number of days after planting, 9 November was used as the date of planting.

[c] The clams were planted at the barrier beach site.

hardening of the sealant. The sealant was applied and a disk or tape was then pressed into it. All the clams were notched and planted at Chincoteague Point (Fig. 1, area B).

Additional tests were made in 1968 with other adhesives and tape (Table 3), since the tests in 1966 were not considered conclusive enough to recommend adhesive for use in large-scale tagging in the open ocean. Two adhesives — Eastman 910 (Eastman Kodak Company) and 3M-EC 1341 (Minnesota Mining and Manufacturing Company) used by Conover and Pierce (1956) — were compared with the Thiokol sealant, and retention of strips of white polyester tape was compared with retention of plastic disks. Wiping the shells with alcohol and drying were the only preliminary treatments because no periostracum covered the shell near the umbo — the usual tagging site. The adhesives and tags were applied to 900 surf clams in six combinations. Both valves of each clam were used as a tagging site. To differentiate among the six test treatments, the shells were coded with six different notches. The clams were planted behind a 24-inch-high, 1-inch mesh chicken wire fence in Assateague Cove (Fig. 1, area C) to reduce losses from predation and storms.

GENERAL REMARKS ON THE RECOVERY OF MARKED CLAMS

Since there is no commercial fishery for surf clams in Chincoteague Inlet, Va., we recovered the marked clams ourselves. The hand-digging methods used to collect the clams for marking were also used to recover the clams from the planting sites.

A total of 3.0% (690) of the 23,397 clams marked and planted during 1964-66 was recovered. Marked clams burrowed into the bottom (as described by Ropes and Merrill, 1966), but storms and predation probably reduced the numbers available for recovery. Empty shells of marked clams were occasionally found on the beaches. At Wallops Island beach the presence of windows of dead clams, shells bored by the moon snail (*Polinices duplicatus*), and shells regurgitated by birds gave evidence that storms and predation were affecting the clam population. Density estimates of the wild Wallops Island clams decreased from a high of 20.5 per square foot in July 1965 to a low of 0.2 per square foot in October 1966. Planting marked clams behind a fence increased recovery of their shells; shells of 53% of those marked in 1968 were collected. High

air and water temperatures during June 1968 apparently killed the marked clams, however — only shells (no live clams) were recovered.

EVALUATION OF THE MARKING METHODS

Notching

A total of 2.4% (374) of the 15,445 clams marked with notches alone and planted at the Chincoteague Point site was recovered (Table 1). The recovered clams had been at the planting site for 1 to 21 months — time periods long enough to deposit new shell and show any damage to the shell caused by notching.

The notches made by the carborundum disk or file appeared as distinct white grooves on the light brown to white shell surfaces of recovered clams (Fig. 2). Magnification was usually unnecessary to recognize new shell growth which began at the notch mark.

Notching might be considered detrimental to clam growth. During the notching operation, sand grains, shell fragments and foreign matter may become lodged between the mantle and shell or the mantle may be cut. Shuster (1951) observed that sand grains lodged between the mantle and shell formed mid-season "checks" in the shells of soft-shelled clams. Posgay (1950) and Merrill, Posgay and Nichy (1966) attributed the occurrence of "shock rings" in the shells of sea scallops to any serious disturbance.

An evaluation of "marking checks" caused by notching of surf clams was based on 136 recoveries from Chincoteague Point (Table 4). Since these were the smallest clams marked during the study (Table 1), they were the most likely to be damaged by notching. They were separated into three categories: (1) Slight checking — minor lapping of the old shell over the new shell. The post-notched shell was smooth and damage-free. (2) Moderate checking — distinct lapping of the old shell over the new shell. The old

TABLE 3. *Surf clams marked with adhesives or sealant and tapes or disks and planted in Chincoteague Inlet, Va., 1964-68. (Unless specifically noted, all of the clams were collected from Wallops Island.)*

Release				Recovery					
Type of tag, adhesive or sealant, & date of planting	Number planted	Shell length (mm) Average	Range						
Thiokol sealant & plastic disk 11 Dec. 1961 [a]	250	22.7	14-37	Four shells with disks attached were recovered 66 days after planting.					
				Recovery condition	Days after planting, number of clams, and (percentage) 76	97	126	183	Total
Thermogrip adhesive and plastic disk	102	66.2	42-87	With disk	11(38)	11(65)	0	7(41)	29(44)
				With tape	10(35)	0	0	0	10(15)
Thermogrip adhesive and vinyl tape	90	"	"	Thermogrip only	2(7)	0	1(25)	3(19)	6(9)
				No Thermogrip, tape or disk	6(21)	6(35)	3(75)	6(38)	21(32)
Thiokol sealant and plastic disk	103	"	"	With disk	27(87)	8(73)	5(83)	7(58)	47(78)
				With tape	0	0	0	0	0
Thiokol sealant and vinyl tape 7 April 1966 [b]	50	"	"	Thiokol only	4(13)	3(27)	1(17)	5(42)	13(22)
				No Thiokol, tape or disk	0	0	0	0	0
				Days after planting, number of shells recovered, and (percentage retaining the tag) 14	74	331	Total		
Thiokol sealant and polyester tape	200	68.2	48-100		105(99)	132(96)	1(100)	238(98)	
Thiokol sealant and plastic disk	100	"	"		102(92)	26(81)	1(100)	129(90)	
3M adhesive and polyester tape	100	"	"		130(88)	61(75)	1(100)	192(84)	
3M adhesive and plastic disk	100	"	"		87(56)	92(91)	3(33)	182(43)	
Eastman 910 and polyester tape	200	"	"		71(71)	35(9)	6(0)	112(63)	
Eastman 910 and plastic disk 13 June 1968 [c]	100	"	"		74(62)	39(9)	2(0)	115(41)	

[a] The clams were planted at the barrier beach site.

[b] The clams were planted at Chincoteague Point.

[c] The clams were collected from a beach at Cape May, N. J., and planted at Assateague Cove.

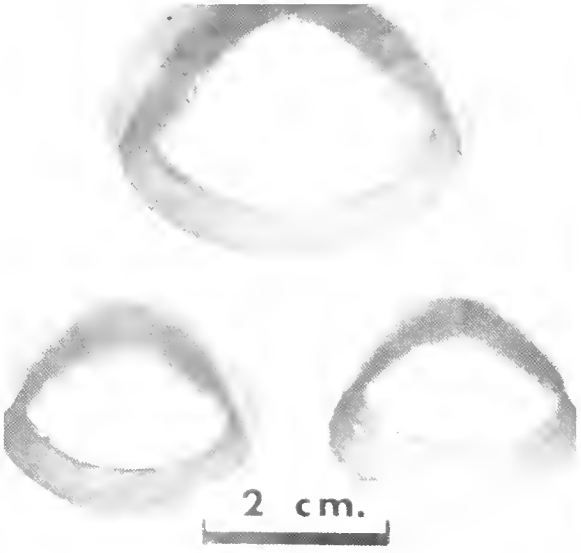

FIG. 2. *Clearly visible notch marks and new shell deposition on recovered surf clams.*

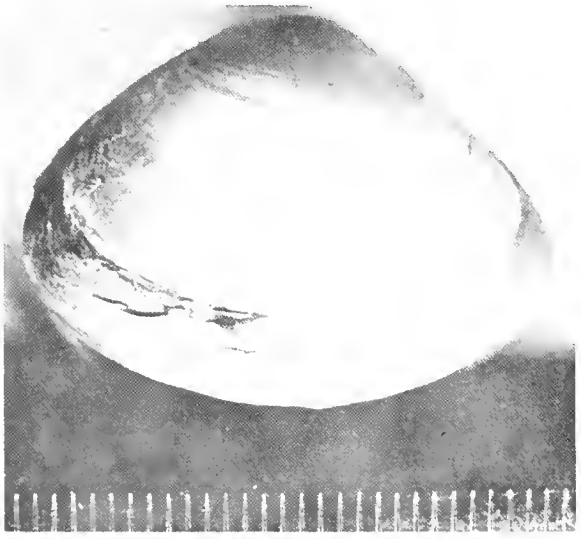

FIG. 3. *Severe checking of new shell deposited by a notched surf clam. The scale at the bottom of the photograph is in millimeters.*

shell was definitely raised along its entire margin; a secondary lapping of the new shell was sometimes evident at the old shell margin, but the remaining new shell was smooth and free of checks. (3) Severe checking — distinct lapping of the old shell over the new shell and additional damage extending into the new shell margin (Fig. 3). This severe checking may have been caused by cutting of the mantle edge. Shell checking was slight on 83% of the shells, moderate on 16%, and severe on 1%. All three types of checks were also seen on 268 unnotched surf clams from the surf zone of Wallops Island beach, where the "checks" occurred in almost the same proportions as in the notched clams. Thus, notching caused no more "checks" than might be expected from natural causes (Table 4).

Abnormal shell deposition does not necessarily indicate a decreased growth rate. Loosanoff and Nomejko (1955) reported on the growth of oysters after their shell edges had been experimentally damaged more extensively than they were by notching in our study. Oysters with uninjured mantles grew more rapidly to repair the damage and then grew at the same rate as control oysters. Surf clams also appear to compensate for notching injuries. "Students" t-test was used to estimate the probability of chance occurrence of observed differences between the shell length measurements of 37 unmarked clams from Wallops Island and 27 notched clams recovered from Chincoteague Point on 7 April 1966. We found no statistically significant differences between the growth of the Wallops Island and Chincoteague Point clams ($t = 0.215$, df 62, P is $< .9 > .7$).

An important advantage of notching is that the time-consuming measurement of shell lengths and the recording of the measurements during marking is eliminated. Measurements need be made only after recovery, when there are far fewer individuals to be handled. Shell size at the time of marking was easily measured on recovered clams.

TABLE 4. *The relative frequency of "checks" in the shells of surf clams marked by a single notch and planted at Chincoteague Point in 1964 and unmarked surf clams at Wallops Island.*

Type of Surf Clam	Type of Check: Slight N	Slight %	Moderate N	Moderate %	Severe N	Severe %
Notched	113	83.1	22	16.2	1	0.7
Unmarked	268	83.2	51	15.8	3	0.9

Colored Liquids

A total of 3.6% (190) of the 5,283 clams marked with colored liquids and planted at Assateague Cove was recovered over a 21-month period (Table 2). The clams marked with fingernail polish and planted at the barrier beach site were destroyed by shifting sand; none was recovered.

Inks made the least permanent marks; fading and abrading occurred before recovery and some marks were easily rubbed off at recovery. Of the

five colored liquids, the fingernail polish and spray enamel adhered best. Bonding to shell margins was poor, however, and color markings did not separate new from old shell growth. Also, the exposed marks were not conspicuous; when small clams were marked, the mark became less obvious as the clam grew.

Sealant and Adhesives

Only a few marked shells were found in February 1965 at the barrier beach site — shifting sand had destroyed the planting site (Table 3). Plastic disks were still adhering to the shells however — evidence that Thiokol sealant might be useful.

At Chincoteague Point, 36% (126) of 345 clams marked in April 1966 with two adhesives and colored plastic disks or vinyl tapes were recovered within a 6-month period (Table 3). Of 66 recovered clams on which Thermogrip adhesive had been used, 44% retained the disk; 15% retained the vinyl tape; 9% retained only the adhesive; and 32% showed only the slot — evidence that the adhesive, disks and tapes had been lost due to a poor bond. Disks and vinyl tapes had been bonded to 60 of the recovered clams by Thiokol sealant; 78% retained the disks; none retained a vinyl tape; and Thiokol, alone, remained on 22% of the clams. Clearly, then, the attachment of plastic disks by Thiokol sealant gave the best results in the 1966 test series.

In 1968, Thiokol sealant gave the highest tag retention during the 2½-month test period (Table 3). Polyester tape was retained on 98% of the shells and disks were retained on 90%. Higher percentages of tags were lost when either 3M or Eastman 910 adhesive was used, and the remaining tags were easily dislodged, in contrast to tags attached by Thiokol. Regardless of the adhesive or sealant used, the polyester tape was retained on more shells than were disks — its fibrous texture apparently formed a better bond. Only 14 shells were found in the spring of 1969, 334 days after planting the clams, and, although these were too few to clearly show the permanence of tag retention, Thiokol held a tape to one shell by a firm bond.

Of the adhesives tested, Thiokol formed the firmest bond with the shells, but it was only partially satisfactory in trials during 1964 and 1966. The technique for applying adhesives and the disks or tapes was generally more time-consuming than that for inks or paints. The Thiokol hardened very slowly, even though an increase in the proportion of catalyst hastened the reaction. Low air and water temperatures during the tagging in December 1964 and April 1966 apparently retarded hardening of the Thiokol sealant; the clam shells probably did not reach the 27°C (80°F) temperature recommended by the manufacturer of the sealant for rapid hardening. In June 1968, Thiokol sealant applied in bright, warm sunlight began to set within less than an hour. When air and water temperatures were high, all of the adhesives hardened soon after the tags were applied. When the marked shells were recovered, the polyester tapes and plastic disks were firmly bonded by the Thiokol sealant, but were weakly attached by the other two adhesives.

The tendency of adhesives to raise the disk or tape tags slightly above the shell surface may increase the chances of recovering marked clams because fishermen and shuckers can feel as well as see the tag. The yellow vinyl tapes, although initially very colorful, became gray upon exposure to chemicals in the substrate. Neither the disks nor the polyester tapes became discolored, but the disks were less conspicuous on recovered clams than long white tapes. A message imprinted in color on the white tapes, giving directions for return of the recovered clam to the appropriate authority, adds to their visibility.

Handling the Thiokol sealant is facilitated by the use of special disposable containers. One manufacturer [4] produces a cartridge which holds the sealant and catalyst separately until needed, at which time they are mixed within the cartridge. No refrigeration is necessary. Another manufacturer mixes and freezes the sealant in plastic syringes where it is kept frozen until needed. Both have hand- or air-driven units that force the sealant from the cartridges or syringes.

Efficiency in tagging clams is increased by applying the sealant to the tags and storing them in a freezer, a preparatory step that may be done several hours or days before the tagging operation. By fastening 25 or more tags to a board or metal base, the sealant is dispensed on one end of each tag; the sealant is covered with a polyethylene sheet and the entire assembly stored in a freezer. The polyethylene sheet must be removed quickly after the tags are removed from the freezer because the sealant rapidly develops its adhesive qualities. A brief exposure of the sealant to air at 27°C for 1 to 1½ hr before freezing shortens the 2 hr period of setting.

Pre- and post-warming of the shells is necessary during the tagging operation, if the clams have been taken from water well below the recommended temperature for setting the sealant. Likewise, if air temperatures under field conditions

[4] The names and addresses of these manufacturers can be obtained from the Bureau of Commercial Fisheries Biological Laboratory, Oxford, Md. 21654.

are low, an infared heat source is, then, advantageous during the marking operations. A notch ground into the clam shells either before or after attaching the tags is necessary to complete the marking procedure (Fig. 4).

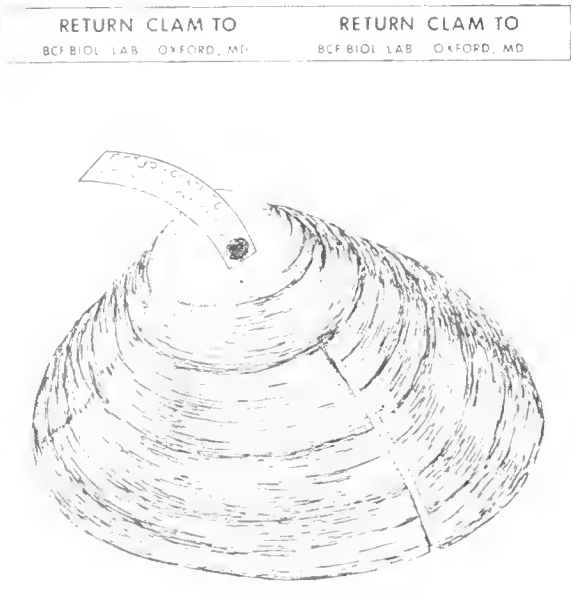

FIG. 4. *A surf clam bearing the tape tag and notch.*

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PRELIMINARY OBSERVATIONS ON THE PROPERTIES OF BOTTOM SEDIMENTS WITH AND WITHOUT EELGRASS, *ZOSTERA MARINA*, COVER

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ABSTRACT

In mid-July sediment conditions beneath a cover of Zostera *were compared with those of an open area on a shoal estuarine site in southern New England. Then the* Zostera *was rooted out of a plot; the* Zostera *blades were broken off to clear another tract; and in the open area some of the sediment was raked. The sediments from the altered and from control plots were compared again in mid-August. The analyses focussed on organic C, percent water and gross color characteristics for successive levels through the top 13 cm of the sediments. Silt-clay was measured at the sediment surface. Data obtained on pH, Eh and total plant pigments are not elaborated on because of questionable reliability. At the sediment surface the areas where* Zostera *grows had higher levels of organic C, a higher silt-clay content, and more interstitial water than did the open areas. Sediments from contrasting areas were more alike beneath the surface. Possible interrelationships between these surface parameters are discussed. No changes attributed to the clearing or raking of plots were observed in the one-month period.*

INTRODUCTION

Although the absence of a normal plant cover must bring about marked changes in any habitat, the effects of the eelgrass blight, with the disappearance of this community in the early 1930's, were not always as drastic nor as damaging as many had anticipated. In some instances the absence of eelgrass seemed to favor benthic populations, particularly those that might benefit from resulting changes in the sediment and from an increased flow of water close to the bottom, high in oxygen, plankton and seston and efficient in carrying off metabolic wastes (see Marshall, 1947 and 1960 for reports on bay scallops prospering where eelgrass had disappeared).

For a preliminary investigation of relationships between *Zostera* and sediment characteristics, of possible importance as such habitats may change or be changed, we selected two areas near the middle of the shoals about one mile north of the mouth of the Point Judith Pond estuary in Rhode Island. One area had a dense *Zostera* cover (by wt. 630 gm/m² for sample including rhizomes, and 445 gm/m² for sample of leaves only). The other was essentially free of macroscopic vegetation, except for a late season *Ulva* growth which tended to fill all open stretches. Our intent was to work with two areas similar except for the presence or absence of the eelgrass; however, the average depths in the eelgrass area ranged from the extreme low water mark to almost one foot below this level, while the open areas were just above the extreme spring low where eelgrass does not grow.

METHODS AND RESULTS

Plots 20 X 100 ft were staked out in the contrasting areas (two in the open area, three in the eelgrass). The program of modifications to and sampling of the sediments of the plots was as follows:

A. Open plots
  Sediments sampled 13 July 1967.
    On 17 July one plot left unchanged as a control and one plot raked vigorously to a depth of about 12 inches.
  Sediments resampled 14 August.

B. Eelgrass plots

Sediments sampled 17 July 1967.

On 17 July one plot left unchanged as a control and one plot denuded, the eelgrass being rooted out by hand.

On 20 July one plot denuded, the eelgrass blades being pulled out or broken off in an attempt to simulate cutting as contrasted to removing entire plants.

Sediments resampled 14 August.

Unfortunately, since clam diggers were active on the open area the so-called open plot control was probably turned over about as much as the raked area.

Samples were taken with plastic coring tubes 3½ cm in diameter. Each core was taken up-current of the previous one, working clear of surface disturbances. Care was taken to spread the coring over the sites under study.

Analyses of the cores were made as soon as they could be brought to the laboratory on the day of collection. A brief description was made of the cores noting changes with depth in the color and the gross characteristics of the sediment (Fig. 1). Next, the water was pipetted from the top of each core and sediment was extruded through the top of the tube for analyses of successive 1 cm layers.

Percent carbon (Table 1) was determined with a F & M Corporation CHN analyzer, model 185. About 2 ml 4% HCl was added to approximately 5 g of each dried sediment sample to remove carbonate carbon. After 24 hr at 80°C these samples were washed in distilled water, then dried, ground and processed in the CHN analyzer. Since some organic carbon may be lost in this procedure one must regard the residual as a quantity after a standardized treatment rather than an absolute value for total organic levels. Nitrogen levels were too low for measurement in these small samples.

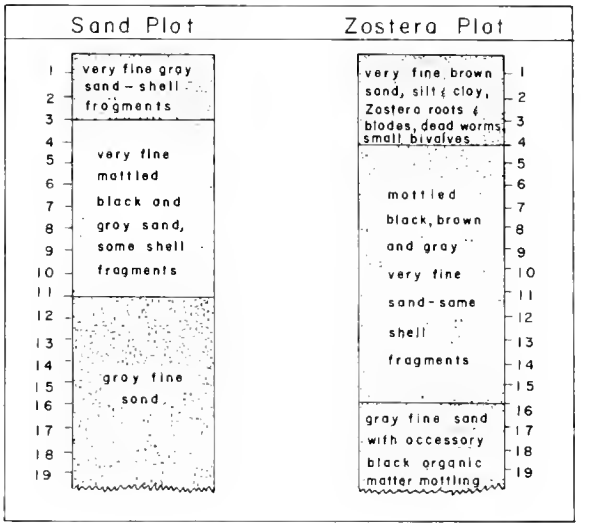

FIG. 1. *Generalized diagram comparing the gross appearance of sediment profiles in the open and the* Zostera *covered areas. There were no conspicuous changes in general appearance between the beginning and end of the observation period and even the most extreme alterations, raking an open plot and rooting* Zostera *from another, did not appreciably modify these profiles. (Depths are in cm).*

Percent water (Table 2) was calculated as the difference between the weight of a fresh sample and the reading after the sample had reached constant weight in an oven at 65-70°C.

On noting the difference in organic C at the surface, silt-clay analyses (Table 3) were made

TABLE 1. *Organic C (% by weight) of sediment samples from observation plots on the shoals of Point Judith Estuary, 1967. Number of samples (N) in parentheses. Standard deviation is given below each observation.*

Depth from sediment surface cm	Open			*Zostera* area			
	July	August		July	August		
	Both plots	Undisturbed plot	Raked plot	All plots	Undisturbed plot	Plot with *Zostera* pulled	Plot with *Zostera* rooted
Top cm	0.89(9) ±0.11	0.88(5) ±0.17	0.84(5) ±0.11	1.57(10) ±0.50	1.25(5) ±0.22	1.89(5) ±0.34	1.39(5) ±0.30
2-3	0.87(10) ±0.10	0.84(5) ±0.17	0.64(5) ±0.15	1.34(10) ±0.32	1.22(5) ±0.27		
12-13	0.87(9) ±0.08	0.64(5) ±0.18		0.66(7) ±0.10	0.67(5) ±0.11		

TABLE 2. *Water content (% by weight) of sediment samples from observation plots on the shoals of Point Judith Estuary, 1967. Number of samples (N) in parentheses. Standard deviation is given below each observation.*

Depth from sediment surface cm	Open			*Zostera* area			
	July	August		July	August		
	Both plots	Undisturbed plot	Raked plot	All plots	Undisturbed plot	Plot with *Zostera* pulled	Plot with *Zostera* rooted
Top cm	24(9) ±0	26(5) ±2	24(5) ±1	43(10) ±6	36(5) ±4	33(5) ±6	40(5) ±3
2-3	25(9) ±2	27(5) ±3	24(4) ±0	36(10) ±5	33(5) ±2	37(5) ±4	36(5) ±3
5-6	29(10) ±3	28(5) ±2	26(5) ±2	28(10) ±2	30(5) ±4	33(5) ±3	28(5) ±3
8-9	24(10) ±2	24(5) ±3	23(5) ±3	26(10) ±2	27(5) ±2	27(5) ±2	26(5) ±1
12-13	22(10) ±1	22(5) ±1	21(5) ±1	24(10) ±2	24(5) ±1	25(5) ±2	24(4) ±2

on subsamples taken from the top layer. Each was mixed with approximately 100 ml hydrogen peroxide and the mixture was heated gently for 5-10 min to remove organic matter. Next it was evaporated to dryness to expel the hydrogen peroxide. The samples were then divided into two fractions by dispersing in water, allowing the sand and coarser particles to settle[1] and decanting off the suspension of silt-clay. Both fractions were dried and weighed.

Eh readings (Table 4) were made with a Photovolt model 85 meter. This is a very unsatisfactory measurement to attempt, at least with the equipment available; furthermore, once the sediment sample is removed in a coring tube from the bottom environment there may be a rapid release of chemicals, such as H_2S and CO_2, which influence Eh. Oppenheimer and Kornicker (1958) comment on this release with respect to the unreliability of pH measurements and we are not reporting on this parameter except to note that for all areas and depths our readings were around pH 6.

Similarly we are not reporting determinations made for total plant pigments. We were unable to differentiate chlorophyll and phaeotype pigments by fluorimetry, due we believe to interfering fluorescence by other sediment subtances. Absorption methods gave readings usually greater than 100 g/m² on layers 1 cm thick. There was considerable variation in samples from a given plot; there was a lack of patterns indicative of differences between areas or with time; and, in view of the high values, it seems probable the pigments were made up largely of residual, inactive components.

[1] Settling time was as stipulated in Krumbein, W. C. and F. J. Pettijohn, 1938. Manual of sedimentary petrography. D. Appleton-Century, New York.

TABLE 3. *Percent silt-clay (by weight) of sediment samples from observation plots on the shoals of Point Judith Estuary, 1967. Number of samples (N) in parentheses. Standard deviation is given below each observation.*

Depth from sediment surface	Open			*Zostera* area			
	July	August		July	August		
	Both plots	Undisturbed plot	Raked plot	All plots	Undisturbed plot	Plot with *Zostera* pulled	Plot with *Zostera* rooted
Top cm	4(10) ±2	5(3) ±3	5(5) ±3	13(9) ±4	14(5) ±6	15(5) ±6	13(5) ±6

TABLE 4. *Eh (mv) of sediment samples from observation plots on the shoals of Point Judith Estuary, 1967. Number of samples (N) in parentheses. Standard deviation is given below each observation.*

Depth from sediment surface cm	Open			*Zostera* area			
	July	August		July	August		
	Both plots	Undisturbed plot	Raked plot	All plots	Undisturbed plot	Plot with *Zostera* pulled	Plot with *Zostera* rooted
Top cm	−60(10)	−22(5)	−28(5)	−166(10)	−89(5)	−159(5)	−27(5)
	±61	±24	±47	±39	±69	±59	±44
2-3	−124(9)	−79(5)	−78(5)	−225(10)	−145(5)	−184(5)	−144(5)
	±70	±68	±56	±21	±63	±44	±73
5-6	−151(9)	−163(5)	−130(5)	−216(10)	−186(5)	−203(5)	−216(5)
	±48	±43	±35	±27	±18	±14	±17
8-9	−153(9)	−144(5)	−90(5)	−196(10)	−182(5)	−200(5)	−183(5)
	±49	±49	±49	±29	±28	±10	±8
12-13	−123(9)	−100(5)	−69(5)	−164(10)	−174(5)	−193(5)	−172(5)
	±52	±30	±43	±59	±19	±24	±16

DISCUSSION OF RESULTS

Differences between the open and the *Zostera* covered areas are seen in the top cm layer whereas in the deeper layers the properties considered tend to fall within the range of the sampling or measurement variability. No consistent changes were observed in the one-month period as a result of removing the *Zostera* or raking the plots. The sediment surface differences quite obviously reflect a greater silt deposition and higher sustained organic carbon levels in the areas where *Zostera* grows (Table 2 and 3). Interactions between these two factors and other properties of the environment may account for other differences.

Marshall (a and b, in press) has pointed out that, though organic matter is added to shoal benthic environments at a high rate, utilization, particularly by microbiota, is so rapid that the residual organic C levels are characteristically low. In an area where the remaining organic matter is a little higher than on an adjacent tract the difference may reflect a greater settling of organics, less removal by scour, bonding with silt-clay particles and a depressed rate of mineralization. Probably all processes interrelate. The higher levels of silt-clay in the area suggest that there is a parallel increased settling of organic matter or that less of the silt-clay and organic matter input is removed by scour. Added silt-clay also increases the surface area available for bonding organic matter and the bonding in turn depresses the extent of mineralization. Finally, the utilization of organic matter by the interstitial community may take place at a slower rate in the *Zostera* area if sediment surface conditions are anaerobic, and there are several observations which suggest that this is so. For example, the circulation of the overlying water is somewhat restricted around the leaves of the dense vegetation, thus oxygen losses from oxidation of organic matter in the sediment and from respiration of the *Zostera* and its awfwuchs are not readily offset from the passing flow. This is illustrated in Table 5. According to our observations on three summer dates on an estuarine shoals near Point Judith Pond, the benthic microflora productivity,

TABLE 5. *Dissolved oxygen (all recorded as % saturation) obtained over a dense bed of* Zostera *in 9 feet of water near Mystic, Connecticut.*

Date	Time	Tide	Temp	Dissolved Oxygen	
				Mid Depth	Amongst stems of *Zostera*
7/4/68	2200	ebbing	19.5°C	100	63
7/5/68	0625	ebbing	14°C	95	71
7/5/68	0640	ebbing	15°C	95	73

a significant source of oxygen input at the sediment surface, was always higher in the open and on one date was five time the production recorded under adjacent *Zostera* cover. The Eh measurements (Table 4), though very inconsistent, also suggest anaerobic conditions at the surface of the sediment.

In addition to the higher organic matter and silt-clay content, the sediments from the *Zostera* area had a higher water capacity (Table 2). This could have been due to complexes of organic matter bonded to silt-clay, resulting in physical properties that offset compaction. Properties of this sort are of considerable ecological importance (Marshall b, in press) but have not been studied appreciably in sediments.

Beneath the sediment surface the utilization of organics by the interstitial biota apparently advances in both environments until a minimum residual quantity prevails (Table 1); furthermore, at these layers, sediments from both areas are decidedly reduced (Table 4) and thus may be more alike with respect to mineralization processes. The gross observations on the cores (Fig. 1) support the generalization that differences were greatest near the sediment surface.

It seems likely that, if properties of the *Zostera*-free area are to be brought about by clearing, tracts of larger dimensions must be maintained for longer periods. In the area we worked, cleared plots will not maintain themselves. In fact we were not able to distinguish the cleared plots in July of the next growing season.

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ASSOCIATION AFFAIRS

ANNUAL CONVENTION

The National Shellfisheries Association's 1969 Convention was held jointly with the Oyster Institute of North America and the Oyster Growers and Dealers Association of North America, Inc. from July 13-17, in New Orleans, Louisiana.

Officers and Executive Committee members elected for the term 1969-1970 were:

President	Albert K. Sparks
Vice-President	Frederick W. Sieling
Secretary-Treasurer	Mrs. Helen J. Haynie
Members-at-large	James E. Hanks
	R. Winston Menzel
	Michael Castagna
Co-Editors, NSA Proceedings	
	William N. Shaw
	Arthur S. Merrill

John W. Ropes of the Bureau of Commercial Fisheries Biological Laboratory at Oxford, Maryland is Custodian of back issues of the NSA Proceedings.

Dr. G. Robert Lunz was elected to honorary membership in the National Shellfisheries Association. Mr. Arthur Merrill is to receive a suitable plaque for his excellent work as Editor of the Proceedings and also a Life Membership in the Association.

It was recommended that a symposium be held at the 1970 meeting. Dr. Jay D. Andrews, Dr. R. Winston Menzel and Dr. Kenneth K. Chew were appointed to serve as a committee to prepare a symposium for our next annual meeting.

The membership has steadily grown with the membership now totaling 271, including Honorary and Life Members, with 78 active library subscribers and 4 abstract companies.

The Pacific Coast Section of the NSA met jointly with the Pacific Coast Oyster Growers Association on 22 August 1969 at the Edgewater Inn, Seattle, Washington. Officers of the Section elected for the term 1969-1970 were:

Chairman	Ronald E. Westley
Vice-Chairman	Robert B. Herrmann
Secretary-Treasurer	Walter Jakubowski

The Pacific Coast Section noted that there was a good possibility for the 1971 joint meeting of the National Shellfisheries Association and the Oyster Institute of North America being held in Seattle, Washington.

Regular membership to the NSA is $6.00, library subscription is $6.00, and patrons contribute $100.00 or more.

INFORMATION FOR CONTRIBUTORS TO THE PROCEEDINGS OF THE NATIONAL SHELLFISHERIES ASSOCIATION

Original papers given at the Annual Association Convention and other papers on shellfish biology or related subjects will be considered for publication. Manuscripts will be judged by the Editorial Committee or by other competent reviewers on the basis of originality, contents, clarity of presentation and interpretations. Each paper should be carefully prepared in the style followed in the 1965 PROCEEDING (Volume 56) before submission to the Editorial Committee. Papers published or to be published in other journals are not acceptable.

Manuscripts should be typewritten and double-spaced: original and two copies are required to facilitate reviews. Tables, numbered in arabic, should be on separate pages with the title at the top. Scientific names should be underlined. Illustrations preferably should be 8 x 10 inch prints which can be reduced to a size of 6 1/4 x 8 inches or smaller. Glossy photographs are preferred to originals. Illustrations smaller than a page should be carefully oriented and loosely attached to plain white paper with rubber cement. Legends should be typed on separate sheets and numbered in arabic.

Authors should follow the style prescribed by *Style Manual for Biological Journals* which may be purchased for $3.50 from the American Institute of Biological Sciences, 2000 P. Street, NW, Washington 6, D. C. In case of a question on style that is not answered by this manual, the author should refer to the latest volume of PROCEEDINGS. *American Standard for Periodical Title Abbreviations*, available for $2.00 through American Standards Association, Inc., 10 E. 40th Street, New York, New York 10016, should be followed in the "Literature Cited" section.

Each paper should be accompanied by an abstract which is concise yet understandable without reference to the original article. It is our policy to publish the abstract at the head of the paper and to dispense with a summary. A copy of the abstract for submission to Biological Abstracts will be requested when proofs are sent to authors.

The author or his institution will be charged $20.00 per printed page for all pages over 10. If figures and/or tables make up more than 1/3 of the total number of pages, there will be a charge of $30.00 for each page of this tabular material (reckoned on the actual amount of page space taken up) in excess of the set limit, regardless of the total length of the article.

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Contributions are accepted at any time. However, for inclusion in the PROCEEDINGS of the *current* year, all manuscripts should reach the Editor prior to October 1. Send manuscripts and address all correspondence to the Editor, William N. Shaw, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland 21654.

PROCEEDINGS OF THE NATIONAL SHELLFISHERIES ASSOCIATION

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