

ABSTRACT

Roger Moser Crump. POPULATION DENSITY AND DISTRIBUTION OF THE
ESTUARINE CLAM RANGIA CUNEATA IN CROATAN SOUND, NORTH CAROLINA.

(Under the direction of Dr. Vincent Jerome Bellis) Department of
Biology, June, 1971.

Rangia cuneata, an estuarine clam, occurs in scattered patches along the northwestern shore in Croatan Sound. Population density ranged up to 12 clams per square meter. Overall distribution of Rangia was correlated with bottom sediment type, being found primarily on fine and medium-fine sand substrates. Local distribution is related to mean grain size, organic content of the sediment, and water depth. Shallow, mesohaline water with a medium-fine sand substrate, low in organics, best describes the habitat of Rangia cuneata in Croatan Sound.

Six separate size frequencies (year classes) were found during the survey. The fourth and fifth year clams were most abundant. According to this study, the five year Rangia should be the most economically profitable clams, since their meat weight was double that of the four year clams. Rangia's thick shell accounted for 75% of its total weight, thus making it an important carbonate source, both commercially and ecologically.

POPULATION DENSITY AND DISTRIBUTION
OF THE ESTUARINE CLAM RANGIA CUNEATA
IN CROATAN SOUND, NORTH CAROLINA

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INTRODUCTION

Rangia cuneata is an estuarine clam of potentially great economic value and ecological significance to the Middle and South Atlantic States. Dense populations of this clam have long been exploited in the Gulf States, especially Louisiana and Texas, where commercial beds annually yield as high as \$775 per acre (Hopkins and Andrews, 1969). Over fifty-one thousand pounds of Rangia cuneata were harvested in North Carolina in 1966 (Godwin, 1968), just fifteen years after the clam was first reported in that state (Wells, 1961). Although it has yet to be established whether Rangia cuneata has been reintroduced to the Atlantic Coast in recent times, or whether present populations originated from disjunct native stock, current authorities agree that the clam is rapidly increasing in relative abundance and is expanding its range from Maryland to Florida.

Rangia cuneata is valued primarily for its shell which may be used in roadmaking and construction, or crushed and converted to agricultural lime. The meat is also of economic importance. Local residents of many coastal areas are using Rangia as food. In the latter part of the nineteenth century, its meat was eaten in the Gulf States, with one Texas oyster packing house canning and marketing it under the name "Little Neck Clams" (Singley, 1893 as cited by Hopkins and Andrews, 1969).

Little is known about the importance of Rangia cuneata in the benthic community. It is a significant addition to the estuary because it populates the mesohaline zone where few other invertebrates live.

It is of ecological importance because it converts detritus to meat, feeding many fishes and blue crabs. Rangia's thick shell serves as a "carbon sink" for the estuary, pulling dissolved carbon from the water and storing it as calcium carbonate shell material.

No previous investigations concerning Rangia cuneata have been undertaken in Croatan Sound. Few non-residents knew of this clam's presence, though it now appears that Rangia cuneata is a well established benthic inhabitant in Croatan Sound. The principal objectives of this study were three-fold: (1) to establish a base study showing the present distribution and density of Rangia cuneata in Croatan Sound; thus enabling future investigators in this area to estimate population growth rates and changes in local range; (2) to establish the best parameters for estimating total clam biomass using various growth relationships, such as length-width ratio, and meat weight-shell weight comparisons; (3) to correlate the distribution and density of Rangia cuneata in Croatan Sound with bottom sediment type and depth. Sediment parameters analyzed were particle size distribution and organic content.

LITERATURE REVIEW

Rangia cuneata Gray, 1831, is a pelecypod mollusk of the Family Mactridae. According to Abbot (1956), its range is from northwest Florida to Texas. Pleistocene deposits containing Rangia cuneata have been found along the Atlantic Coast from New Jersey southward to the Gulf Coast (Dall, 1894; Richards, 1939 as cited by Fairbanks, 1963).

Prior to 1955, no extant populations of Rangia cuneata were recorded for the Atlantic Coast. Now living Rangia populations have been found in estuaries from Maryland to Florida. What is the cause of this recent surge in population growth? Biologists have two theories: (1) that Rangia cuneata is a recent invader from the Gulf Coast, extending its range 1000 miles, or (2) that some unknown ecological change sparked the resurgence of an undiscovered population surviving since the Pleistocene in East Coast estuaries (Hopkins and Andrews, 1969).

Wells (1961) included Rangia cuneata among the fauna associated with oyster beds in the Newport River, North Carolina. This study, carried out in 1955-1956, constitutes the first report of living Rangia cuneata on the Atlantic Coast. Large populations of Rangia cuneata have since been found in the Potomac River, Maryland, where they were consumed as food by local residents (Pfitzenmeyer and Drobeck, 1964). These same investigators suggested that the clams had been introduced about 1960 through oyster cultivation, the seed oysters having been obtained from the James River in Virginia where Rangia were already established (Chanley, 1965).

In North Carolina Rangia cuneata has been collected from the Neuse

and Trent Rivers in 1965 (Wolfe and Schelske, 1969), and from the Pamlico River (Tenore, 1968). In Georgia dense populations of Rangia cuneata have been discovered in the Altamaha River (Godwin, 1968).

Very little information is available concerning the reproduction, anatomy, or physiology of Rangia cuneata. Chanley (1965) collected adult clams from the James River in Virginia, induced them to spawn, and successfully raised the larvae in the laboratory. He observed that they develop a foot and metamorphose at a much smaller size than other mactrids, beginning metamorphosis after seven days. The growth rates of Rangia cuneata have been investigated using clams found in the Trent River, North Carolina (Wolfe and Petteway, 1968). Length-frequency ratios were determined, revealing five distinct size and age groups. A von Bertalanffy curve was established describing the growth of Rangia cuneata. This curve indicated maximum length of 75 mm. would be reached in ten years.

Fairbanks (1963) has undertaken the most complete investigation of Rangia cuneata with respect to population density, size of individuals, and the reproductive cycle. Two localities in Lake Pontchartrain, Louisiana were sampled in 1957 and 1958. The north shore area was found to have a greater population density of adult (sexually mature) Rangia than the south shore area. The adults of the north shore area were smaller and less variable in length than those of the south shore area. Sex was more easily distinguishable, the gonad firmer, and coloration of the gonadal tissue more distinctive in the south shore clams. Growth rates, except the larger ten percent of adults, were consistently higher in the south shore area. Fairbanks

(1963) reported that, with the exception of organic matter in solution, the physical and biological environmental factors that were measured or estimated did not differ greatly between the two study areas. The greatest difference in the two environments was the empirically determined organic content of the sediments, the north shore having the higher values. His conclusions were that the observed differences in Rangia cuneata (density, length, sex) between the two areas could be attributable chiefly to differences in organic content of bottom deposits and organic matter in solution.

Other workers have attempted to correlate the distribution and density of Rangia cuneata with substrate. Tenore (1968) used in situ experiments which revealed that the mud sediments, especially with high concentration of organics and phosphate, adversely affect survival and growth. However, sand sediments with high levels of organics and phosphate, were found to be favorable to Rangia survival and growth. Only large clams were used in this experiment, leaving open the possibility that smaller Rangia might survive in mud sediments, and larger Rangia in sandy sediments.

The findings of Godwin (1968) appear to confirm the conclusions drawn by Tenore. Sampling the Altamaha River in Georgia, he found Rangia cuneata on predominantly mud-sand substrates. The majority of the clams found were large, averaging 45 to 50 mm. in length.

Dense populations of Rangia cuneata have been sampled in the Pamlico River (Slaughter and Yonce, 1970). These clams were all taken from a clay-silt substrate of high organic content, contradicting the results of Tenore. Very high densities of clams were recorded, 993 clams

per square meter at one station. Average length was only 28 mm., so according to Wolfe and Petteway (1968) these clams were approximately two years old. This suggests that the survival rate of Rangia on clay-silt substrates is very low after the first two years of growth.

Tenore (1970) discovered that new set of Rangia cuneata larvae occurred in mud areas during winter in the Pamlico River, but quickly disappeared in response to environmental selection. He found adult Rangia only in sandy sediments. Thus he demonstrated that Rangia cuneata could not survive on mud substrates. However, Godwin (1968), in his Georgia survey, collected some large clams from two stations containing mud sediments. Godwin (1968) quotes Woodburn as stating that Rangia cuneata occurred only on soft muddy bottoms in the Peace and Myakka Rivers in Florida.

Bottom sediment relationships with other benthic mollusks have been established also. Newcombe and Kessler (1936) studied variations in growth indices of the clam Mya arenaria on the Atlantic Coast of North America. They found large differences between shell weight-to-total weight ratios in the four areas studied. These authors attributed this to temperature differences. The sediments in these study areas varied from mud to sand, with the heaviest shell weights recorded in the mud or high organic bottom types. Body weights were highest in the sandy areas. This study suggested a sediment relationship to shell and body weight.

Swan (1952) reported different growth rates in populations of Mya arenaria living only a few miles apart. The larger clams were found in a sandy bottom with some mud, while smaller clams were

associated with a mud, gravel, and shell substrate. In clams planted experimentally, both in sand and in a mud-gravel mixture, the clams grown in sand had growth rates double of those grown in the mud-gravel mixture.

Rhoads and Young (1970) suggested reasons for the absence of suspension-feeding benthic organisms in soft muddy substrata. Three reasons were given: (1) clogging the filtering structures of suspension feeding organisms, (2) burying newly settled larvae or discouraging settling of suspension-feeding larvae, and (3) preventing sessile epifauna from attaching to an unstable mud bottom. The authors state in their summary: "Correlation of the benthic trophic structure with the sediment-water interface stability in the region of subtidal muds may be one of the most important but neglected parameters of benthic ecology."

Pfritzenmyer and Drobeck (1967) investigated factors affecting the reburrowing activity of Mya arenaria. Laboratory experiments revealed three variables, water temperature, clam size, and sediment particle size to be highly significant. Smaller clams reburrowed sooner, 18 degrees centigrade being optimum water temperature for reburrowing, and a decrease in reburrowing capacity occurred as sediment particle size increased. They concluded that most clams deposited on the bottom by commercial dredgers would reburrow back into the sediment.

Most authors have agreed that there is a sediment relationship governing distribution and growth of Rangia cuneata. Discrepancies occur when the type of substrate that is beneficial or harmful to Rangia is discussed. Studies so far have indicated that dense populations

of small Rangia occur in mud and clay-silt substrates, while larger, sexually mature clams are found in sandy sediments. This investigation and future studies will aid in answering the question as to which type or types of substrate are most favorable for Rangia cuneata survival and growth.

MATERIAL AND METHODS

Collections of Rangia cuneata were made in Croatan Sound, Dare County, North Carolina, during August 1970. These collections were made in conjunction with a comprehensive study of the benthic ecology of Croatan Sound headed by Dr. Vincent Bellis. Croatan Sound was chosen for this study because it offered, in one sound, nearly the full range of benthic habitats characteristic of estuaries in this region. Figure 1 shows the location of Croatan Sound in relation to the Outer Banks of North Carolina. A grid was set up covering the entire sound (Figure 2) and subsequent sampling along this grid indicated areas where Rangia was most abundant (Figure 3).

Individual Rangia beds were sampled by various techniques. First, a survey was made of the western shore to locate major populations of Rangia cuneata. Next, depending on the size of the clam bed and the shore line contour, one of three types of transects was employed.

A system of radiating transects was used at Station 14 (Figure 4) to sample a cove (U-shaped shoreline) where the Rangia distribution was restricted to the cove. To construct this system a base station was established on the shore, being marked by a permanent metal stake in the beach. Then, with the aid of compass and range-finder, dive stations were marked by buoys at 50 yard intervals along radiating compass lines. A sandy substrate underlain by peat was found throughout much of Station 14. The northern end of this cove, however, had been stripped of its sand covering by waves and currents, exposing the peat. This sand had apparently been piled up along the southern shore, creating

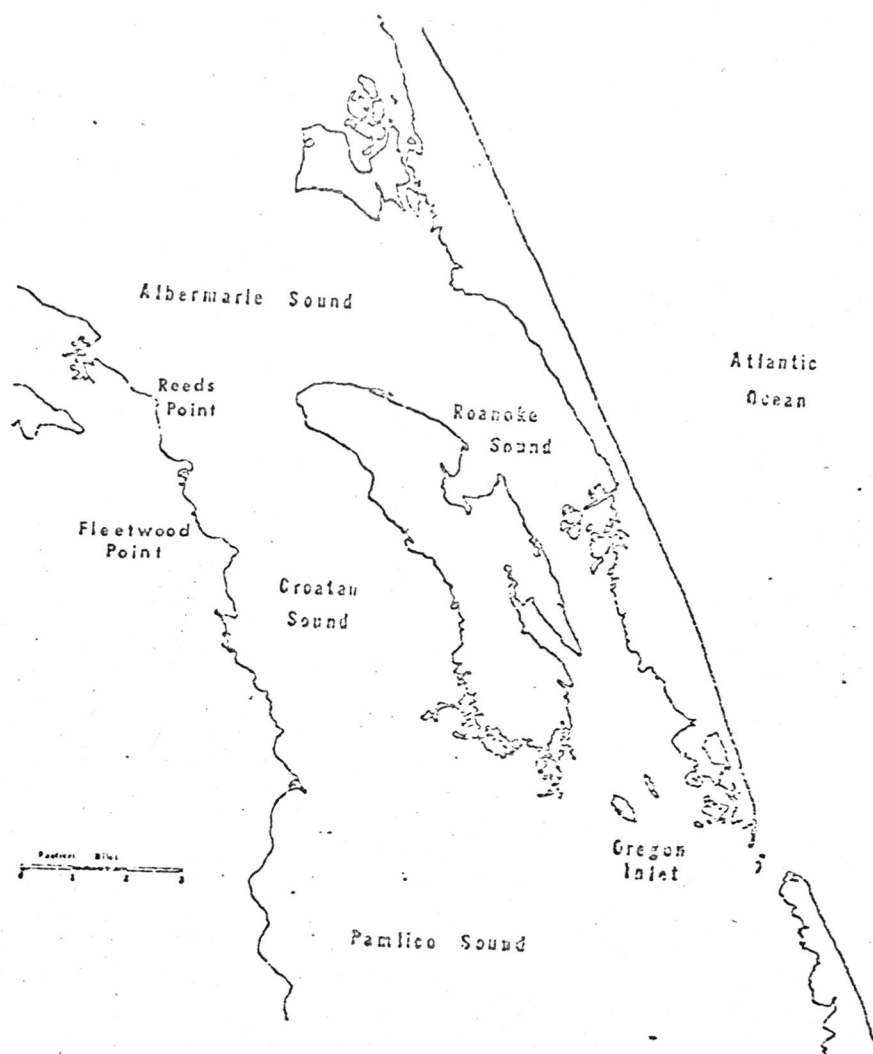


Figure 1. The position of Croatan Sound along the Outer Banks of North Carolina.

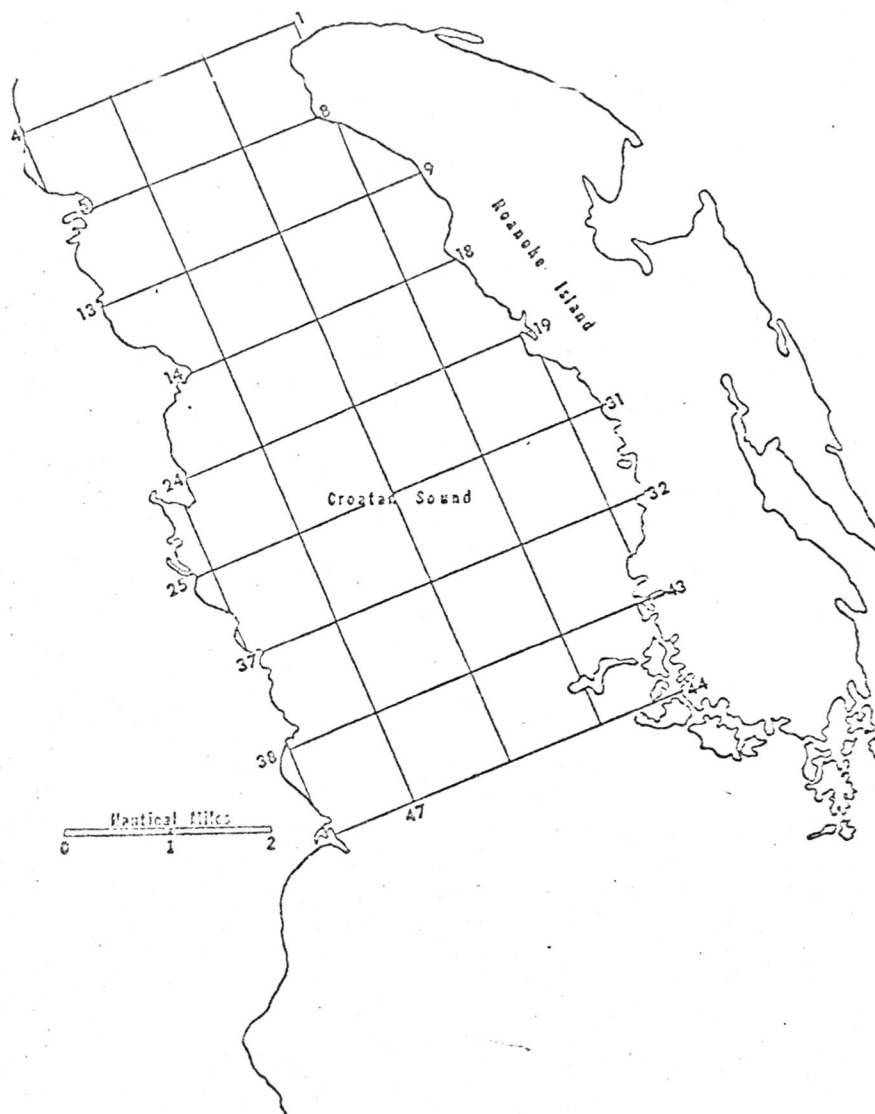


Figure 2. Grid used in benthic ecology study in Croatan Sound.
(Numbers on grid indicate dive stations.)

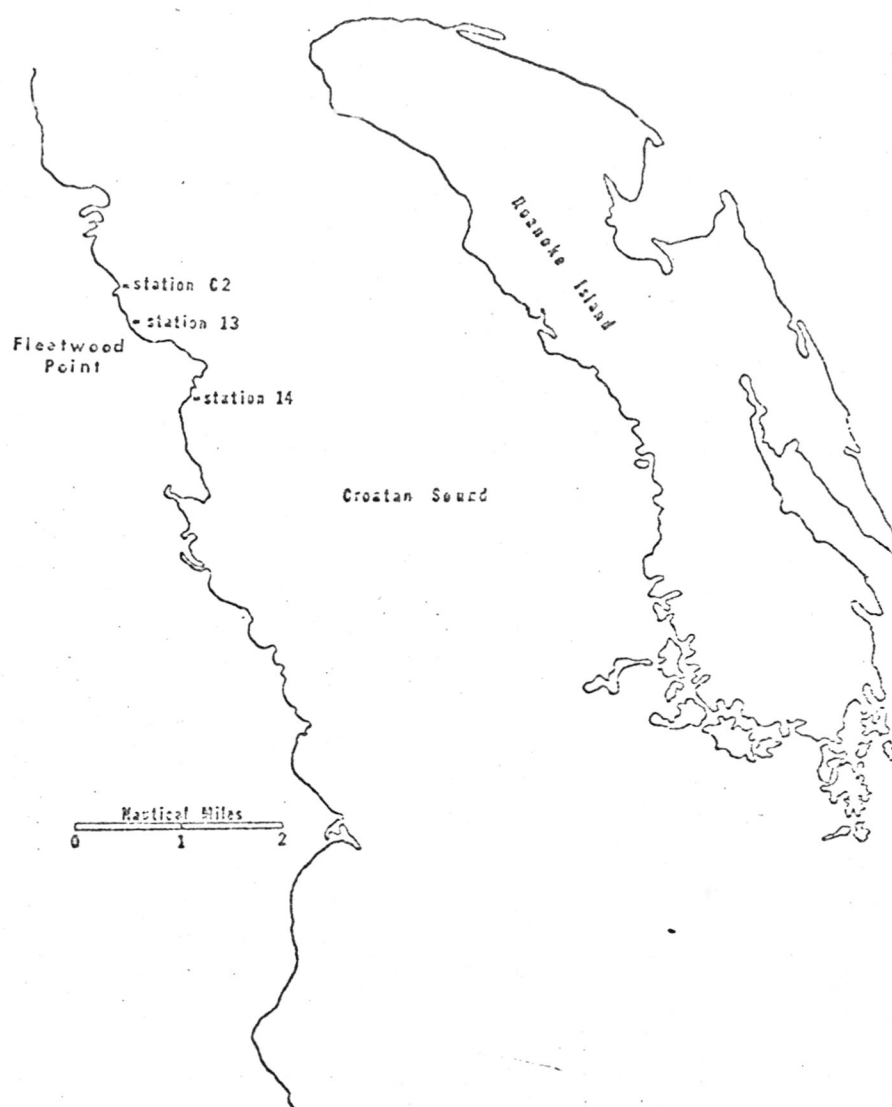


Figure 3. Location of collection stations in Croatan Sound.

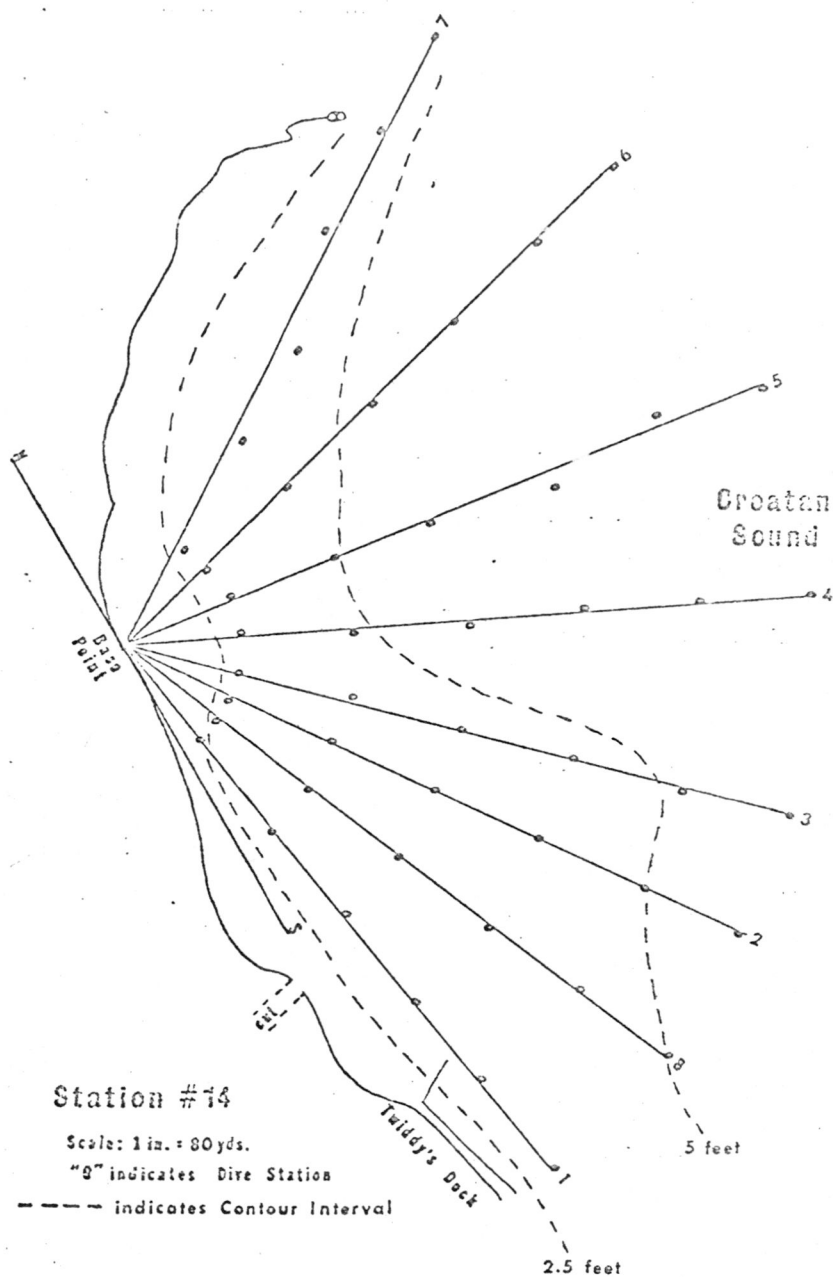


Figure 4. System of "radiating" transects used at station 14.
 (Dive station one occurs 50 yards from base point on each
 transect, station two-100 yards,.....station six-300 yards)

a small beach ridge.

A grid pattern (Figure 5) was used at Station 13 where there was a straight shoreline and widespread distribution of Rangia. Transect lines were extended from the shore along a baseline at a fixed compass reading, each marker being 50 yards apart. Transect one, marked by a metal stake, was considered the base point. The substrate of Station 13 was also sandy, although an eroding ferruginous sandstone outcropping was found at the northern end. The bottom was also composed of this material in the northern section. A sandy beach and ridge had been created along the shoreline, except in the northern end, behind which was an extensive Juncus marsh.

Station C-2 (Figure 6), a straight line transect, was used because there was a small isolated population of clams in a small cove. On this transect the buoys were 10 yards apart. The substrate was predominantly sand, but was underlain by clay and peat. A Juncus marsh grew to the edge of the water, no sand beach having been formed.

A motorized barge was used to transport equipment to and from the collection areas. SCUBA divers were sent down to collect, by hand, all Rangia within a meter-square metal frame. The author feels that there were certain advantages in using SCUBA during this study. A diver can cover a large sampling area accurately and efficiently and actually "sees" what he is collecting, providing a visual description of the benthic habitat. In addition, any type of bottom substrate can be sampled, whereas with a grab or dredge only soft sand and mud can be worked effectively. Disadvantages in using SCUBA would be that smaller

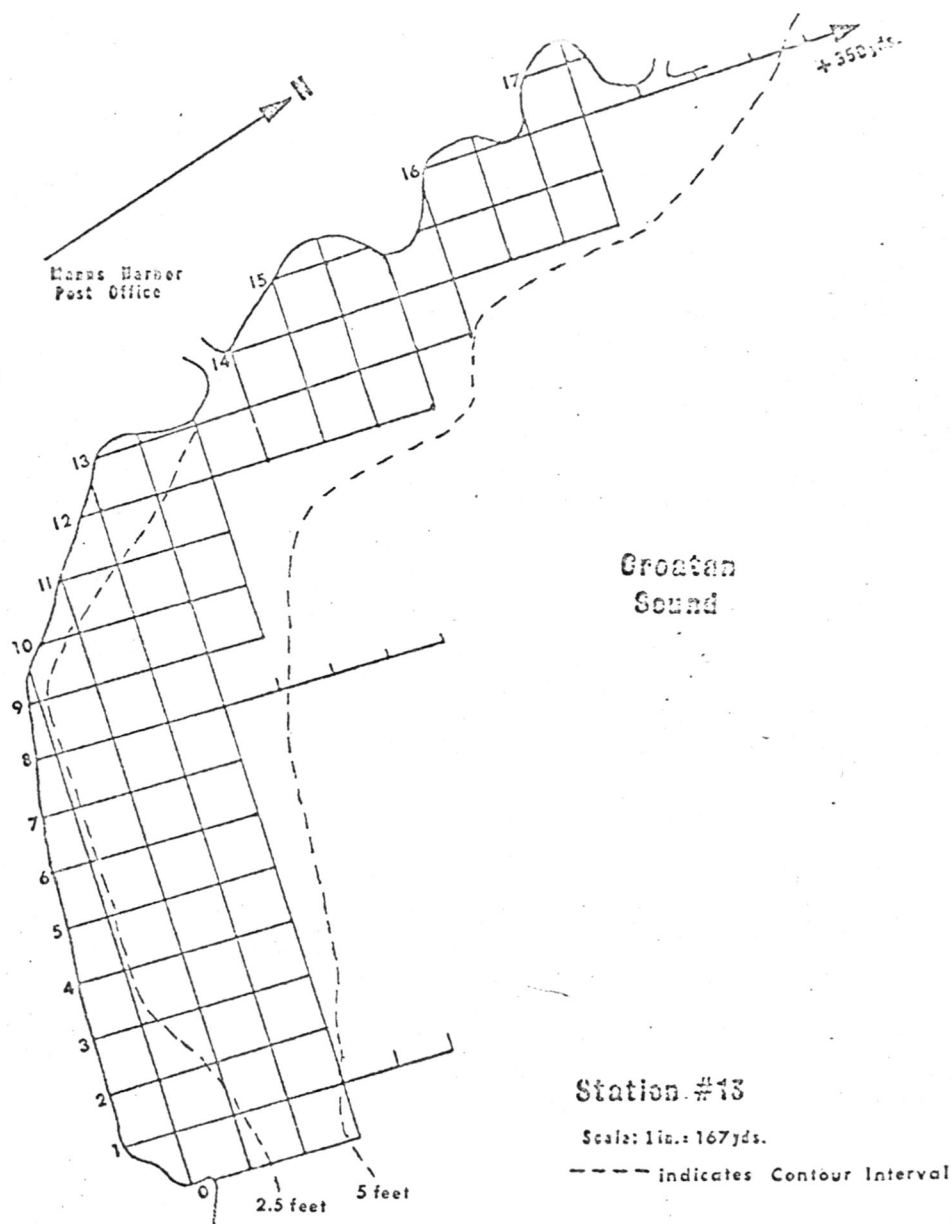


Figure 5. Grid pattern used at station 13.

(Dive station one occurs at the intersection of the first line perpendicular to each transect, dive station two-50 yards from station one,.....dive station four-150 yards.)

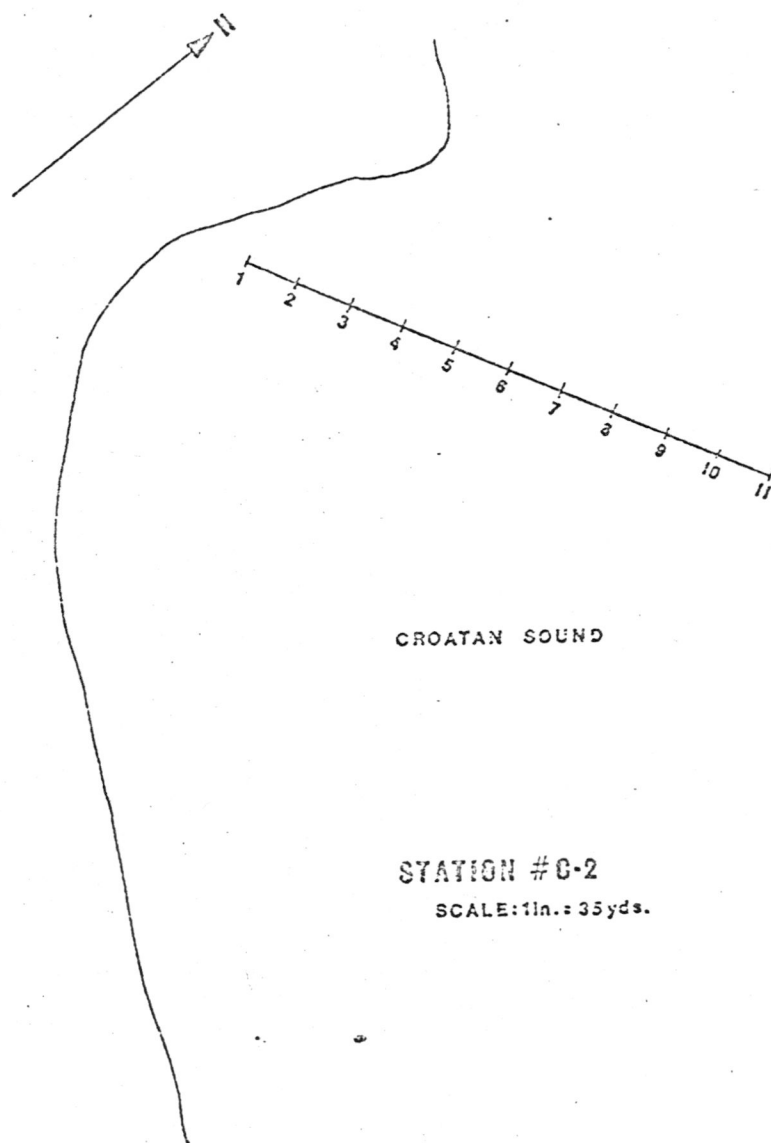


Figure 6. Transect used at station C-2.

clams (less than 10 mm.) were missed and that there were individual variations in the different diver's techniques.

During the survey, 154 dive stations were sampled, with over 650 live clams being collected. Both live clams and empty Rangia valves were collected from the meter frame. Length and thickness of each live Rangia cuneata were measured with a Vernier caliper to the nearest millimeter. The total weight, meat weight, and shell weight of each clam was measured to the nearest one-hundredth gram. The individual lengths of the empty Rangia valves were measured and the total weight of these shells per station was recorded.

At each dive station a sediment sample was taken in an undisturbed area adjacent to the frame. A four-inch-diameter transparent poly-vinyl-chloride core tube, hand operated by the diver, was used to collect sediment (Figure 7). The top three inches of each core were saved and subsequently used for substrate analysis. Rangia burrow just beneath the substrate surface, thus interacting with only the top three inches of sediment. Cummins (1962), in his evaluation of collection methods for benthic invertebrates and sediments, states that the core tube is the only accurate method for the collection of sediment samples. Grabs and dredges do not retain the entire sediment sample, and will not work effectively in all types of substrates.

Analysis of sediment samples consisted of measuring grain size distribution and the percentage organic material contained in the sediments. These two parameters are of prime importance in studies of benthic organisms and their substrate relationships (Cummins, 1962).

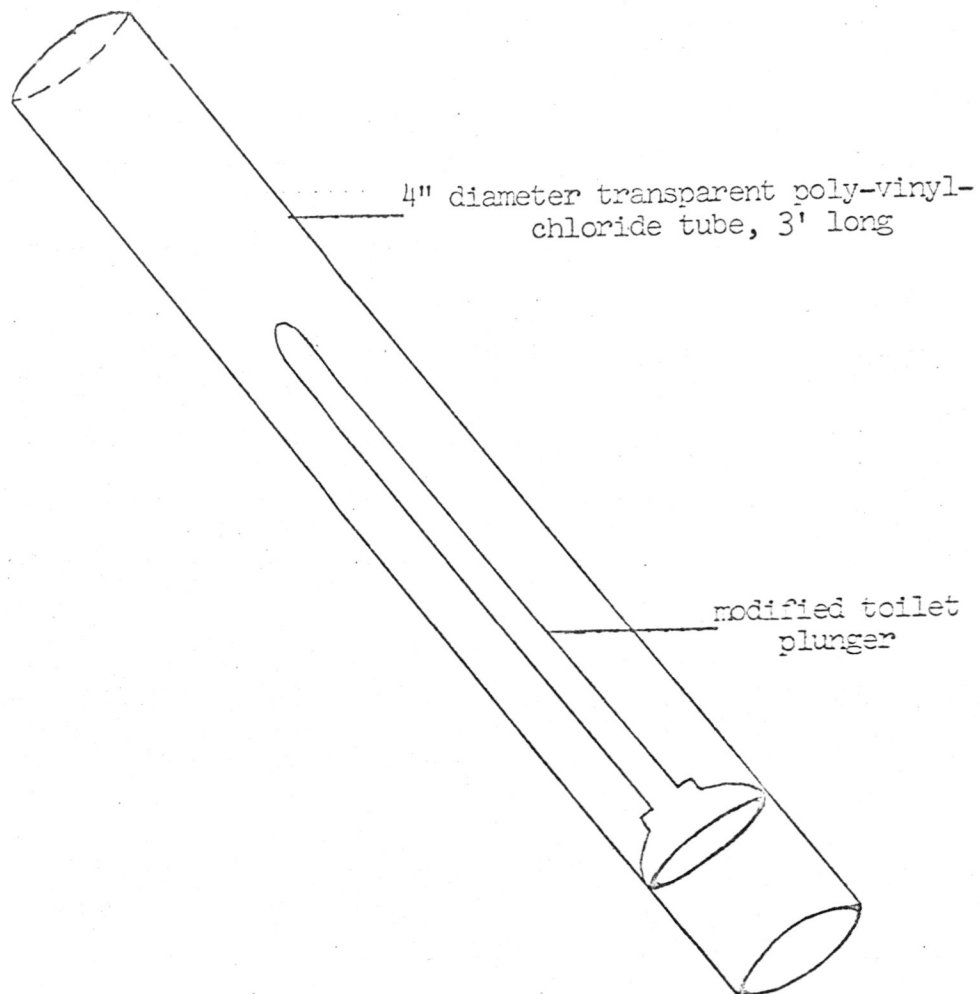


Figure 7. Hand operated coring device.

Grain size distribution was determined according to dry and wet seive techniques described by Folk (1968). Each sample was first broken up to destroy sand aggregates, then a fifty-to-seventy gram sample was weighed to the nearest one-hundredth gram. This sample was placed into a set of Fisher U.S. Standard Seives, ranging in phi size from -2.0 phi to 4.5 phi, at one-half phi intervals. This sample was then ro-tapped for 15 minutes on a Tyler RoTap. Each grain size fraction was then taken from the seive and weighed.

Wet seiving was used only when a high proportion of the sample consisted of organics or clay. A weighed sample was washed through a 4.5 phi seive, using Calgon solution to disperse the clay particles. The fraction remaining in the seive was dried and then dry sieved. The fraction that passed through the screen was classified as silt and clay, its weight being added to the 4.5 phi grain size interval.

A computer program was used to calculate the statistical parameters for grain size distribution. This program, written in Fortran IV, is given in Table 10 in the Appendix. Statistics calculated by this program were mean grain size, sorting, skewness, and kurtosis, which are defined in the Glossary.

The amount of organic matter present in the sediments was determined by "loss of weight on ignition." Each sediment sample was dried at 100 degrees centigrade for 24 hours. Then approximately 5 grams of dry sample were weighed to the nearest milligram and ashed for 5 hours at 500 degrees centigrade in a Lab Heat muffle furnace. The difference in weight before and after ashing represented the organic fraction.

Modified standard computer programs were used to calculate various statistical correlations. These programs can be found in Table 11 in the Appendix. Various individual Rangia cuneata size-weight parameters were compared to establish relationships between:

- 1) length to body thickness, length to total weight, length to meat weight, and length to shell weight.
- 2) body thickness to total weight, body thickness to meat weight, and body thickness to shell weight.
- 3) total weight to meat weight and total weight to shell weight.
- 4) meat weight to shell weight.

A regression program was used to determine the degree of correlation between various sediment parameters, water depth, and density of Rangia cuneata at each station.

RESULTS

Distribution Patterns

Populations of Rangia cuneata were found near the western shore of Croatan Sound from Reeds Point to an area just south of Fleetwood Point. O'Connor, Riggs, and Winston (in press) have described the dominant surface sediment distribution in Croatan Sound (Figure 8). Fine sand and fine to medium sand are present from an area one-half mile south of Fleetwood Point to Reeds Point and beyond. One-half mile south of Fleetwood Point organic rich mud and peat are present. The eastern shore of Croatan Sound is composed of a thin layer of medium to coarse sand, underlain by peat.

Salinity was consistently lower in the western half of Croatan Sound, as shown by Table 1. Major freshwater flow was nearer the western shore of Croatan Sound. This salinity pattern may be related to the deep channel that has been dredged near the western shore.

During this study approximately 650 living Rangia cuneata were collected from 154 dive stations. Density of these clams varied little among the three stations sampled. Station 14 had a density of 2.2 clams per square meter; station 13, 2.3 clams per square meter; and station C-2, 3.0 clams per square meter (Table 2). The distribution of the Rangia is best described as "patchy", since densities ranged from 0 clams per square meter to 12 clams per square meter. This data is given in Tables 7, 8, and 9 in the Appendix.

Distribution and density of Rangia cuneata over the entire Croatan Sound appears to be related to sediment type and salinity.

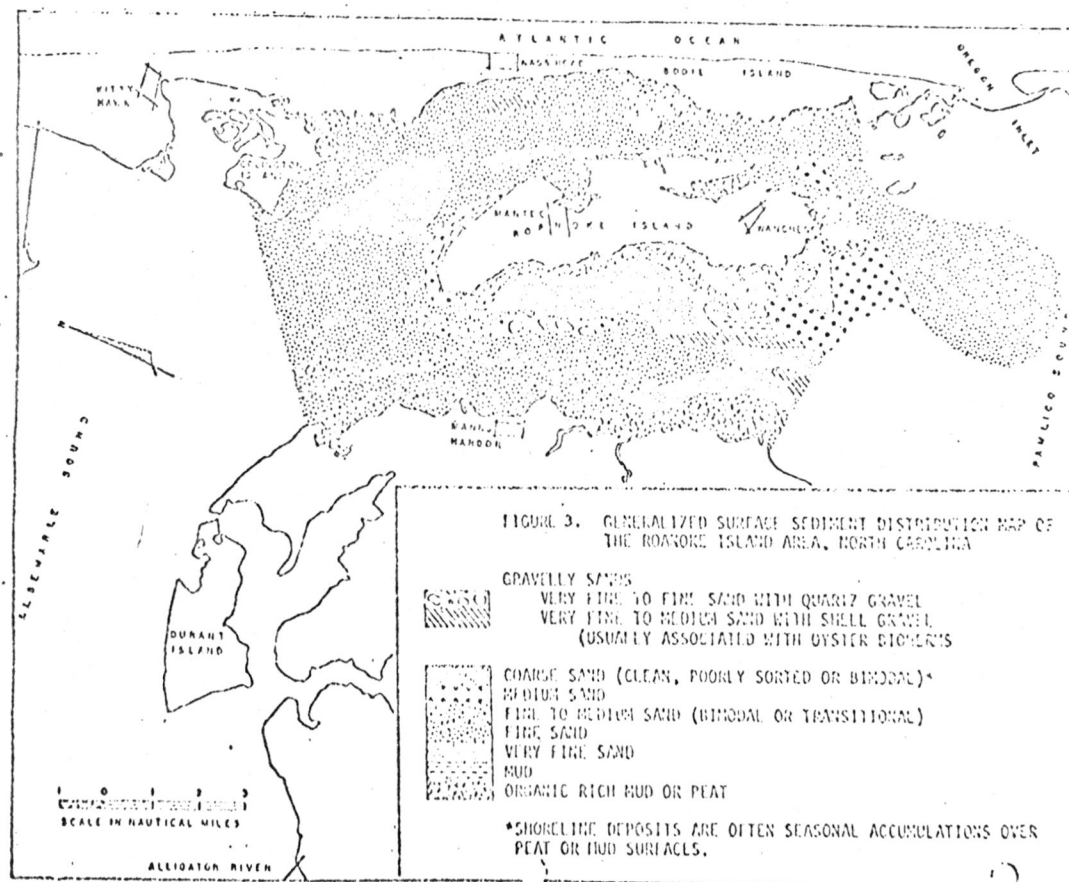


Figure 8. Generalized surface sediment distribution in Croatan Sound (after O'Connor, Riggs, and Winston, in press).

Table 1. Salinity data comparing the eastern and western portions of Croatan Sound.

<u>Western Shore</u>			<u>Eastern Shore</u>		
<u>Station No.</u>	<u>Salinity-ppt.</u>		<u>Station No.</u>	<u>Salinity-ppt.</u>	
	<u>June</u>	<u>July</u>		<u>June</u>	<u>July</u>
4	4.0	5.0	1	6.0	6.0
5	4.5	5.0	8	5.0	6.0
13	6.0	6.0	9	6.5	6.5
14	6.0	6.0	18	6.5	6.5
24	—	5.5	19	—	7.0
25	—	5.5	31	11.0	7.0
37	6.0	6.5	32	8.0	10.5
38	16.0	7.0	43	18.5	9.0
47	8.5	7.0	44	8.0	13.5
<u>Mean</u>	7.3	5.9	<u>Mean</u>	8.7	8.0
<u>Range</u>	4.0-16.0	5.0-7.0	<u>Range</u>	5.0-18.5	6.0-13.5

Table 2. Density of Rangia cuneata from stations 14, 13, and C-2.

<u>Station No.</u>	<u>No. of Dive Stations Sampled</u>	<u>Mean Density (Clams/m²)</u>	<u>Standard Deviation</u>	<u>Range (Clams/m²)</u>
14	48	2.2	1.39	0-9
13	96	2.3	1.69	0-12
C-2	11	3.0	1.40	0-7

Local density and distribution of Rangia within the three collecting areas (stations 14, 13, and C-2) demonstrated a high degree of correlation with sediment type and water depth.

By combining the data from all three collecting stations, it was found that ninety-two percent of the clams were located in sandy substrates having a mean grain size of 1.7 - 2.5 phi (0.30 - 0.18 mm.). The mean grain size range for all the dive stations was 1.4 - 3.6 phi (0.37 - 0.08 mm.). Percent organics in the sediment ranged from 0.02 to 5.50%. Ninety-three percent of all clams were recovered from sediments with organic percentages between 0.03% and 0.17%. Water depth ranged from 2.0 feet to 7.5 feet. However, eighty-eight percent of the clams were found in depths of 2.5 feet to 5.0 feet. Tables 7, 8, and 9 in the Appendix contain the actual data. In summary, Rangia appeared to prefer the lower end of the overall range with respect to the three parameters investigated. Thus fine sand, low organics, and shallow water seem to describe the habitat of Rangia cuneata in Croatan Sound.

Statistical correlations of number of clams versus mean grain size, organic percentage, and depth were significant or approached significance. The mean grain size and the depth were both significant at greater than ninety-five percent, while organic percentage closely approached significance. All these parameters showed a negative correlation coefficient, meaning that as the value of the environmental variable increased, Rangia density decreased (Table 3). Sorting, skewness, and kurtosis did not approach significance, and thus could not be correlated with clam density.

Table 3. Statistical correlations from stations 14, 13, and C-2.

<u>Station No.</u>	<u>D.F.</u>	<u>Product-Moment Correlation Coefficients</u>		
		<u>Clams vs. Depth</u>	<u>Clams vs. %Organics</u>	<u>Clams vs. Mean Grain Size</u>
14	47	-0.53	-0.22	-0.55
13	95	-0.16	-0.18	-0.06
C-2	10	_____	-0.32	-0.15

Growth Correlations

The length-frequency graphs (Figures 9, 10, 11, and 12) indicate that six age groups were sampled. The following size ranges were observed from these length-frequency graphs, and ages assigned to each based on grouping of size classes: (1) 0 to 19 mm. - 1 year, (2) 20 to 29 mm. - 2 years, (3) 30 to 37 mm. - 3 years, (4) 38 to 45 mm. - 4 years, (5) 46 to 52 mm. - 5 years, and (6) 53 mm. and over - 6 years and older. The four and five year living Rangia cuneata age classes were dominant. The largest die-off of clams was also during the four and five year periods, with few clams ever reaching their sixth year. By comparing Figure 9 with Figure 11, and Figure 10 with Figure 12, it can be seen that the total number of Rangia valves is much greater for the four and five year classes than for the one, two, and three year groups.

Growth correlations were computed and analyzed using various indices based on shell length, body thickness, and weight of the clams. Clam length proved to be the more accurate correlation factor, body thickness being highly variable. As seen in Figure 13, a Rangia cuneata with a length of 45 mm. could have a thickness ranging from 26 mm. to 36 mm.. Clam thickness correlated with other factors, such as meat weight and shell weight, revealed the same or greater variability and are therefore not presented. Rangia shell length, however, showed a consistent pattern when plotted against total clam weight (Figure 14), clam meat weight (Figure 15), and clam shell weight (Figure 16). This growth reached its peak in clams between 40 mm. and 50 mm. in length, or when the Rangia were four to five years old.

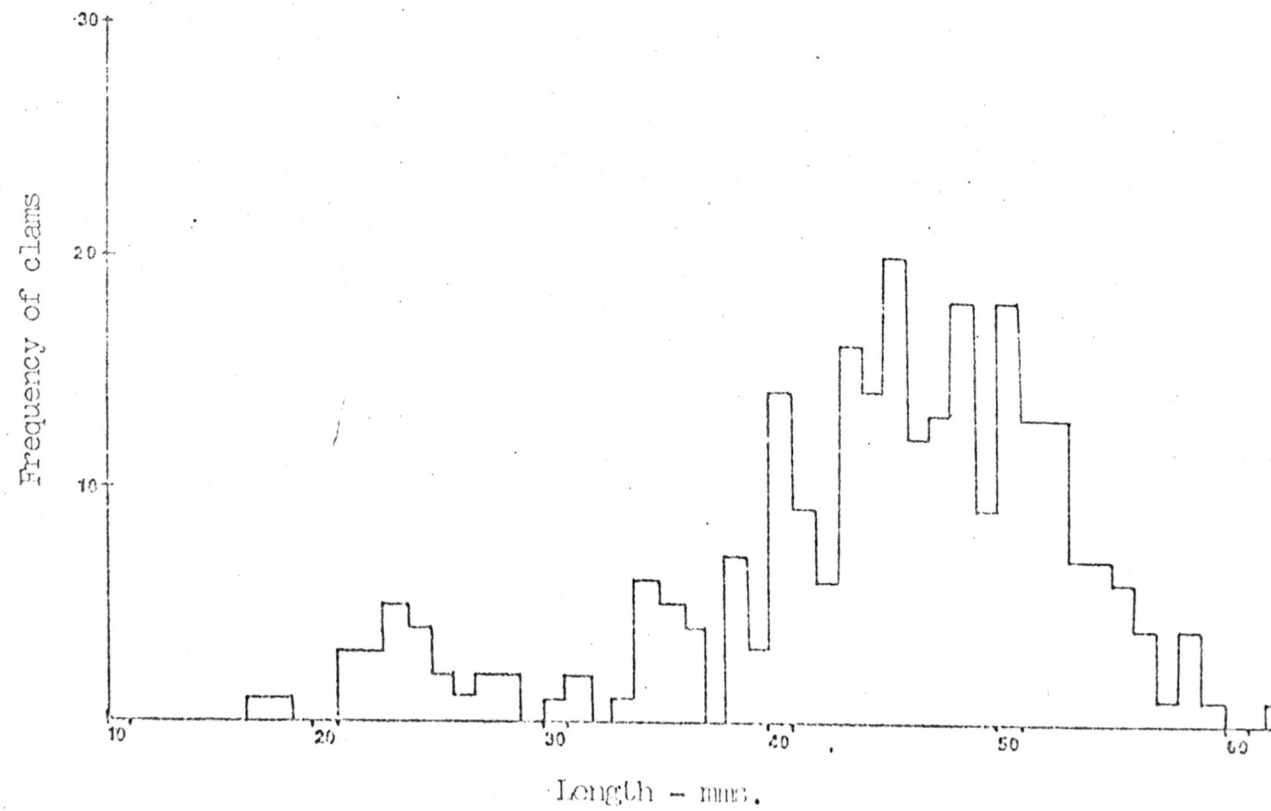


Figure 9. Length-frequency graph - live clams from station 14.

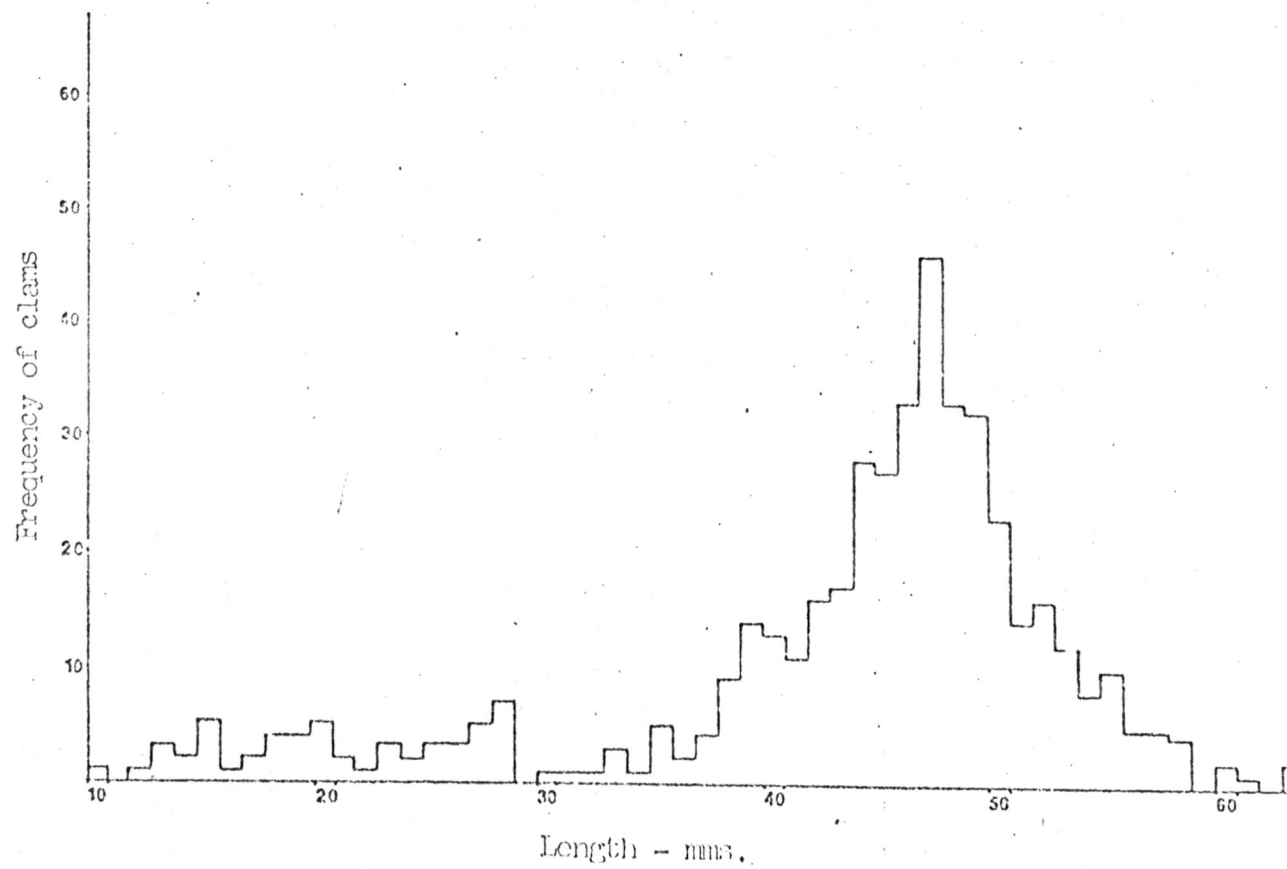


Figure 10. Length-frequency graph - empty valves from station 14.

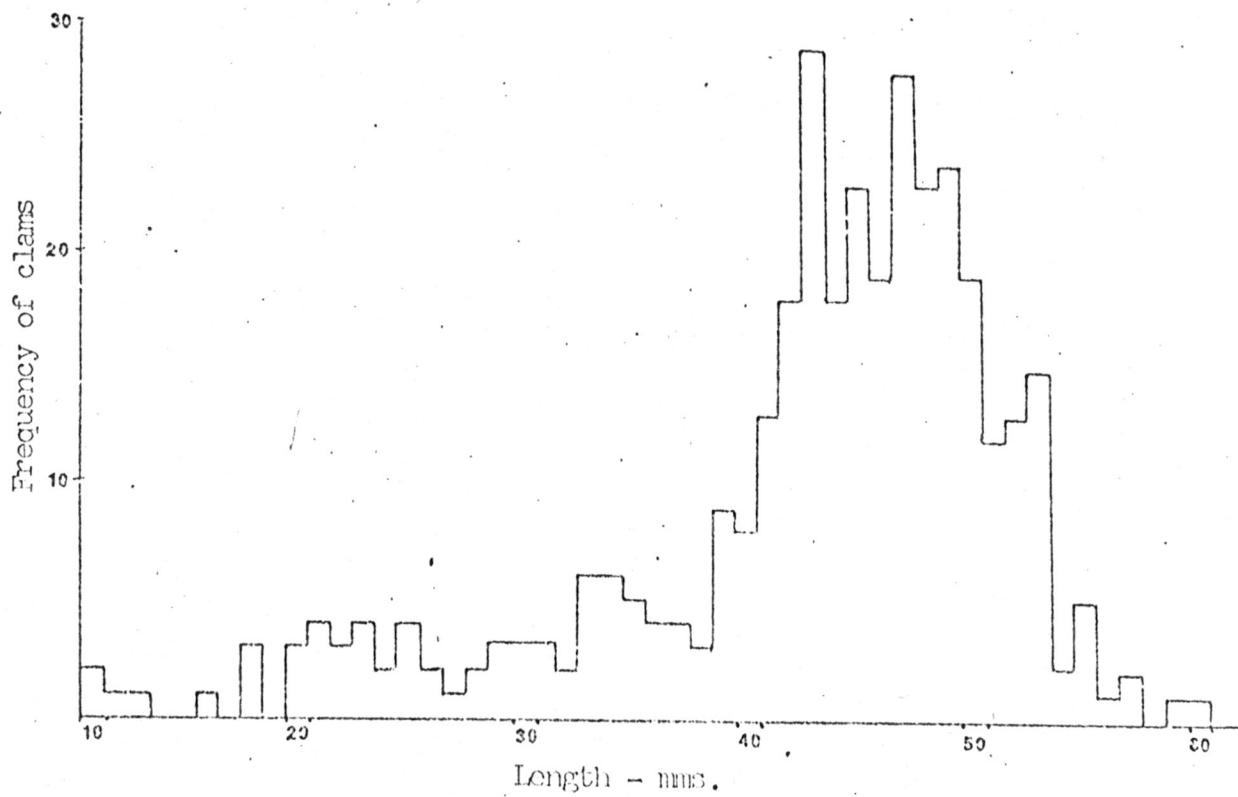


Figure 11. Length-frequency graph - live clams from station 13.

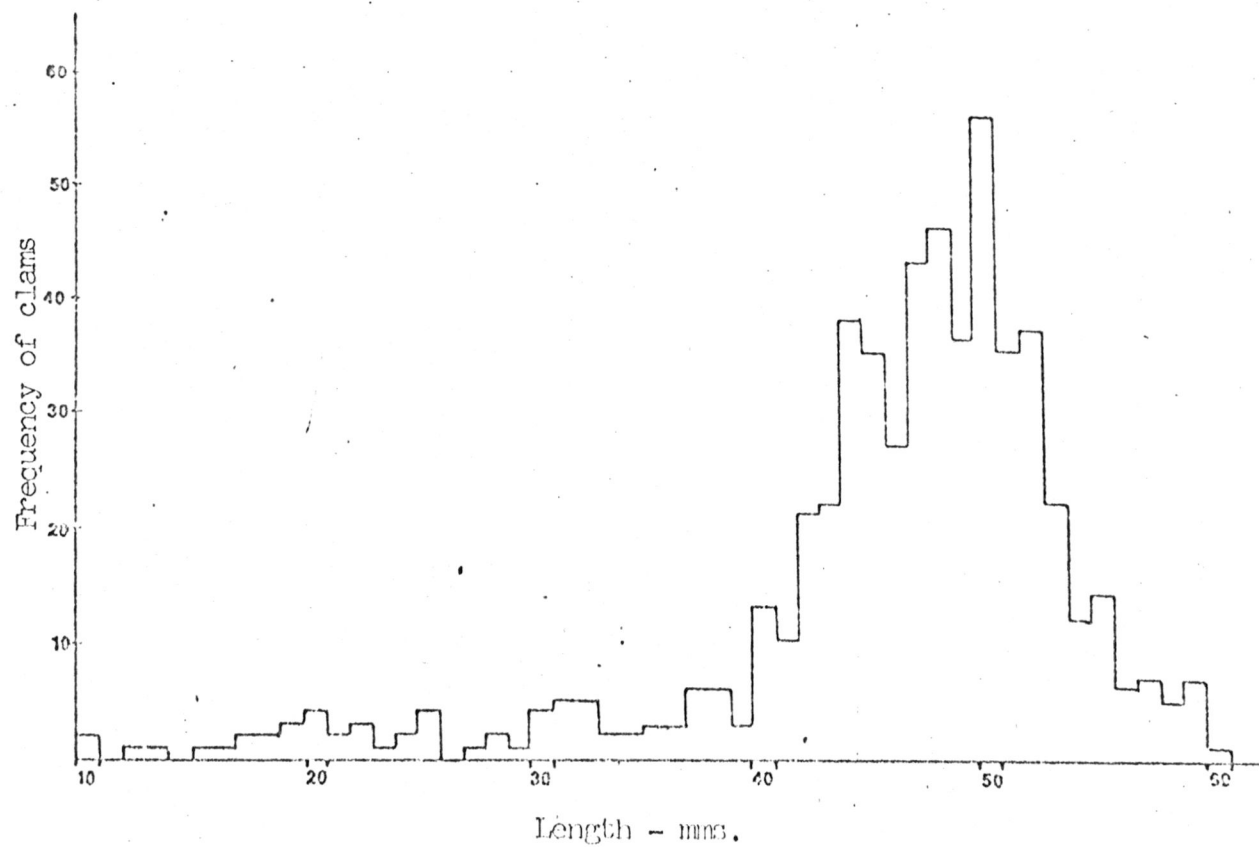


Figure 12. length-frequency graph - empty valves from station 13.

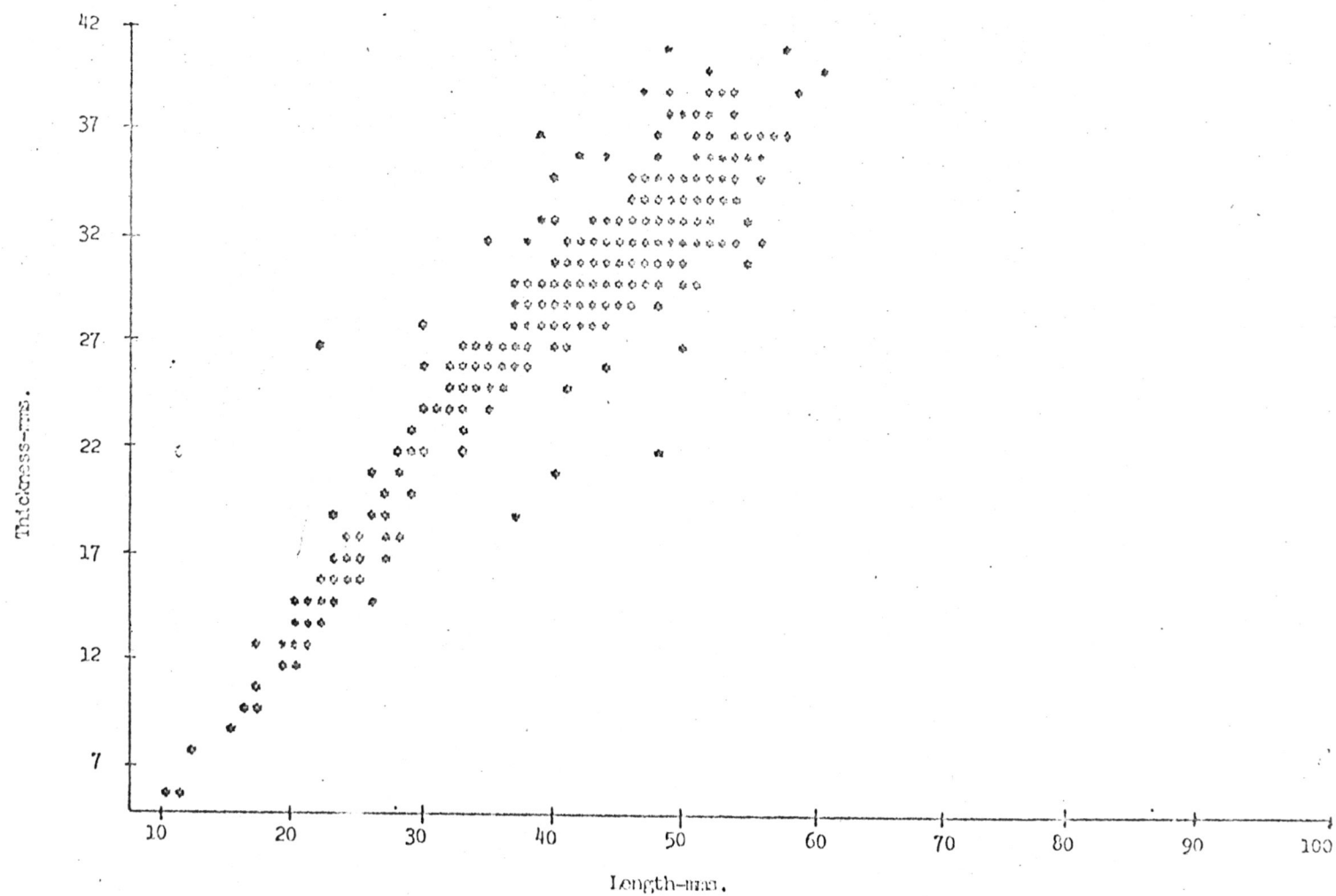


Figure 13. Growth correlation graph - length versus body thickness.

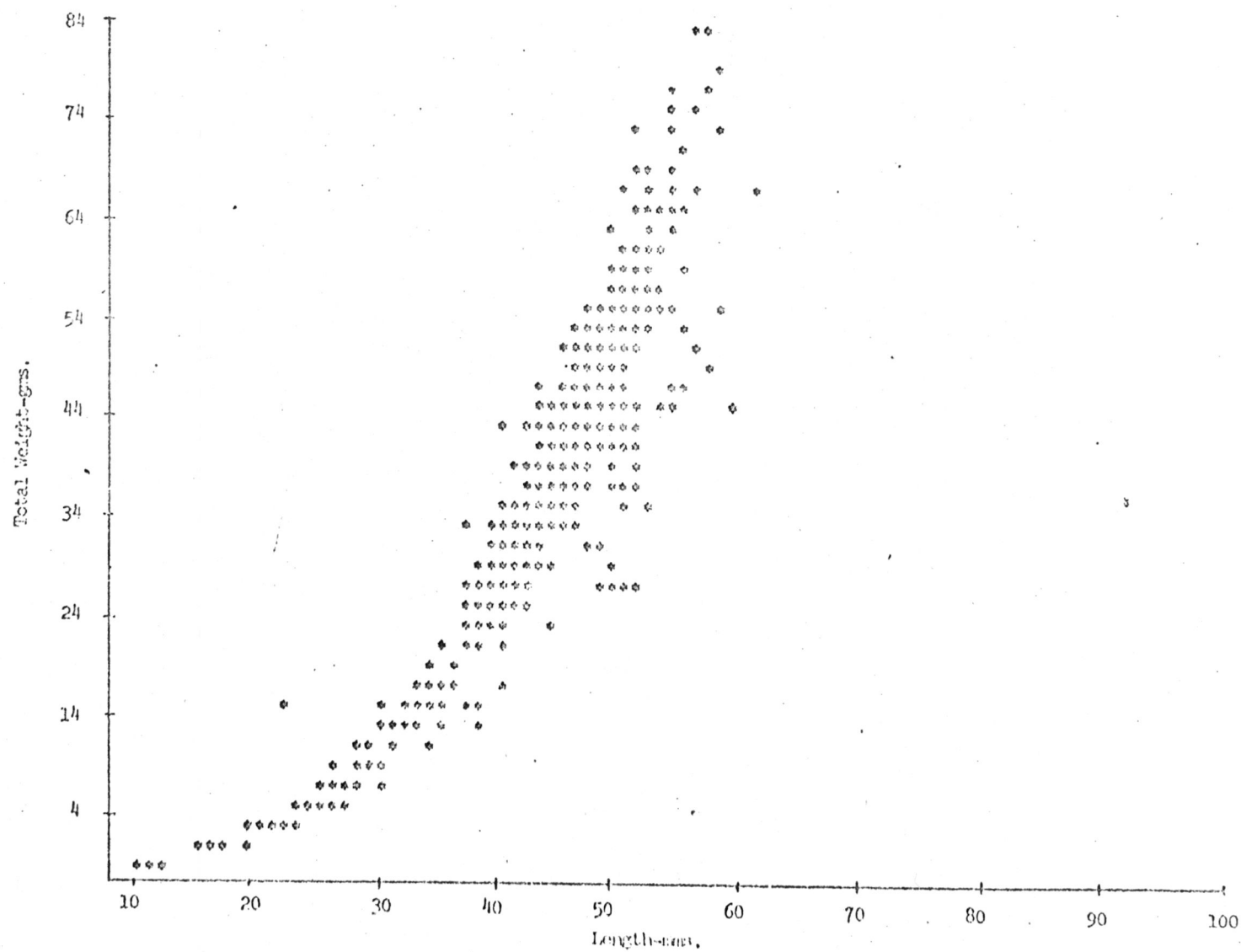


Figure 14. Growth correlation graph - length versus total weight,

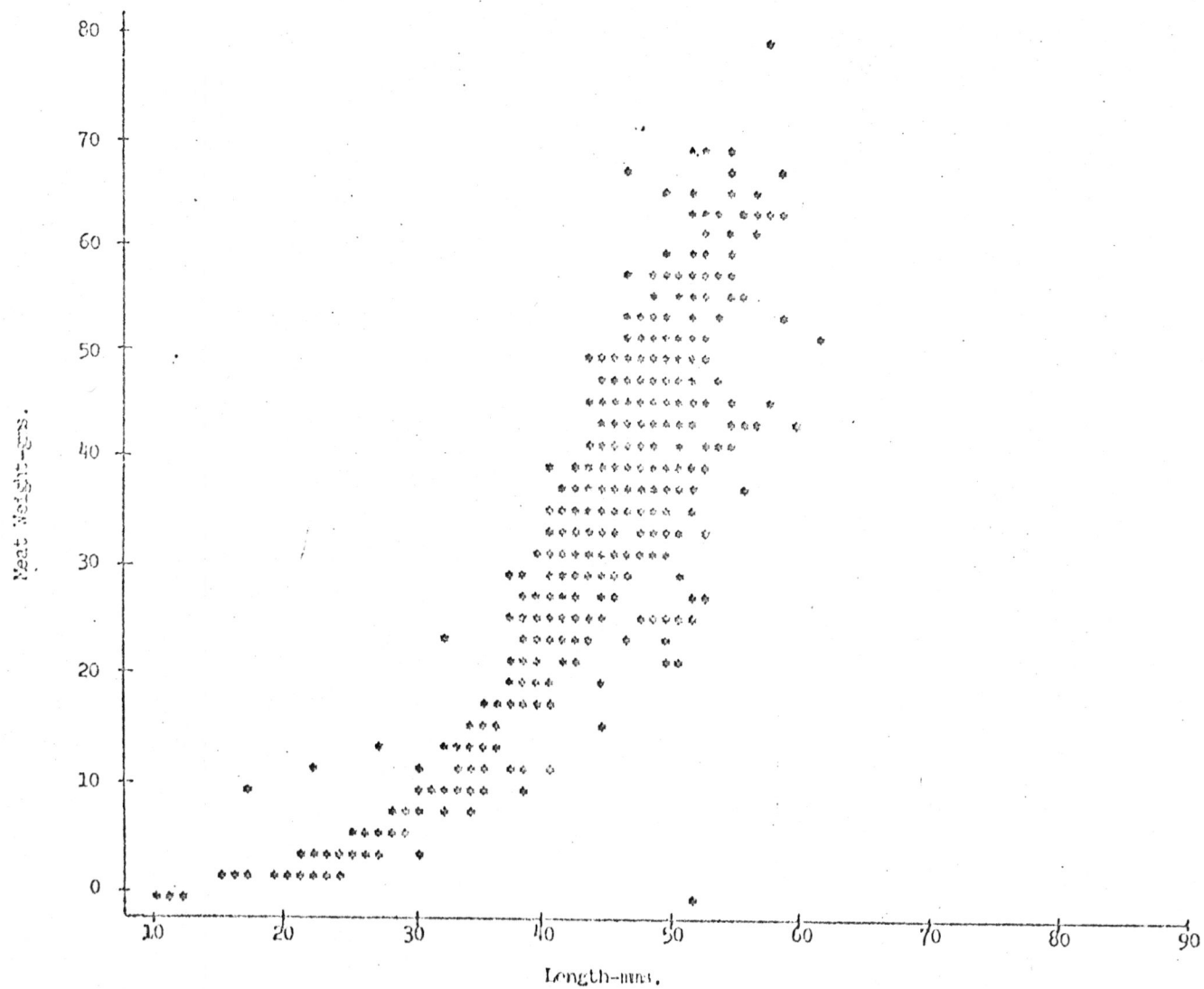


Figure 15. Growth correlation graph - length versus meat weight.

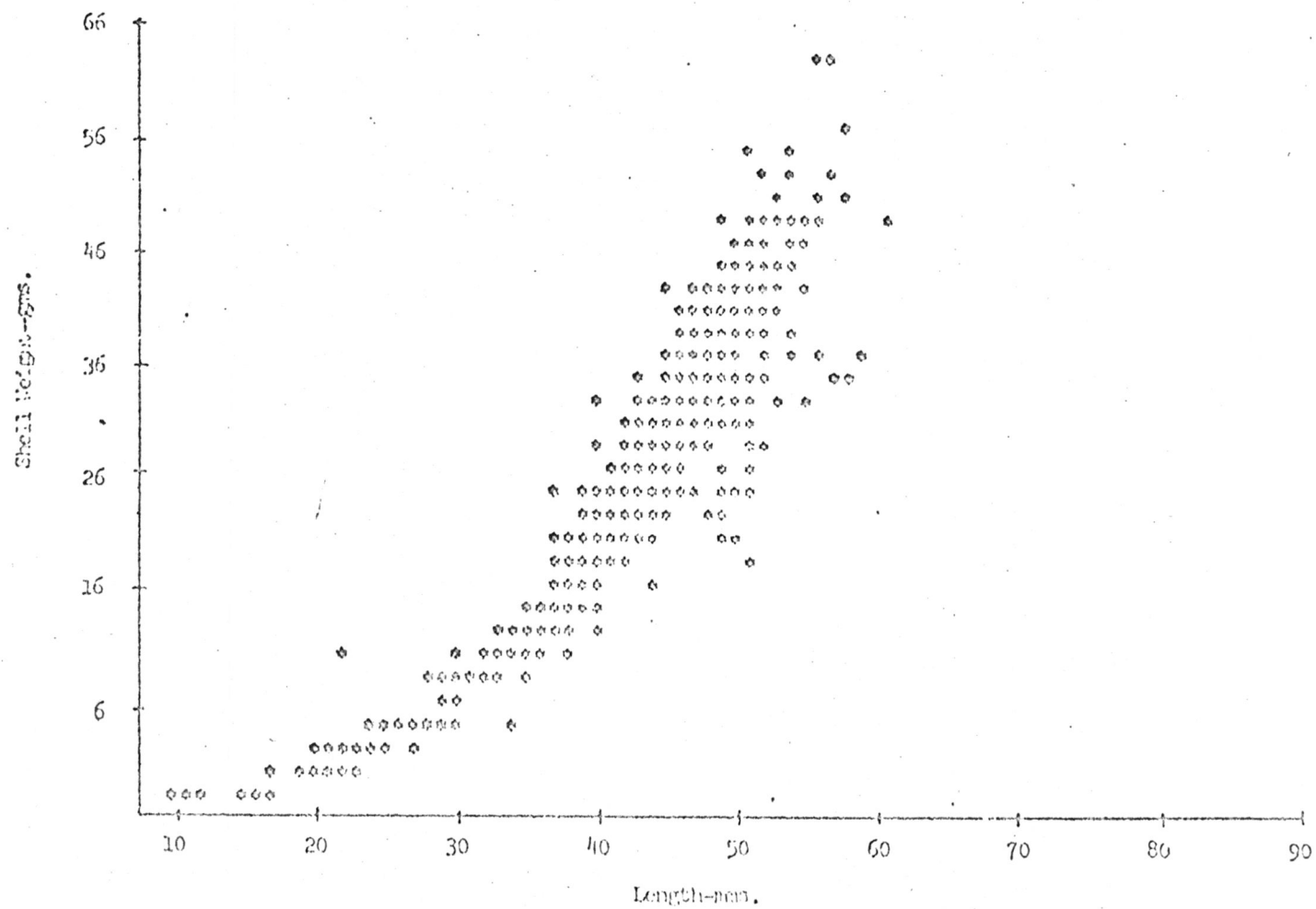


Figure 16. Growth correlation graph - length versus shell weight.

Rangia cuneata has a thick heavy shell, meat weight contributing only about 10% to the total weight (Figure 17), while shell weight accounted for almost 75% of total weight (Figure 18). The remaining 15% was water retained in body cavities of living clams.

Reburrowing Activity

The effect of various sediment types on the reburrowing rate of Rangia cuneata was determined by laboratory experiments. It was hoped that reburrowing rate might indicate a sediment preference for Rangia. Six sediment types were used in the experiment, all taken from bottom types found in Croatan Sound. The sediments used were as follows: tank 1 - coarse sand, tank 2 - medium to fine sand of high organic content, tank 3 - medium to fine sand with low organic content, tank 4 - peat, tank 5 - organic mud, and tank 6 - a sandy clay sediment. The experiment was conducted over a twelve hour period, with ten clams placed in each of the six tanks. It was repeated four times, the clams being randomly mixed before each new test (Table 4).

Two more experiments of similar design were performed to determine the effect of light on reburrowing rate of Rangia cuneata. The first experiment was carried out during the daylight hours, 6:00 AM to 6:00 PM, while the second experiment was done in darkness, from 6:00 PM to 6:00 AM. A period of twenty-four hours between experiments allowed the clams time to fully recover (Tables 5 and 6).

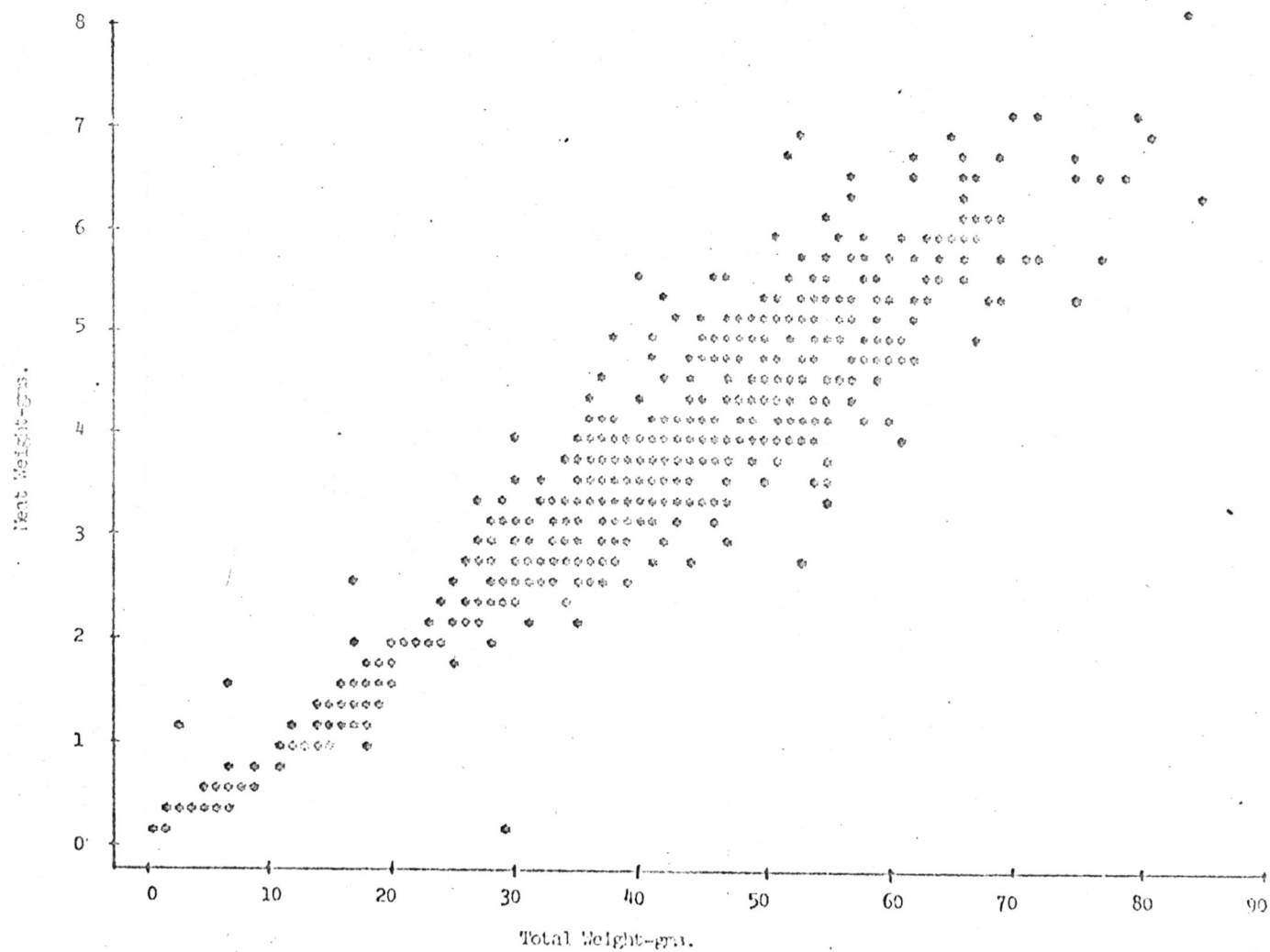


Figure 17. Growth correlation graph - total weight versus meat weight.

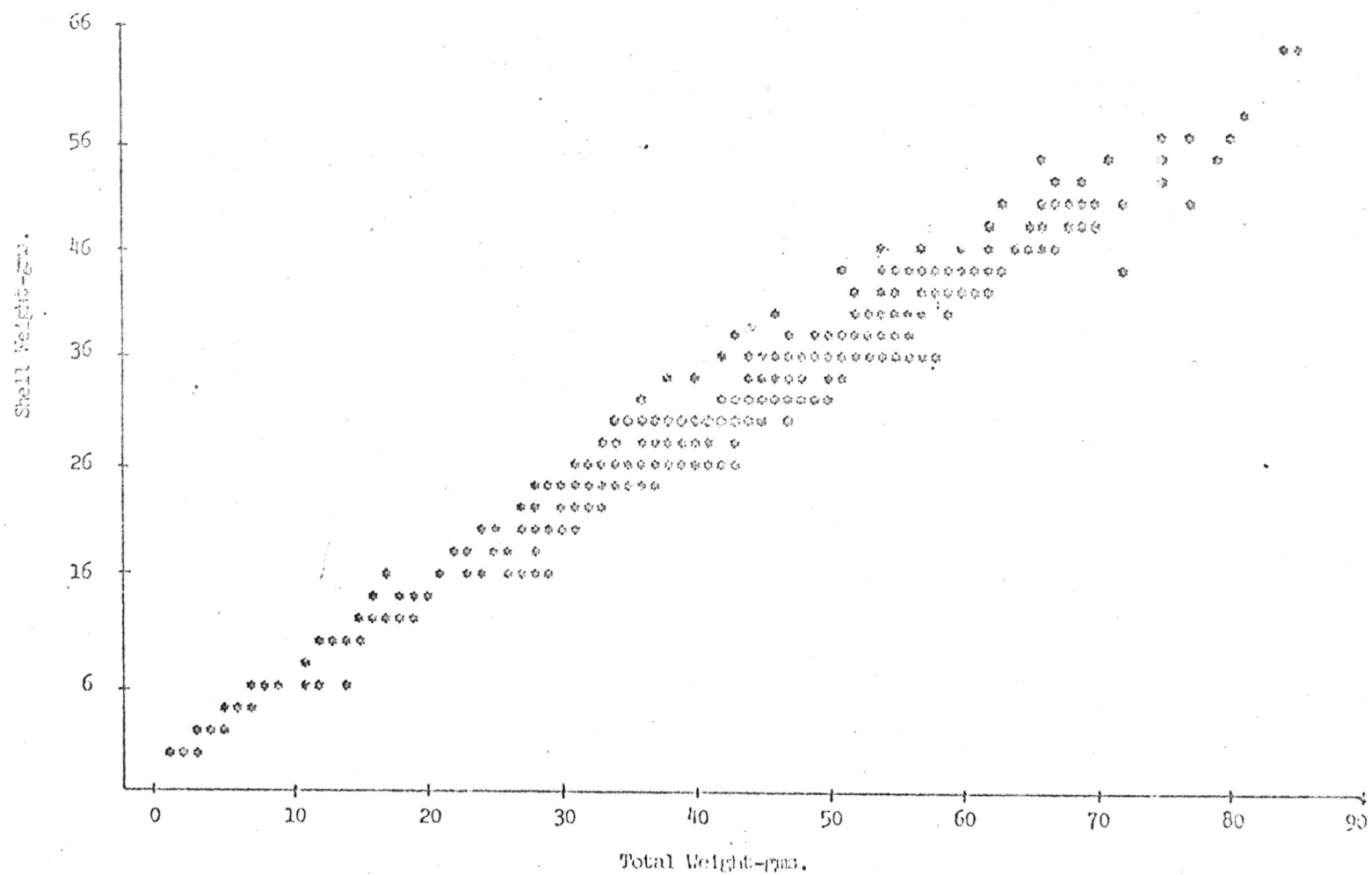


Figure 13. Growth correlation graph - total weight versus shell weight.

Table 4. Reburrowing activity-sediment preference.

	cs	ho mfs	lo mfs	p	om	sc
Tank:	1	2	3	4	5	6
Totally reburrowed	0	7	2	0	0	0
Partially reburrowed	13	8	10	7	8	5
No activity	27	25	28	33	32	35
Total no. of clams	40	40	40	40	40	40

Table 5. Reburrowing activity-in light

	cs	ho mfs	lo mfs	p	om	sc
Tank:	1	2	3	4	5	6
Totally reburrowed	0	0	0	0	1	0
Partially reburrowed	1	0	3	0	2	0
No activity	9	10	7	10	7	10
Total no. of clams	10	10	10	10	10	10

Table 6. Reburrowing activity-in dark

	cs	ho mfs	lo mfs	p	om	sc
Tank:	1	2	3	4	5	6
Totally reburrowed	0	3	3	0	0	0
Partially reburrowed	4	4	3	4	3	5
No activity	6	3	4	6	7	5
Total no. of clams	10	10	10	10	10	10

cs= coarse sand

ho

mfs= high organic medium-fine sand

lo

mfs= low organic medium-fine sand

p= peat

om= organic mud

sc= sandy clay

DISCUSSION

Distribution Patterns

Rangia cuneata is not abundant in Croatan Sound. Scattered populations occur along parts of the western shore. This study has provided a base map of the distribution and density of Rangia cuneata in Croatan Sound. Hopefully, future work will reveal whether these populations are increasing or decreasing in density or changing in age distribution.

Rangia cuneata is found only in sand substrates in Croatan Sound. This is true also for Rangia found in Pamlico Sound (Tenore, 1971). The clam is not found in peat or organic mud sediments. Fine sand and medium-fine sand are the most common substrate for Rangia, while medium to coarse sand is usually void of these clams. This may be due not so much to actual grain size being detrimental, as to the energy associated with forming sediments of various size particles. High energy is associated with coarse sand, while low energy will form fine-grained sediments. Rangia appear to prefer low to medium energy environments.

Rangia were not found in sand of high organic content. As suggested by Tenore (1971), high organic sediments may be detrimental to larval survival. This type of substrate may also be detrimental to the adults, due to its texture which prevents Rangia from burrowing, or it may clog the Rangia's filtering apparatus.

Water depth is also an important limiting factor in the distribution of Rangia cuneata. This clam is excluded from very shallow water because

the wave action causes increased turbulence, possibly preventing the settling of larvae. Deeper water is not favorable for Rangia survival, possibly due to the increase of very fine particles of organic detritus.

Growth Correlations

The six age classes found during this survey correspond closely to those predicted by Wolfe and Petteway (1969). They predicted from a von Bertalanffy equation that maximum growth for 1 year was 16.0 mm.; 2 years, 28.3 mm.; 3 years, 38.0 mm.; 4 years, 45.8 mm.; and 5 years, 51.0 mm..

There was no readily apparent explanation for the large numbers of four and five year old Rangia, and so few one, two, and three year old clams. Possibly, environmental conditions were favorable for larval settling and juvenile clam growth four and five years ago. More recently perhaps, larvae and juveniles have not been as successful. Shifting sands and increased wave energy during the rugged winter months may have caused this mortality. The presence of numerous 40 to 50 mm. Rangia valves and few 10, 20, and 30 mm. valves adds support to this theory. Sampling procedures could have caused some error, since the smaller clams were more difficult to locate than were the larger ones. Godwin (1968) also has reported a high density of Rangia in the Altamaha River having lengths of 45 mm. to 55 mm. In Lake Pontchartrain, however, the most abundant sizes were 35 mm. to 40 mm. (Fairbanks, 1963), while Pfitzenmyer and Drobeck (1964) found Rangia populations in the Potomac River averaging less than 30 mm. in length.

By the time a Rangia cuneata reaches five years of age, or

approximately 50 mm. in length, its maximum weight has been attained. The thick shell of Rangia makes up the majority of the clams' total weight. Thus, in regarding Rangia cuneata as a "carbon sink" in the estuaries, its thick shell should be considered a carbonate source, both commercially and ecologically. Commercial harvesters of this clam should be aware also that meat weight is almost doubled between a 4 year (40 mm.) clam and a 5 year (50 mm.) clam . This difference in meat weight due to one year's growth may well be worth waiting for.

Reburrowing Activity

Laboratory experiments dealing with the reburrowing of Rangia indicated no definite sediment preference. The clams did show somewhat more activity towards reburrowing in the sandy substrates than in the mud, peat, or clay sediments. Texture and degree of compaction may have influenced this preference. Light sensitivity was apparent in Rangia. Their reburrowing activity was greatly reduced during the daylight hours.

SUMMARY AND RECOMMENDATIONS

1. Large adult Rangia cuneata are found primarily in sandy substrates. According to other studies cited previously, smaller clams appear to thrive in high organic sediments. No explanation for this difference in sediment preference has been suggested. Certainly future studies should attempt to establish definite sediment relationships for large and small Rangia and explain why they exist in different substrates.

2. Distribution patterns of Rangia cuneata must be established by the motile larvae. Instead of concentrating on sediment and salinity preferences of adult Rangia, future work should involve sediment and salinity tolerances of Rangia larvae. Laboratory experiments testing survival of larvae on various substrates, using different salinities and temperatures, would be helpful in determining the mechanisms of Rangia distribution.

3. The role of Rangia cuneata in the complex food web of an estuary has not been determined. As a filter feeder, Rangia utilizes plankton and detritus as food. Very little is known as to the size and type of food used by Rangia, the percentage of food utilized, or the filtering mechanism.

Predators of Rangia cuneata have not been studied thoroughly. Some fish, such as black drum and Atlantic croaker, have been suggested. Sea gulls have been observed breaking open live Rangia. Blue crabs might possibly prey upon these clams, as might muskrats and sea otters. Field observation studies, gut content analysis, and laboratory experiments would aid in determining the predators of Rangia.

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GLOSSARY

KURTOSIS - A quantitative measurement used to describe departure from normality.

$$\text{Graphic kurtosis (Folk, 1968)} = \frac{\phi 95 - \phi 5}{2.44 (\phi 75 - \phi 25)}$$

MEAN GRAIN SIZE - Average grain size diameter.

$$\text{Graphic mean (Folk, 1968)} = \frac{(\phi 16 + \phi 50 + \phi 84)}{3}$$

SKEWNESS - A measurement of the degree of asymmetry of the grain size distribution.

Inclusive graphic skewness (Folk, 1968) =

$$\frac{\phi 16 + \phi 84 - 2 \phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2 \phi 50}{2(\phi 95 - \phi 5)}$$

SORTING - The extent to which the grains spread on either side of the average.

$$\text{Sorting (Folk, 1968)} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

APPENDIX

Table 7

Station data-Station # 14

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size**	Sorting	Skewness	Kurtosis
1-1*	2.5	2	.05	1.968	.675	-0.083	.831
1-2	3.0	3	.08	1.957	.631	-0.094	.744
1-3	3.5	5	.06	2.111	.585	-0.025	.870
1-4	4.0	2	.09	2.169	.570	-0.016	.932
1-5	4.0	1	.10	2.154	.504	-0.022	.753
1-6	4.3	2	.07	2.138	.433	-0.004	.605
2-1	3.0	6	.06	2.149	.566	-0.025	.872
2-2	3.7	7	.06	2.041	.561	0.013	1.090
2-3	4.0	3	.12	2.072	.516	0.018	.758
2-4	5.5	2	.05	1.931	.408	-0.164	1.100
2-5	5.0	1	.07	1.805	.390	0.137	1.100
2-6	5.5	3	.06	1.830	.389	0.123	1.108
3-1	2.7	6	.06	2.130	.497	-0.003	.709

* The first digit in this sequence refers to the transect number, the second to the dive station; thus 1-2 refers to dive two along transect 1 at Station 14 (See Figure 4 for details).

** ϕ - phi unit

Table 7 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
3-2	3.5	3	.11	2.105	.550	0.009	.857
3-3	4.0	5	.05	2.032	.478	0.009	1.093
3-4	5.0	5	.04	1.830	.386	0.124	1.096
3-5	5.0	4	.10	1.821	.406	0.143	1.159
3-6	6.0	0	.19	2.474	.602	-0.125	.766
4-1	3.0	3	.30	2.504	.752	-0.102	1.699
4-2	6.0	2	.65	2.839	.997	0.138	.581
4-3	6.0	0	.54	3.203	.778	0.215	1.560
4-4	6.0	0	.39	2.660	.675	-0.016	1.193
4-5	5.5	0	.16	2.783	.298	0.124	.854
4-6	5.0	0	.10	2.755	.305	0.148	2.488
5-1	3.5	2	.60	2.759	1.058	0.170	1.004
5-2	5.0	0	1.10	2.938	.921	0.237	.578
5-3	6.0	0	1.10	3.598	.717	-0.925	.599
5-4	5.0	1	.15	2.772	.295	0.128	.913

Table 7 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
5-5	5.0	1	.10	2.727	.290	0.142	2.616
6-1	3.5	4	.04	2.308	.736	0.059	1.557
6-2	4.5	0	1.70	2.969	.974	0.242	.799
6-3	5.5	0	.26	2.513	.771	-0.106	1.075
6-4	5.0	0	.18	2.779	.304	0.134	.903
6-5	4.5	1	.09	2.749	.290	0.134	2.442
6-6	5.5	1	.11	2.509	.314	-0.151	2.397
7-1	3.3	2	2.10	2.847	1.003	0.133	.575
7-2	3.5	1	5.50	3.310	1.024	-1.130	.576
7-3	4.5	2	.06	1.631	.475	0.007	2.657
7-4	4.5	1	.07	1.809	.636	0.116	1.314
7-5	4.5	3	.09	2.457	.655	-0.239	1.441
7-6	4.5	1	6.10	3.589	.810	-1.766	.729
8-1	2.5	3	.05	2.161	.541	-0.002	.861
8-2	3.5	9	.04	2.061	.514	0.007	1.047

Table 7 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
8-3	3.5	0	.35	2.758	1.055	0.180	1.032
8-4	4.5	2	.09	2.083	.570	0.009	.902
8-5	4.0	5	.10	2.067	.498	-0.000	1.114
8-6	5.0	2	.04	2.061	.482	-0.003	1.095

Table 8

Station data-Station #13

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size**	Sorting	Skewness	Kurtosis
0-1*	2.3	0	.17	2.552	.665	0.013	1.726
0-2	2.0	1	.59	2.094	.726	0.042	1.967
0-3	3.5	3	.50	2.962	.920	0.239	.563
0-4	5.5	0	.47	2.984	.988	0.312	.532
1-1	2.5	4	.03	1.356	.680	0.114	1.349
1-2	2.5	4	.05	1.454	.599	0.024	1.359
1-3	3.5	1	.29	2.645	1.000	0.272	1.490
1-4	5.0	0	.25	2.285	.338	0.141	.894
1-5	6.0	0	.09	2.453	.421	-0.361	1.278
1-6	8.0	0	.25	2.484	.406	-0.316	1.398
2-1	2.5	5	.04	1.728	.752	0.151	1.061
2-2	2.5	2	.06	2.101	.430	0.006	.867
2-3	3.0	0	.04	1.564	.631	0.065	1.362

* The first digit in this sequence refers to the transect number, the second to the dive station; thus 0-2 refers to dive two along transect 0 at Station 13 (See Figure 5 for details).

**φ - phi unit

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
2-4	4.5	0	.04	2.186	.406	0.018	.915
3-1	2.5	0	.04	1.713	.688	0.153	1.404
3-2	3.0	0	.06	1.762	.751	0.146	.909
3-3	3.5	1	.06	2.094	.437	0.013	.591
3-4	4.5	1	.13	2.283	.385	0.145	1.092
4-1	2.7	5	.04	1.736	.694	0.155	.882
4-2	3.0	4	.02	1.874	.670	0.111	.816
4-3	3.3	2	.05	2.114	.435	0.005	.599
4-4	4.0	0	.38	2.313	.410	0.136	1.154
5-1	2.7	3	.05	2.036	.773	-0.311	.963
5-2	3.3	7	.05	1.800	.431	0.160	1.215
5-3	3.0	3	.06	2.088	.444	0.013	.587
5-4	3.7	1	.04	2.143	.424	0.005	.926
6-1	2.5	3	.09	1.970	.688	-0.071	.812
6-2	3.5	3	.09	1.981	.737	-0.137	.812
6-3	3.5	2	.03	2.143	.578	-0.021	.870

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
6-4	3.5	2	.05	2.129	.491	0.002	.714
7-1	2.7	0	.05	1.838	.707	0.098	.630
7-2	3.0	3	.05	2.112	.445	0.007	.586
7-3	3.5	1	.06	2.080	.572	0.018	.853
7-4	3.7	0	.04	2.126	.532	-0.001	.835
8-1	2.5	2	.04	1.699	.879	0.006	.732
8-2	3.5	2	.04	2.210	.490	-0.021	1.061
8-3	3.0	4	.06	2.123	.554	0.006	.825
8-4	3.5	0	.05	2.113	.560	-0.006	.873
8-5	4.5	1	.06	2.093	.586	-0.067	.925
8-6	6.0	0	.12	2.446	.424	-0.310	1.198
8-7	6.2	0	.05	2.140	.565	-0.040	.841
8-8	7.5	1	.07	2.482	.379	-0.265	1.264
9-1	2.5	4	.04	2.178	.506	-0.023	1.039
9-2	3.0	2	.12	2.144	.597	-0.028	.897

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
9-3	3.0	4	.03	2.106	.572	-0.000	.865
9-4	3.7	0	.05	2.119	.509	-0.009	.789
10-2	2.5	2	.05	2.169	.494	-0.004	.740
10-3	3.5	4	.06	1.980	.812	-0.235	1.150
10-4	3.5	1	.04	2.209	.599	-0.060	1.294
10-5	4.0	1	.04	2.073	.481	0.007	1.058
11-2	2.5	0	.07	2.165	.484	0.002	1.068
11-3	2.5	1	.05	2.135	.560	-0.018	.886
11-4	3.5	0	.11	2.160	.560	-0.028	.865
11-5	3.7	1	.09	2.104	.524	-0.007	.747
12-4	3.0	5	.05	2.209	.499	-0.025	1.052
12-5	3.5	4	.06	2.305	.503	-0.281	1.079
12-6	3.5	0	-	-	-	-	-
12-7	3.7	1	.43	2.156	.709	0.006	1.212
13-4	2.0	0	.09	1.927	.423	-0.214	1.039

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
13-5	2.5	0	.15	2.549	.506	-0.049	1.179
13-6	6.0	0	.40	2.224	.515	-0.007	1.101
13-7	4.0	4	.13	2.326	.494	-0.300	1.107
13-8	3.5	5	.06	2.345	.498	-0.314	1.128
13-9	3.5	8	.12	2.115	.582	-0.015	.871
13-10	4.0	0	1.32	2.967	.898	0.250	.704
13-11	5.5	2	.14	2.509	.383	-0.333	3.248
14-6	4.0	0	.09	2.451	.388	-0.264	1.147
14-7	3.0	2	.06	2.455	.407	-0.269	1.161
14-8	3.5	11	.15	2.448	.420	-0.292	1.183
14-9	3.7	5	.10	2.539	.500	-0.065	1.167
14-10	4.0	9	.09	2.192	.502	-0.021	1.053
14-11	4.5	12	.03	2.153	.493	-0.006	.737
14-12	4.7	5	.05	2.539	.631	-0.308	1.917
15-8	3.0	5	.08	2.222	.490	-0.014	1.077

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
15-9	3.2	0	.05	2.324	.480	-0.276	1.093
15-10	3.5	0	.20	2.593	.472	-0.029	1.341
15-11	2.7	0	-	-	-	-	-
15-12	4.7	4	.07	2.202	.496	-0.034	1.046
16-11	4.0	1	-	-	-	-	-
16-12	4.5	2	.11	2.331	.506	-0.299	1.092
16-13	4.7	1	.06	2.417	.393	-0.260	1.082
16-14	5.0	1	.06	2.156	.554	-0.024	.877
16-15	3.0	8	.10	2.475	.453	-0.781	1.696
16-16	4.5	4	.16	2.465	.371	-0.262	1.177
16-17	5.5	3	.06	2.139	.502	-0.017	.757
16-18	5.5	2	.14	2.137	.502	-0.020	.700
16-19	5.7	4	.05	2.155	.430	0.001	.928
16-20	6.0	3	.06	2.102	.417	-0.010	.997
16-21	7.0	2	.05	1.964	.334	-0.132	.903

Table 8 Cont.

Dive Station	Depth(ft.)	Clams/m ²	% Organics of Sediment	Mean Grain Size	Sorting	Skewness	Kurtosis
16-22	7.5	0	.03	1.811	.383	0.142	1.123
16-23	7.5	0	.10	1.935	.516	0.219	1.081
16-24	7.5	0	.07	2.424	.406	-0.276	1.123
17-13	3.0	0	.08	2.161	.611	-0.062	.932

Table 9

Station data-Station # C-2

Dive Station	Depth(ft.)*	Clams/m ²	% Organics of Sediment	Mean Grain Size**	Sorting	Skewness	Kurtosis
1	-	0	.18	2.217	.483	-0.023	1.090
2	-	2	.12	2.147	.606	-0.055	.911
3	-	2	.09	2.921	.423	-0.457	1.250
4	-	0	.26	2.317	.627	-0.033	.836
5	-	7	.08	2.292	.576	-0.414	1.224
6	-	3	.12	2.137	.627	-0.033	.836
7	-	3	.06	1.980	.747	-0.139	.957
8	-	2	.06	2.119	.592	0.010	.861
9	-	2	.06	2.143	.615	-0.014	.853
10	-	8	.10	2.172	.522	-0.013	.729
11	-	5	.17	2.136	.601	-0.013	.828

*Depths not recorded - approximate depths were 2' - 5'.

**φ - phi unit

Table 10. Computer program for sediment grain size analysis

```

C      PROGRAM FOR 1/2 PHI UNITS SIEVING
0001  DIMENSION PHI(4,1000),PCT(300),WT(300),DF(20),AZ(10)
0002  DIMENSION AA(100)
0003  J=13
0004  K=5
0005  P=.25
0006  NO=0
0007  PHI(1,1)=-1.00
0008  DO 50 N=2,J
0009    50 PHI(1,N)=PHI(1,N-1)+ .50
0010  M=200
0011  1001 DO 700 II=1,M
0012    DO 2 I=1,J
0013      2 READ (1,420, END=999) WT(I)
0014    420 FORMAT (F10.0)
0015    CONTINUE
0016    READ (1,430) TOTWT
0017    430 FORMAT (F10.0)
0018    READ (1,440) (AZ(I),I=1,K)
0019    440 FORMAT ( 10A4)
0020    SUM=0.0
0021    DO 36 N=1,J
0022      SUM=SUM + WT(N)
0023    SUMWT=SUM
0024    36 CONTINUE
0025    PLOST=(TOTWT-SUMWT)*100./TOTWT
0026    WRITE (3,301) (AZ(I),I=1,K)
0027    WRITE (3,888) TOTWT
0028    888 FORMAT (1X,'TOTAL WEIGHT =',3X,F10.3)
0029    WRITE(3,777) SUMWT
0030    777 FORMAT(1X,'SUM WEIGHT =',3X,F10.3)
0031    WRITE(3,399) PLOST
0032    399 FORMAT(14H PERCENT LOST=, F11.6)
0033    TOTWT=SUMWT
0034    DO 3 N=1,J
0035      3 PCT(N) = 100.0*(WT(N)/TOTWT)
0036      PHI(2,1)=PCT(1)
0037      DO 4 N=2,J
0038        4 PHI(2,N)=PCT(N)+PHI(2,N-1)
0039      N=1
0040      612 IF (PHI(2,1)-5.0) 613,613,614
0041      614 PHI5=1.25/PHI(2,1)+PHI(1,N)
0042      IF (PHI(2,1)-16.0) 9,9,615
0043      615 PHI16=4.0/PHI(2,1)+PHI(1,1)
0044      GO TO 13
0045      613 IF (PHI(2,N+1)-5.0) 6,6,8
0046      6 N=N+1
0047      GO TO 612
0048      8 WRITE (3,450) N
0049      450 FORMAT (1X, 'THE VALUE OF N IS',14)

```

Table 10 Cont.

```

0050      PHI5=P      *(5.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0051      9 IF (PHI(2,N+1)-16.0) 11,11,12
0052      11 N=N+1
0053      GO TO 9
0054      12 PHI16=0.25*(16.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0055      13 IF (PHI(2,N+1)-25.0) 14,14,15
0056      14 N=N+1
0057      GO TO 13
0058      15 PHI25=      P*(25.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+
                        PHI(1,N)
0059      16 IF (PHI(2,N+1)-50.0) 17,17,18
0060      17 N=N+1
0061      GO TO 16
0062      18 PHI50=      P*(50.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0063      M=N+1
0064      19 IF (PHI(2,N+1)-75.0) 20,20,21
0065      20 N=N+1
0066      GO TO 19
0067      21 PHI75=      P*(75.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0068      22 IF (PHI(2,N+1)-84.0) 23,23,24
0069      23 N=N+1
0070      GO TO 22
0071      24 PHI84=      P*(84.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0072      25 IF (PHI(2,N+1)-95.0) 26,26,27
0073      26 N=N+1
0074      GO TO 25
0075      27 PHI95=      P*(95.0-PHI(2,N))/(PHI(2,N+1)-PHI(2,N))+PHI(1,N)
0076      EMZ=0.3333*(PHI16+PHI50+PHI84)
0077      SIGI=0.25*(PHI84-PHI16)+0.1515*(PHI 95-PHI15)
0078      DKI=(PHI16+PHI84-2.0*PHI50)/(2.0*(PHI84-PHI16))+
      1      (PHI15+PHI95-2.0*PHI50)/2.0*(PHI95-PHI15)
0079      AL2FI=(PHI95+PHI15-2.0*PHI50)/(PHI84-PHI16)
0080      CAYGP=0.4098*(PHI95-PHI5)/(PHI75-PHI25)
0081      28 EMPHI=0.5*(PHI16+PHI84)
0082      SIGFI=0.5*(PHI84-PHI16)
0083      ALFI=(PHI84+PHI16-2.0*PHI50)/(PHI84-PHI16)
0084      701 CAYGI=(PHI16-PHI5+PHI95-PHI84)/(PHI84-PHI16)
C      THIS POINT INDICATED COMPLETION OF FOLK, INMAN.
      START MOMENTIME.
0085      DO 35 L=1,4
0086      35 DF(L)=0.0
0087      DO 40 N=1,J
0088      IF (PCT(N)) 40,40,41
0089      41 A=N-M
0090      IF (A) 42,40,42
0091      42 A=A/4
0092      D=A*A
0093      E=A*D

```


Table 10. Cont.

```

0094      DF(1)=PCT(N)*A+DF(1)
0095      DF(2)=PCT(N)*D+DF(2)
0096      DF(3)=PCT(N)*E+DF(3)
0097      DF(4)=PCT(N)*E*A+DF(4)
0098      40 CONTINUE
0099      DO 45 L=1,4
0100      45 DF(L)=0.01*DF(L)
0101      XBAR=PHI(1,M) -.125+DF(1)
0102      B=DF(1)*DF(1)
0103      SSQD=DF(2)-B
0104      S=SQRT(SSQD)
0105      EM3=DF(3)-(3.*DF(1)*DF(1)*DF(200+(2.*DF(1)*B)
0106      EM4=DF(4)-(4.*DF(1)*DF(3))+(6.*B*DF(2))-(3.*B*B)
0107      SK=.5*EM3/S**3
0108      CTSIS=(PHI95-PHI15)/2.44*(PHI75-PHI25)
C      THIS COMPLETES THE CALCULATION OF MOMENT MEASURE
0109      GO TO 400
C      THE FOLLOWING SECTION PROVIDES OUTPUT FORMS
0110      301 FORMAT(1X, 'SAMPLE NUMBER',5X,10A4)
0111      302 FORMAT(35HOCALCULATION OF INMANS STATISTICS.)
0112      303 FORMAT(34HOCALCULATION OF FOLK'S STATISTICS.)
0113      304 FORMAT(42HOCALCULATION OF MOMENT MEASURE STATISTICS.)
0114      306 FORMAT(18H VERY WELL SORTED.)
0115      307 FORMAT('WELL SORTED')
0116      924 FORMAT(' MODERATELY WELL SORTED')
0117      308 FORMAT(' MODERATELY SORTED')
0118      309 FORMAT(15H POORLY SORTED.)
0119      310 FORMAT(20H VERY POORLY SORTED.)
0120      311 FORMAT(25H EXTREMELY POORLY SORTED.)
0121      312 FORMAT(22H STRONGLY FINE SKEWED.)
0122      313 FORMAT(13H FINE SKEWED.)
0123      314 FORMAT(18H NEAR SYMMETRICAL.)
0124      315 FORMAT(15H COURSE SKEWED.)
0125      316 FORMAT(24H STRONGLY COURSE SKEWED.)
0126      317 FORMAT(18H VERY PLATYKURTIC.)
0127      318FORMAT(13H PLATYKURTIC.)
0128      319 FORMAT(12H MESOKURTIC.)
0129      320 FORMAT(13H LEPTOKURTIC.)
0130      321 FORMAT(18H VERY LEPTOKURTIC.)
0131      322 FORMAT(23H EXTREMELY LEPTOKURTIC.)
0132      111 FORMAT (1X, 'APPROXIMATE PHI VALUES (ACCURATE TO
           WITHIN 0.50).')
0133      222 FORMAT(9H PHI 5  =F7.3)
0134      333 FORMAT(9HPHI 16 =F7.3)
0135      444 FORMAT(9H PHI 25 =F7.3)
0136      555 FORMAT(9H PHI 50 =F7.3)
0137      666 FORMAT(9H PHI 75 =F7.3)
0138      112 FORMAT(9H PHI 84 =F7.3)

```

Table 10. Cont.

```

0139      113 FORMAT(9H PHI 95 =F7.3)
C        THIS LIST PROVIDES OUTPUT TO BE USED IN THE
C        FOLLOWING DECISION NETWORK BASED ON FOLK, JOUR
C        GEOL. V. 162, pp.345-51, JULY 1954
0140      344 FORMAT(21H STANDARD DEVIATION = F7.3)
0141      345 FORMAT(7H MEAN = F8.3)
0142      346 FORMAT(11H SKEWNESS = F7.3)
0143      347 FORMAT(11H KURTOSIS = F7.3)
0144      348 FORMAT(10H SORTING = F7.3)
0145      349 FORMAT(5H MZ = F7.3)
0146      350 FORMAT(8H M PHI = F7.3)
0147      351 FORMAT(12H SIGMA PHI = F7.3)
0148      352 FORMAT(16H ALPHA TWO PHI = F7.3)
0149      353 FORMAT(15H THIRD MOMENT= E12.5/16H FOURTH MOMENT= E12.5)
0150      354 FORMAT(1H)
0151      355 FORMAT(11H VARIANCE = E12.5)
0152      356 FORMAT(13H KG (INMAN)= F7.3)
0153      400 WRITE (3,304)
0154          WRITE (3,345) XEAR
0155          WRITE (3,355) SSQD
0156          WRITE (3,344) S
0157          WRITE (3,346) SK
0158          WRITE (3,347) OTSIS
0159          WRITE (3,353) EM3,EM4
0160          WRITE (3,111)
0161          WRITE (3,222) PHI 5
0162          WRITE (3,333) PHI 16
0163          WRITE (3,444) PHI 25
0164          WRITE (3,555) PHI 50
0165          WRITE (3,666) PHI 75
0166          WRITE (3,112) PHI 84
0167          WRITE (3,113) PHI 95
0168          WRITE (3,303)
0169          WRITE (3,349) EMZ
0170          WRITE (3,348) SIGI
0171          WRITE (3,346) SKI
0172          WRITE (3,347) CAYGP
0173          X1=CAYGP
0174          ESK=SKI+1.0
0175          ES=SIGI

C
C        FOLLOWING NAMES THE SAMPLE ACCORDING TO FOLK'S
C        TEXTURAL GROUPING
0176          WRITE (3,357)
0177          FORMAT(29HOFOLK'S TEXTURAL DESCRIPTION.)
0178      500 IF (ES-4.0) 502,502,501
0179      501 WRITE (3,311)
0180          GO TO 520
0181      502 IF (ES-2.0) 504,504,503
0182      503 WRITE (3,310)

```

Table 10. Cont.

0183	GO TO 520
0184	504 IF (ES-1.0) 506,506,505
0185	505 WRITE (3,309)
0186	GO TO 520
0187	506 IF (ES-0.71) 923,923,507
0188	507 WRITE (3,308)
0189	GO TO 520
0190	923 IF (ES-.50) 508,508,925
0191	925 WRITE (3,924)
0192	GO TO 520
0193	508 IF (ES-0.35) 510,510,509
0194	509 WRITE (3,307)
0195	GO TO 520
0196	510 WRITE (3,306)
0197	520 IF (X1-3.0) 522,522,521
0198	521 WRITE (3,332)
0199	GO TO 540
0200	522 IF (X-1.5) 524,524,523
0201	523 WRITE (3,321)
0202	GO TO 540
0203	524 IF (X1-1.11) 526,526,525
0204	525 WRITE (3,320)
0205	GO TO 540
0206	526 IF (X1-0.90) 528,528,527
0207	527 WRITE (3,319)
0208	GO TO 540
0209	528 IF (X1-0.67) 530,530,529
0210	529 WRITE (3,318)
0211	GO TO 540
0212	530 WRITE (3,317)
0213	540 IF (ESK-1.30) 542,542,541
0214	541 WRITE (3,312)
0215	GO TO 600
0216	542 IF(ESK-1.1) 544,544,543
0217	543 WRITE (3,313)
0218	GO TO 600
0219	544 IF (ESK-0.9) 546,546,545
0220	545 WRITE (3,314)
0221	GO TO 600
0222	546 IF (ESK-0.70) 548,548,547
0223	547 WRITE (3,315)
0224	GO TO 600
0225	548 WRITE (3,316)
0226	600 WRITE (3,302)
0227	WRITE (3,350) EMPhi
0228	WRITE (3,351) SIGFI
0229	WRITE (3,346) ALFI
0230	703 WRITE (3,356) CAYGI

Table 10. Cont.

```
0231      WRITE (3,352) AL2FI
0232      WRITE (3,345)
0233      WRITE (3,823)
0234  823  FORMAT(//////)
0235      WRITE (3,359)
0236  359  FORMAT(5H PHI, 5X, 7H WEIGHT, 3X, 8H PERCENT, 2X,12H
          CUM PERCENT)

0237  751  IA=J
0238      DO 650 N=1,J
0239      WRITE (3,358) PHI(1,N),WT(N),PCT(N),PHI(2,N)
0240  358  FORMAT(1H F7.3,3X,F7.3,3X,F7.3,3X,F7.3)
0241      CONTINUE
0242  700  CONTINUE
0243  999  CONTINUE
0244      END
```

Table 11. Computer program for correlation of Rangia growth parameters

```

CA3 12      LINEAR REGRESSION ANALYSIS PROGRAM
C          USES SUBROUTINES INPUT, TRANSG
0001      DIMENSION IFREQ(1000),YBAR(1000),VAR(1000),FMT(20),X(1000),
          FREQ(1000),AA(3000)
0002      EQUIVALENCE (AA,X),(AA(1001),YBAR),(AA(2001),VAR)
0003      EQUIVALENCE ( FREQ ( 1), IFREQ ( 1))
0004      IPT=1
0005      LST =3
0006      NO=0
C          READ INPUT PARAMETERS,IA = NO. OF X VALUES,
C          ICODE = INPUT CODE, TRANX AND TRANY ARE
C          TRANSFORMATION CODES, TALPH = T VALUE AT
C          P = ALPHA
0007      I1=1
0008      1 READ (IPT,2) IA, ICODE, ITRANX, ITRANY, TALPH,ALPHA
0009      2 FORMAT (4I5,F10.3,F5.4)
0010      IAPIA=IA+IA
0011      IF ( IA.LE.1 ) GO TO 999
0012      WRITE (LST,3) IA, ICODE, ITRANX, ITRANY, TALPH, ALPHA
0013      3 FORMAT(1H1/15, 9H X-VALUES ,I10,13H = INPUT CODE,22H,
          TRANSFORMATION CODES , I3,1H,, I3/3X,3HT=,F6.3,7H AT P
          =,F6.4//)
0014      READ(IPT,4) FMT
0015      WRITE (LST,4) FMT
0016      4 FORMAT (20A4)
0017      DF = 0.
0018      IF ( ICODE ) 5, 5, 7
0019      5 READ (IPT,FMT) (X(I), I=1, IA)
0020      6 CALL INPUT ( IA, IFREQ, YBAR, VAR, WAVVAR, ITRANY )
0021      GO TO 20
0022      7 WAVVAR =0.
0023      DO 12I = 1, IA
0024      READ(IPT,FMT) X(I), IFREQ(I), YBAR(I), VAR(I)
0025      IF ( IFREQ ( I ) - 1 ) 10, 10, 11
0026      10 IFREQ (I) = 1
0027      YBAR ( I ) = TRANSG ( ITRANY, YBAR ( I ))
0028      11 FNM1 = IFREQ ( I ) - 1
0029      WAVVAR = WAVVAR + FNM1 * VAR ( I )
0030      12 DF = DF + FNM1
0031      IF ( DF ) 20, 20, 13
0032      13 WAVVAR = WAVVAR / DF
C          COMPUTE REGRESSION STATISTICS
0033      20 SUMX = 0.
0034      SUMY = 0.
0035      TOTN = ).
0036      DO 25I = 1, IA
0037      X ( I ) = TRANSG ( ITRANX, X ( I ))

```

Table 11. Cont.

```

0038      FREQ ( I ) = IFREQ ( I )
0039      SUMX = SUMX + FREQ ( I ) * X ( I )
0040      SUMY = SUMY + FREQ ( I ) * YBAR ( I )
0041 25 TOTN = TOTN + FREQ ( I )
0042      NIOTMI = TOTN - 1.
0043      IAM1 = IA - 1
0044      IAM2 = IA - 2
0045      FIAM1 = IAM1
0046      FIA = IA
0047      DF = TOTN - FIA
0048      NDF = DF
0049      XBAR = SUMX / TOTN
0050      YBARB = SUMY / TOTN
0051      SUMX2 = 0.
0052      SUMY2 = 0.
0053      SUMXY = 0.
0054      DO 30I = 1, IA
0055      XD = X ( I ) - XBAR
0056      YD = YBAR ( I ) - YBARB
0057      SUMX2 = SUMX2 + XD * XD * FREQ ( I )
0058      SUMY2 = SUMY2 + YD * YD * FREQ ( I )
0059 30 SUMXY = SUMXY + XD * YD * FREQ ( I )

C
0060      VARX = SUMX2 / ( TOTN - 1. )
0061      SSERR = DF * WAVVAR
0062      SSTOT = SUMY2 + SSERR
0063      VARY = SSTOT / ( TOTN - 1. )
0064      B = SUMXY / SUMX2
0065      A = YBARB - B * XBAR
0066      WRITE(LST,41) A, B, XBAR, YBARB, TOTN, VARX, VARY
0067 41 FORMAT(/,31H THE REGRESSION EQUATION IS Y =,
      1F10.5,2H +,F10.5,2H X/,12H MEAN OF X =,F10.5,
      23X,11HMEAN OF Y =,F10.5,3X, 9HTOTAL N=,F5.0 /
      316H VARIANCE OF X =,F15.5,3X,15HVARIANCE OF Y =,
      4F15.5 / )

0068      VARG = SUMY2 / FIAM1
0069      SSEXP = SUMXY * SUMXY / SUMX2
0070      SSUNEX = SUMY2 - SSEXP
0071      VUNEX = SSUNEX / FLOAT ( IA - 2 )
0072      SBXT = SQRT ( VUNEX / SUMX2 ) * TALPH

C
0073      B1 = B - SBXT
0074      B2 = B + SBXT
0075      PCENT = ( 1. - ALPHA ) * 100.
0076      WRITE(LST,42) PCENT, B1, B2
0077 42 FORMAT(/,F6.1,44H PERCENT CONFIDENCE LIMITS
      1FOR THE SLOPE ARE ,F10.4, 4H AND, F10.4)

0078      FSGP = - 9999.9999
0079      FSDEV = - 9999.9999

```

Table 11. Cont.

```
0080      IF ( MDF ) 45,45,43
0081      43 FSGP = VARG / WAVVAR
0082      FSDEV = VUNEX / WAVVAR
0083      45 FSEXP = SSEXP / VUNEX
      C      PRINT ANOVA TABLE
0084      WRITE (LST,50) SUMY2, IAN1, VARG, FSGP, SSEXP,
      1I1, SSEXP, FSEXP, SSUNEX, IAM2, VUNEX, FSDEV, SSEXP,
      2NDF, WAVVAR, SSTOT, NTOIM1
0085      50 FORMAT(//25X,20ANALYSIS OF VARIANCE//7H SOURCE,
      17X, 2HSS, 20X,2HDF, 14X, 2HMS, 18X, 2HFS // 7H
      2GROUPS, F13.4, 1I7,2F20.4/2X, 6HLINEAR, F15.4,
      3 1I7, 2F20.4/ 2X,4HDEV., F17.4, 1I7,, 2F20.4//
      4 6H ERROR, F14.4, 1I7, F20.4// 6H TOTAL, F14.4,
      5 1I7)
      C      PREPARE TABLE OF YHAT, CONFIDENCE LIMITS, AND
      1 DEVIATION
0086      WRITE(LST,60)
0087      60 FORMAT(///2X,6HSAMPLE,5X,1HX,11X,1HY,10X,2HL1,
      110X,4HYAT,8X,2HL2,9X,9HDEVIATION /2X,6HNUMBER
      2 //)
0088      DO 70I = 1,IA
0089      YHAT = A+B * X ( I )
0090      DEV = YBAR ( I ) - YHAT
0091      STDRXT = SQRT ( VUNEX *( 1. / TOTN + ( X ( I ) -
      1 XBAR )*( X ( I ) - XBAR )/ SUMX2 ))# TALPH
0092      Y1 = YHAT - STDRXT
0093      Y2 = YHAT + STDRXY
0094      WRITE(LST,65) I, C(I), YBAR(I), Y1 YHAT, Y2, DEV
0095      65 FORMAT(I8,6F12.5)
0096      AA(I+IA)=YBAR(I)
0097      70 CONTINUE
0098      NO=NO+1
0099      CALL PLOT(NO,AA,IA,2,0,FUNC,0,0,0.0,0.0,0.0)
0100      GO TO 1
0101      999 CONTINUE
0102      END
```