ASSESSMENT OF THE HARD CLAM, *MERCENARIA MERCENARIA*, IN CUMBERLAND SOUND, GEORGIA

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ABSTRACT

The recent expansion of U.S. Navy facilities at Kings Bay, Georgia, included dredging of the ship channel in Cumberland Sound to a depth of 51 feet. Because marine benthic infauna serve as useful monitors of environmental conditions, this study was developed to determine whether the dredging had a measurable impact on the fauna of Cumberland Sound. Hard clams were established in enclosures at the southern (impact) and northern (control) ends of Cumberland Island, in order to compare clam growth and physiological state (as measured by O:N ratios). Clam growth was quite similar between locations, and while the southern Cumberland Island clams had significantly lower O:N ratios, the variability in the data make them unreliable. Reproductive effort was also compared between southern and northern Cumberland Island clams and was significantly lower in clams collected at the southern end of the island. Age-size comparisons were made in clams collected from southern and northern Cumberland Island and from southern Jekyll Island; clam growth rate was similar at Jekyll and northern Cumberland Island and substantially higher at the southern Cumberland location. There appears to have been a period of reduced growth of southern Cumberland clams that can be seen in the annual rings of the shells; a more precise quantification of historical growth rates is being conducted in the second phase of this project.

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INTRODUCTION

The recent expansion of U.S. Navy facilities at Kings Bay, Georgia, to accommodate Trident submarines, included dredging of the ship channel through the Cumberland Sound inlet to a depth of 51 feet. The work reported here is part of a larger project designed and implemented by the National Park Service (NPS) to assess the impacts of that dredging on the physical and biological components of Cumberland Sound. Marine benthic infauna are commonly monitored to assess environmental impacts such as dredging (e.g., Oliver et al. 1977, Rhoads et al. 1978), since they are relatively immobile and long-lived. Dredging activities that may affect these organisms include increased sedimentation, erosion, and/or turbidity of the water. Post-dredging changes to the habitat may include altered salinity levels and water flow, particularly near the Cumberland Sound inlet.

Among the benthic invertebrates, bivalve molluscs (such as clams and mussels) are useful indicators of environmental stress (e.g., TIMW 1980). Physiological changes and reduced growth can be associated with environmental stress (Mann 1978, Widdows 1978, Bayne et al. 1979) and these parameters can be monitored and compared among bivalves collected from different habitats. The hard clam (Mercenaria mercenaria [Linne]) was used in this study to assess the impact of Kings Bay dredging activities on the Cumberland Sound environment. Several approaches were used in the first phase of this work, which is reported here: 1) comparing growth rates and physiological indices in clams that were transplanted to enclosures at an "impact" and a control site; 2) making age-size comparisons of clams naturally occurring in an "impact" and two control sites, as an assessment of historical growth patterns; and 3) making comparisons of reproductive effort in clams collected from an "impact" and a control site. Results of this first year of work have been used to develop the focus of ongoing research efforts, which are described in the Recommendations section of this report.

METHODS

Enclosure Studies

Hard clams used in all enclosure studies were obtained from Y and W Shellfish of Kingsland, Georgia, having been collected from a common source in the Cumberland Sound area. Clams were marked, measured, and placed into enclosures in two locations: the southern end of Cumberland Island, and a control site (away from dredging and construction activities) at the northern end of Cumberland Island. At each location, five 1-m^2 enclosures were placed at three sites that were at least 100 feet apart.

The size of transplanted clams ranged from 26 to 48 mm in shell length over all enclosures. Before placing clams in the enclosures, each received a unique color-coded marking with Mark-Tex paint. The shell length of each clam was measured to the nearest 0.1 mm with vernier calipers and then recorded onto data sheets.

Enclosures consisted of 1-m^2 square fences made of VEXAR (6-mm-mesh size), that were anchored by metal stakes at the corners and at the midpoints of each

side. The netting was attached to stakes with cable ties. The fences were 15 cm in height, and each was forced about 10 cm into the sediments so that approximately 5 cm remained above the sediment surface. After placement of enclosures, large macrofauna was removed by hand, and 15 marked and measured clams were placed into each enclosure.

Three replicate water samples were taken at each site for measurement of total suspended solids and chlorophyll a (APHA 1985). These water samples were placed into acid-washed 1-L plastic bottles, that were put on ice and returned to the laboratory, where they were kept in the dark and on ice until analyzed.

Enclosures were set out October 3 and 4, 1989. On April 10 and 11, 1990, all clams were retrieved to measure shell growth. One clam from each enclosure (n = 15 per location) was then removed for physiological (O:N) measurements, and the remaining clams were returned to their respective enclosures. Shell growth was to have been measured again in the fall of 1990, but only seven live clams were retrieved in the remaining enclosures at the southern end of Cumberland Island, thus making any statistical comparisons between sites of questionable value.

All clams used for physiological tests were scrubbed and rinsed prior to incubation, then each was placed into a separate respiration chamber filled with filtered (Whatman GF-C) seawater. The chambers consisted of plastic food storage containers (approx. 750-mL) that could be sealed so as to exclude all air bubbles. These containers were placed in the shade and incubated for two hours. Two control containers received an identical treatment but contained no clams.

At the end of the incubation time, water samples for ammonia analysis were placed into 100-ml acid-washed centrifuge tubes and preserved with 1 drop of H_2SO_4. A Technicon-TRAACS 800 autoanalyzer was used for the ammonia analysis (using EPA Method 350.1). Dissolved oxygen levels in each container were determined by titration method (APHA 1985). The amounts of oxygen respired and ammonia excreted were determined as the difference in levels between controls and the containers with clams, and O:N ratios were calculated as molar ratios of oxygen respired versus nitrogen excreted. The O:N ratio determination was made only in the spring, since location differences in O:N ratios are not as apparent after bivalves have spawned (Bayne et al. 1979).

Age-Size Study

Approximately 200 hard clams were collected in each of the three sample locations: southern Cumberland Island, northern Cumberland Island, and southern Jekyll Island. Clams were collected from intertidal areas with clam rakes and were then placed in labeled plastic bags and placed on ice. Upon return to the laboratory, all clams were frozen.

Clams were thawed in small batches and each valve of every clam was marked with a unique number. Shell length was measured to the nearest 0.1 mm using vernier calipers. Clams were then opened and all tissues were removed. One valve of each clam was sectioned from umbo to ventral margin (along the axis of greatest growth), using a diamond blade on a slow-speed Isomet saw. The number of internal bands was counted and recorded onto data sheets along with shell size measurements.

Reproductive Effort

Approximately 50 clams were collected from both the northern and southern ends of Cumberland Island on April 9 - 10, 1990. These clams were collected with clam rakes from the intertidal areas near the location of the enclosures. All clams were placed in labeled plastic bags and placed on ice, then washed and frozen upon return to the lab.

Clams were removed individually from the freezer and the frozen lump of tissue was separated from the valves. The gonadal tissue could be rather easily separated from the somatic tissue if still solidly frozen, but still included the stomach, intestines, and digestive glands. The bulk of the digestive gland tissue was removed from the gonadal mass and was included with the rest of the somatic tissue, but no attempt was made to separate the stomach or intestine from the remaining gonadal tissue. Each tissue type was placed onto labeled, tared sheets of aluminum foil, which were sealed and placed in a drying oven at 60°C for 12 - 14 days. Dry weights were determined to the nearest 0.001 mg with a Metler balance. Clam shells were numbered and shell length for each clam was measured to the nearest 0.1 mm with vernier calipers. Reproductive effort (as defined by Bayne et al. 1983) was calculated as gonadal dry weight divided by total tissue dry weight (both soma and gonad); this ratio was then multiplied by 100 to obtain a percentage. Because gonadal weights for all clams included the stomach and intestine, they were slightly higher than the weight of gonadal tissue alone; however, the weight ratios were used only to make reproductive effort comparisons between locations, and not as a measure of absolute weights of clam gonadal tissue.

Statistical Analysis

A t-test was used to test for location differences in O:N ratios (the ratios were arctan-transformed), after first testing for equal variances. Growth (increase in shell length) in transplanted clams was expressed as a mean for each enclosure, and a t-test that does not assume equal variances was used to test for location differences. Reproductive effort was compared between locations by a t-test, after first testing for equal variances. Minitab (Minitab 1989) and SAS (SAS 1985) software were used for statistical analyses.

Description of Study Sites

Enclosures were set out at three intertidal sites along the southern end of Cumberland Island (the "impact" location; Figure 1), where sediment type ranged from sand to muddy sand. Clams for age-size comparisons were collected in the intertidal area of Site 2, referred to by local residents as "Clam Flats."

Enclosures were also established at three intertidal sites at the northern end of Cumberland Island (the Cumberland Wharf/Terrapin Point area), that served as the "control" location (Figure 1). Sediment type at this location ranged from sand to muddy, shelly sand. Clams for age-size comparisons were collected in the intertidal area of Site 5; they were relatively abundant in the shelly substrate there. Water quality parameters were measured at southern and northern Cumberland Island, near where these enclosures were located (Table 1).

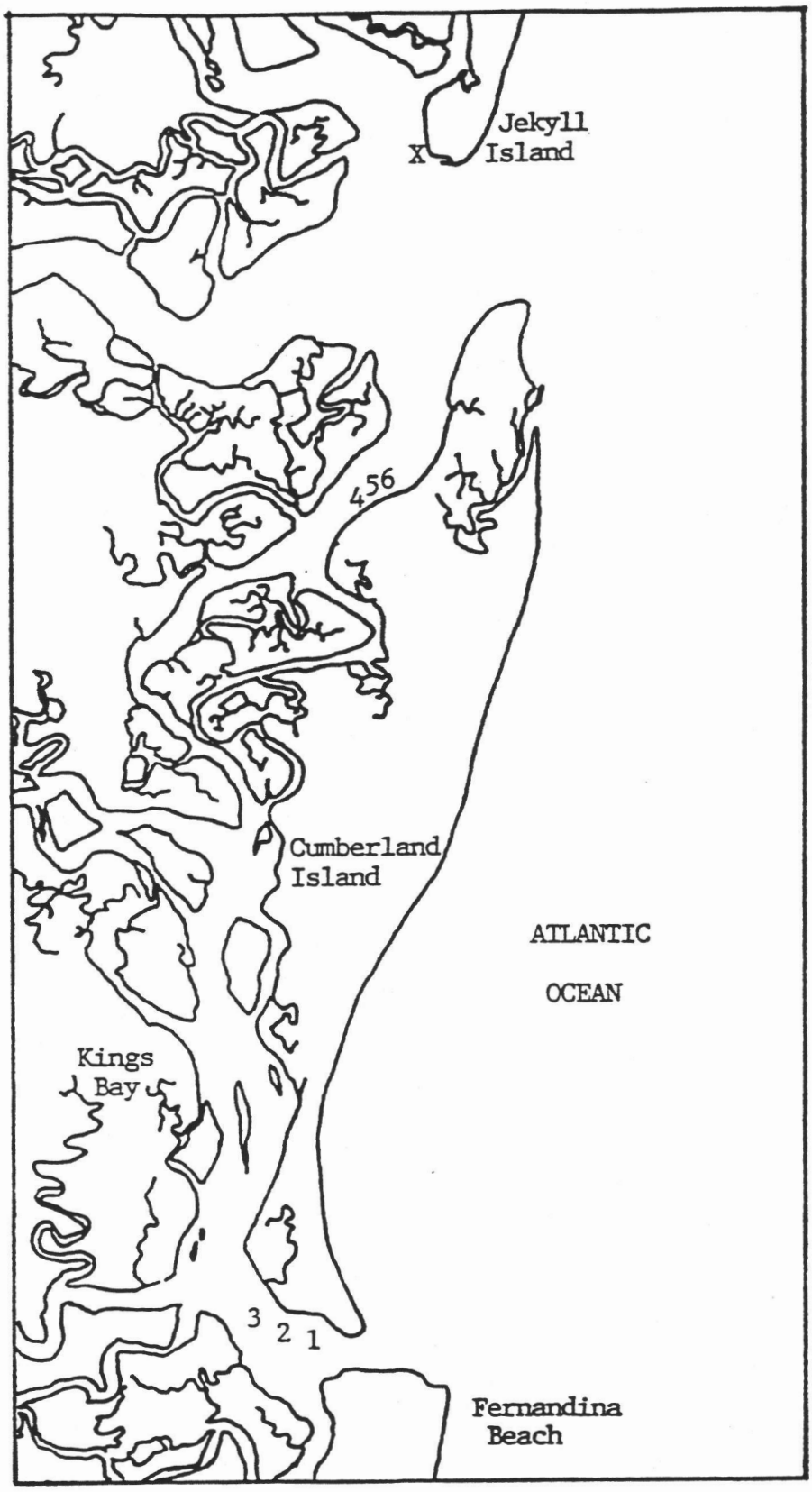


Figure 1. Clam collection sites in the vicinity of Cumberland Island, Georgia. Enclosure sites are indicated by numbers at southern (Sites 1,2, and 3) and northern (Sites 4,5, and 6) Cumberland Island. Dredging occurred from Kings Bay down through the inlet between Cumberland Island and Fernandina Beach, Florida.

Table 1. Water quality parameters measured at southern and northern Cumberland Island, near enclosure locations in April 1990.

	South	North
Temperature (°C)	21.8	21.0
Dissolved oxygen (mg/L)	8.4	9.4
Salinity (ppt)	19.1	15.4
Chlorophyll *a* (mg/L)	0.00574	0.00829
Phaeophytin (mg/L)	0.01342	0.0765
Total Suspended Solids (mg/L)	218.41	82.14
Percent Organic Matter	15.56	16.29

A third clam collection location for age-size comparisons was the southern end of Jekyll Island, across the St. Andrews Sound from the northern end of Cumberland and Little Cumberland Islands (Figure 1). Clams were found only in the very low intertidal zone, in muddy sand at the margins of clumps of marsh grass (Spartina).

RESULTS

Growth in Transplanted Clams

All clams were collected from enclosures in April 1990, for shell length measurements; growth was determined by subtracting the original shell length from the April shell length of each clam. Fewer enclosures (and therefore marked clams) survived the winter at the northern Cumberland Island location (Figure 2) compared to southern Cumberland Island. Growth was averaged within each enclosure (so that each enclosure could be considered to be a replicate), and these enclosure means were compared between southern and northern Cumberland Island locations with a t-test. Although the overall mean growth was higher in transplanted clams at southern Cumberland Island (Table 2), the location difference was not significant ($t=1.70$, $p=0.13$).

O:N Ratios in Transplanted Clams

There was a wider range in O:N ratios in clams that were collected from the enclosures at the southern end of Cumberland Island (1.76 to 52.08), and the mean was less than half (11.15) that found in clams from the northern Cumberland enclosures (23.63; Table 3). A test for equal variances at both locations was significant ($F'=114.07$, $p<0.01$); a t-test for samples with unequal variances indicated a significant difference between locations ($t=3.720$, $p<0.01$).

Reproductive Effort in Collected Clams

Clams that were collected from the northern end of Cumberland Island had a higher mean reproductive effort (36.03%) than did clams from the southern end of Cumberland Island (22.22%). Because there was a wider range in sizes of clams that were collected from the southern end of Cumberland Island (Figure 3), shell length versus reproductive effort was plotted at each location to determine whether these two variables might be related. There was no apparent size relationship (Figure 4), although there was a significant difference (at the 0.05 level) in variablity of reproductive effort between locations ($F'=2.00$, $p=0.017$). A t-test for samples with unequal variances indicated a significant location difference ($t=12.17$, $p<0.01$).

Age-Size Comparisons in Collected Clams

The widest range in age of clams was seen at southern Cumberland Island (Figure 5a); there was also more variability in the size of older clams at this location. At northern Cumberland Island, no 1- or 2-year-old clams were found, and most were in the 3- to 9-year-old range (Figure 5b). In contrast, at Jekyll

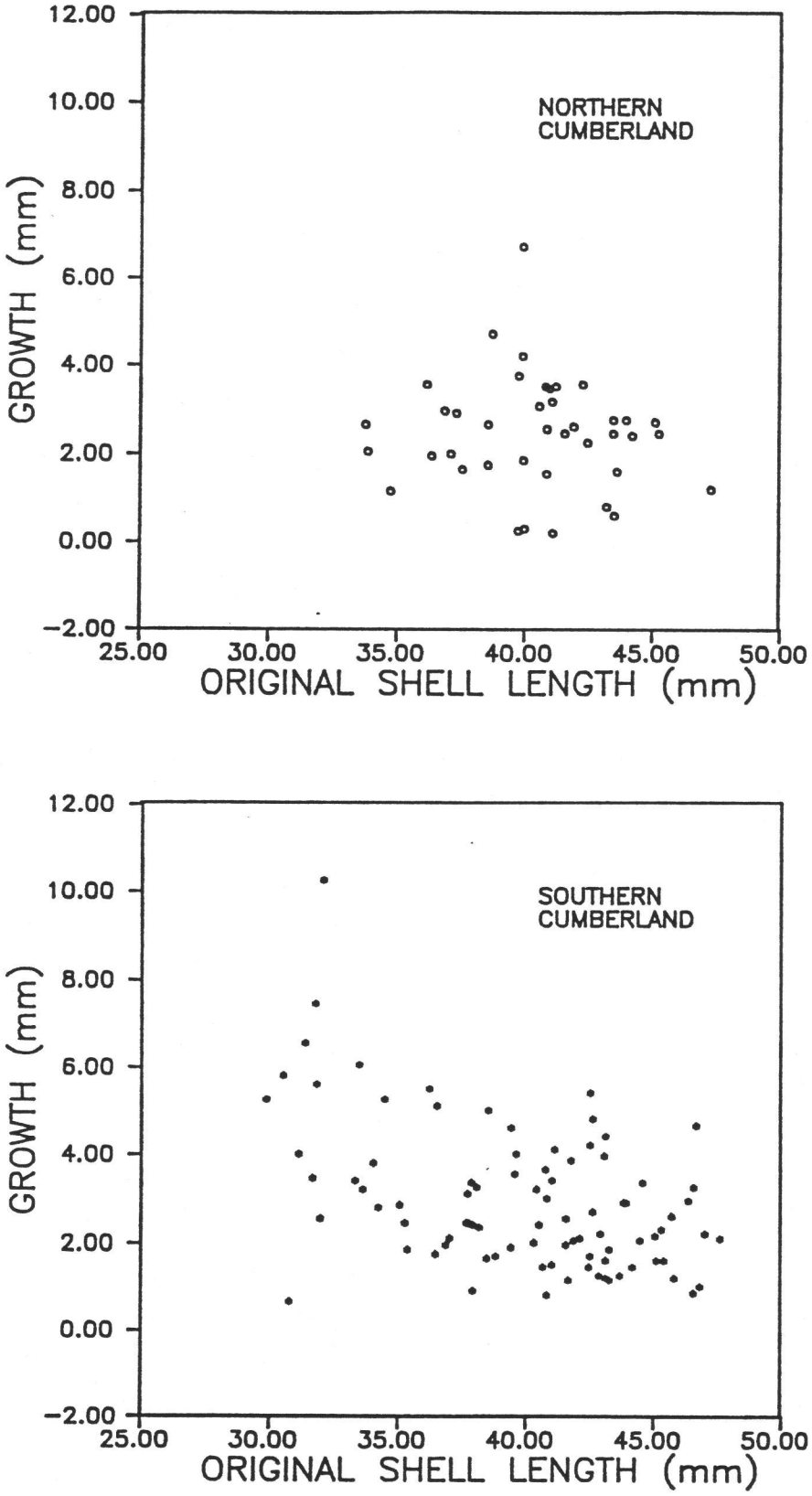


Figure 2. Growth rates (increase in shell length, versus original shell length) of clams transplanted to enclosures at the northern and southern ends of Cumberland Island from October 1989 to April 1990.

Table 2. Mean clam growth (change in shell length from October, 1989 to April 1990) averaged for all clams in each enclosure remaining in April 1990 (15 enclosures were placed at southern and northern Cumberland Island in October 1989) and number of clams recovered for each enclosure in April 1990 (15 clams were originally placed in each enclosure).

	Mean Growth/ Enclosure	# Clams/ Enclosure	# Dead Clams w/ Shell Damage
Northern Cumberland	2.02	10	0
	2.79	10	0
	2.46	11	0
	4.11	6	0
	0.25	1	0
	0.80	1	0
	0.10	2	0
Southern Cumberland	3.59	10	0
	1.97	10	0
	3.59	10	0
	4.24	13	0
	2.40	10	2
	2.40	10	3
	1.83	6	5
	2.78	8	3
	2.81	10	4

Table 3. O:N ratios (oxygen respired:nitrogen excreted) of clams collected from enclosures located at the southern (s) and northern (n) ends of Cumberland Island in April 1990. Means are indicated for each location, with standard errors in parenthesis.

Sample No.	O:N
n-1	18.57
n-2	17.52
n-3	44.01
n-4	44.01
n-5	22.40
n-7	12.02
n-8	27.74
n-9	19.66
n-10	19.67
n-11	30.66
n-13	17.52
n-14	20.44
n-15	16.39
n-16	24.82
n-17	18.98
n-mean	23.63 (2.44)
s-1	21.87
s-2	3.89
s-3	5.35
s-4	3.41
s-5	13.14
s-6	52.08
s-7	13.12
s-8	6.15
s-9	2.63
s-11	3.51
s-12	21.07
s-13	1.76
s-14	1.76
s-15	6.40
s-16	
s-mean	11.15 (3.63)

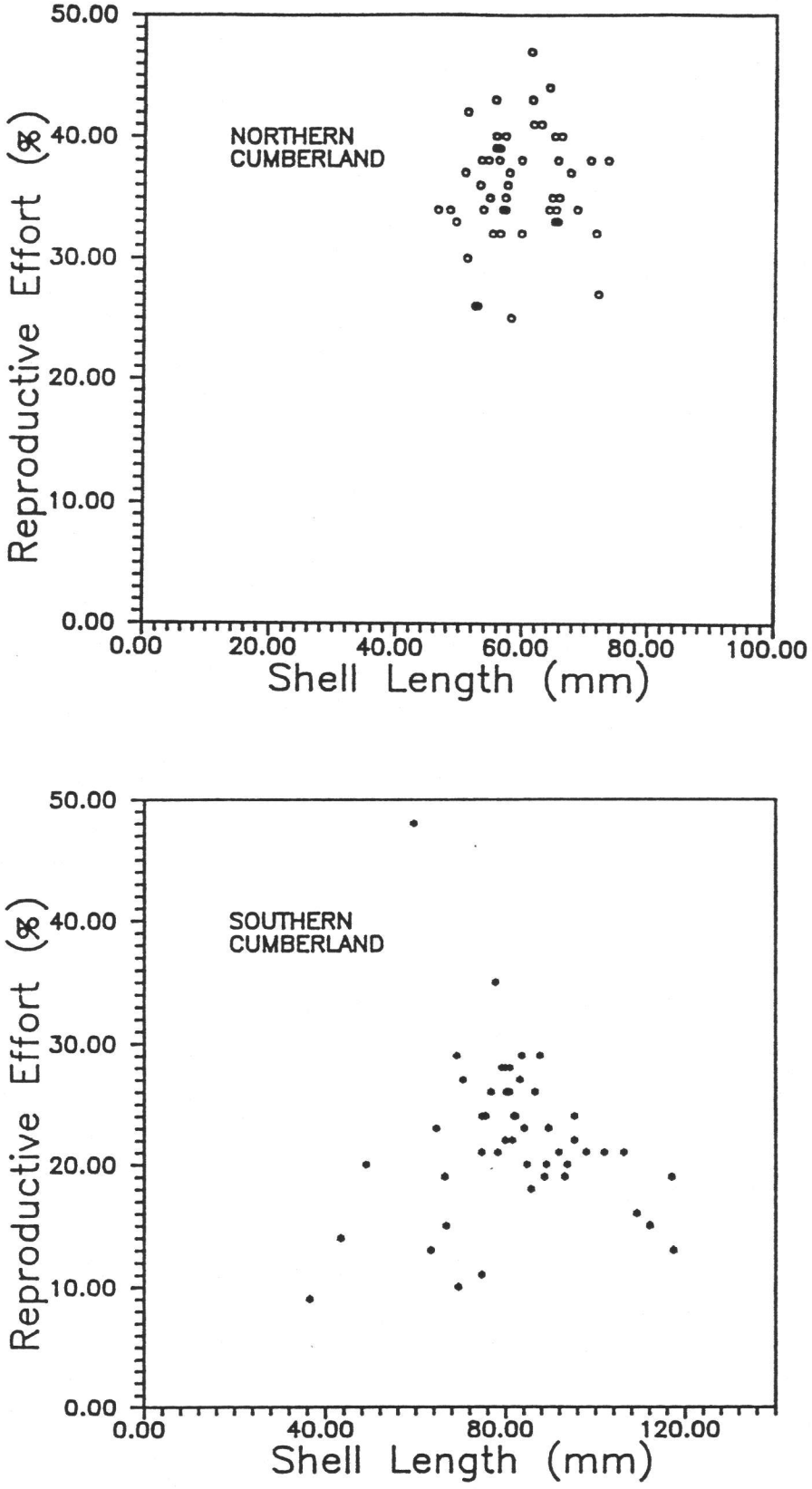


Figure 3. Reproductive effort (a ratio of gonadal mass to total body mass) in clams collected from northern and southern Cumberland Island in April 1990.

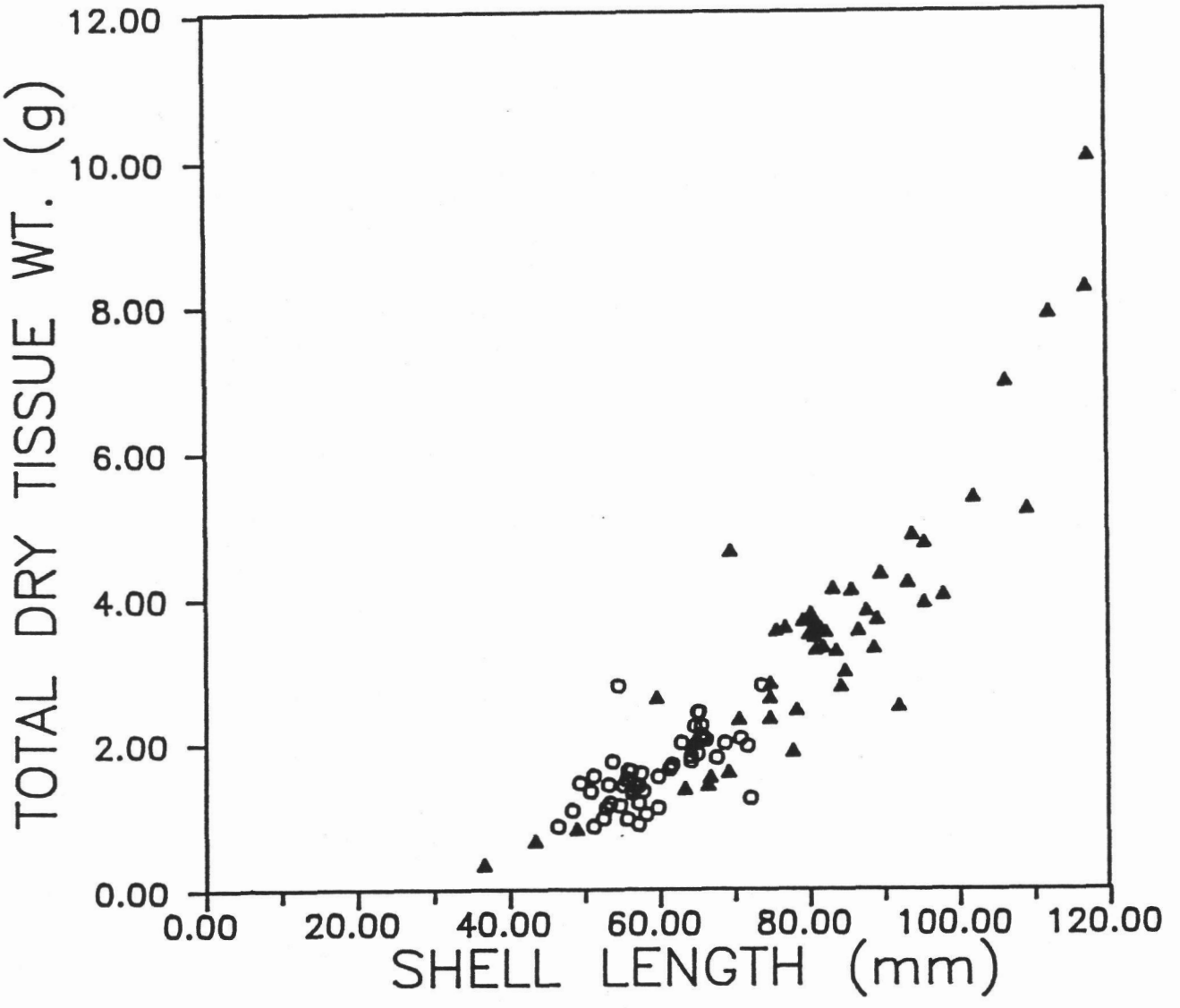


Figure 4. Shell length and dry tissue weight of clams used for determination of reproductive effort (Fig. 3). Open circles denote values for northern Cumberland Island clams, and closed triangles denote values for clams collected from southern Cumberland Island in April 1990.

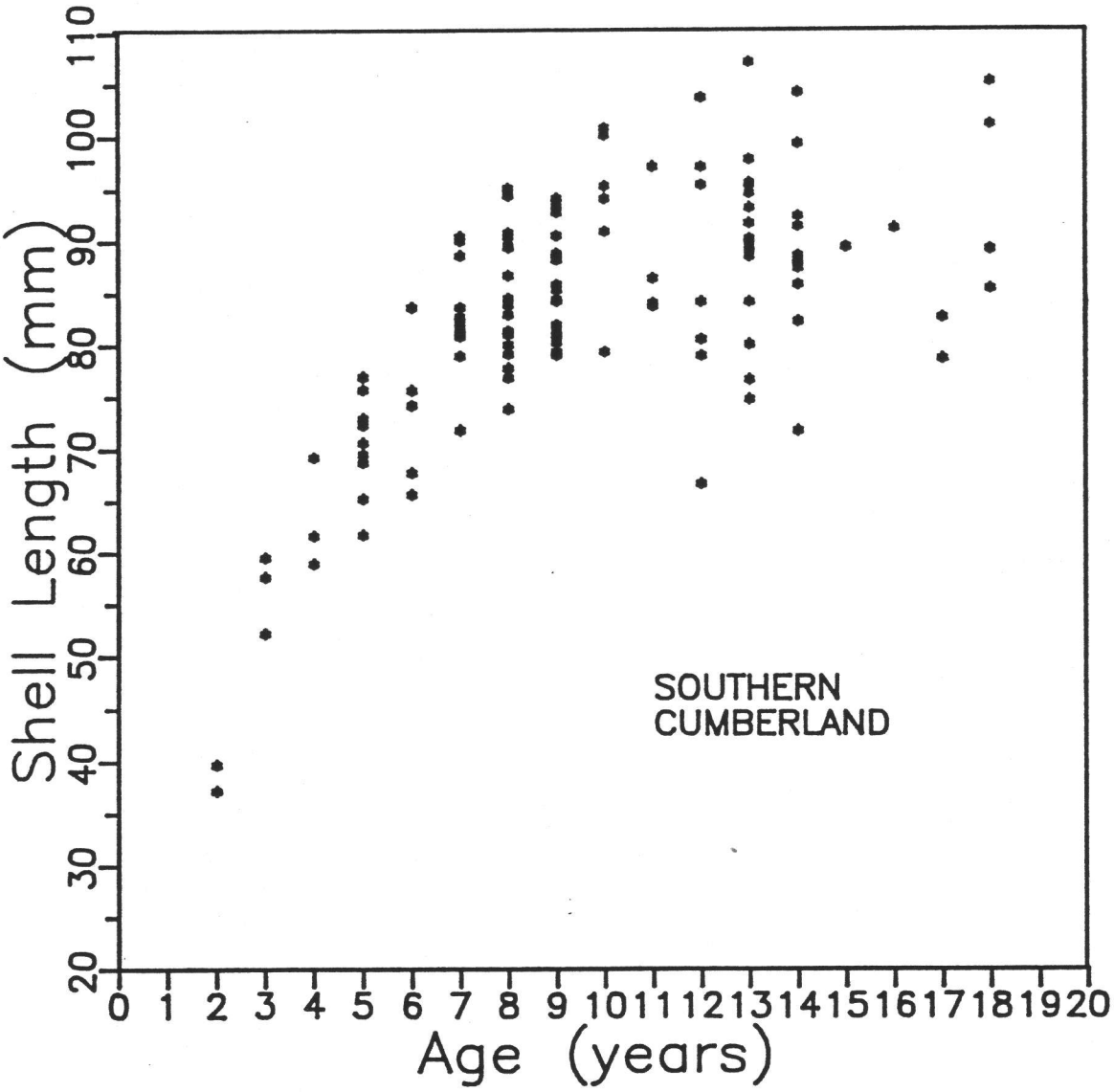


Figure 5a. Age - size comparisons of clams collected from southern Cumberland Island in April 1990.

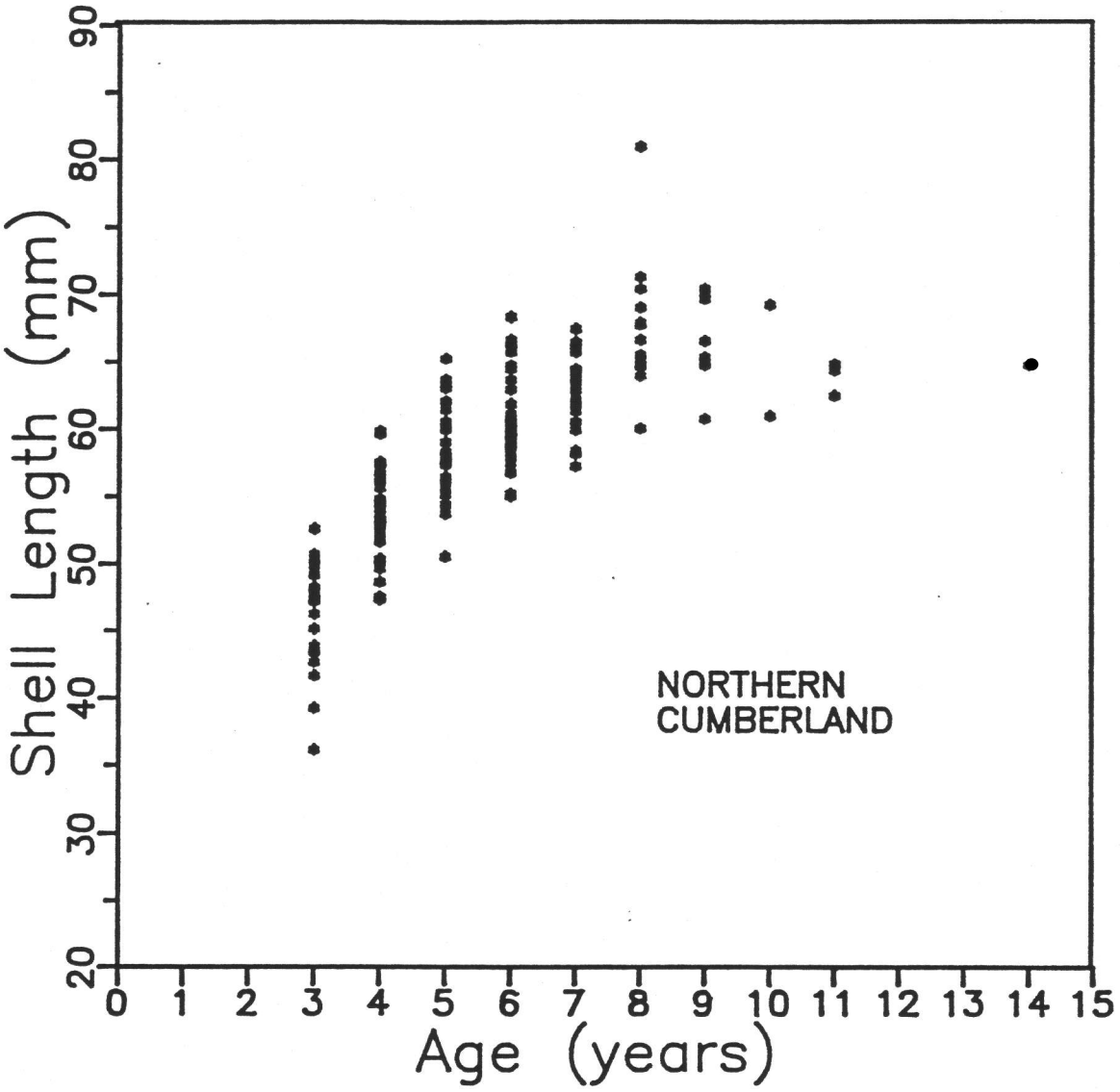


Figure 5b. Age - size comparisons of clams collected from northern Cumberland Island in October 1989.

Island, only younger (1- to 7-year) clams were found (Figure 5c). Mean shell lengths of clams aged 3 to 7 years (the only ages that overlapped among all locations) were compared among locations; the mean size of clams from southern Cumberland Island was consistently highest (Figure 6), indicating substantially higher growth rates there.

DISCUSSION

The original intent of the "assessment" of marine bivalve populations in Cumberland Sound was to determine whether dredging for the Kings Bay Submarine Base had a measurable effect on bivalve growth and physiology. This essentially involved two questions: did dredging activities have any effect on clams while it was in progress; and, did dredging alter physical/chemical components of the habitat, resulting in longer-term effects to the clam community. Because the research reported here was initiated after dredging was completed, it addresses only the second question.

Clam growth rates can vary widely, even among populations that are closely situated (Walker 1987); factors that can affect hard clam growth rates include salinity, substrate type, food availability, and other habitat-specific factors (Eversole 1987). Results of transplant experiments indicated that there was no significant difference in growth rates of clams at the "impact" site (southern Cumberland Island) versus a control site at the northern end of the island. It is possible, however, that the relatively short duration of these experiments played a role in the lack of significance. Age-size comparisons in collected clams indicated that clams from the southern end of Cumberland Island grew faster than clams from both the northern end of the island and from southern Jekyll Island (clam growth was quite similar at the latter two locations, however). Salinity, which is higher at the southern end of Cumberland than at the northern end, could be an influence on clam growth rates in the area. Neither exposure duration at low tide nor substrate type appeared to influence growth rates, since the Jekyll Island site had the lowest exposure time (about 1 h) and a muddy sand substrate, and clam growth was very similar to that seen at the northern end of Cumberland Island (where exposure time was about 3.5 h and the substrate type was shelly, muddy sand). This is in contrast to Walker (1987), who noted that clams that were collected from shelly substrates had lower growth rates than did clams from muddy sand, while exposure time seemed to have no affect on clam growth.

A comparison of Mercenaria growth rates determined in this study (from age-size data) was made with earlier collections by Walker (1987) in similar locations in the Cumberland Sound area. His clam growth rates from Crooked River were very similar to rates reported in this study for southern Cumberland Island, although his rates for southern Cumberland clams were lower (Walker 1987).

Oxygen:Nitrogen (O:N) ratios have been used by a number of researchers as a measure of the physiological state of bivalves, since they show an increase in ammonia excretion during starvation (bivalves must then catabolize protein for maintenance metabolism; Bayne and Scullard 1977). A low ratio of oxygen respired to ammonia excreted (an O:N ratio of about 10) therefore signifies considerable protein catabolism, with no energy available for growth or reproduction (Bayne and Newell 1983). A high ratio (greater than 24) indicates exclusive carbohydrate catabolism (Mayzaud 1973). The comparisons of physiological states

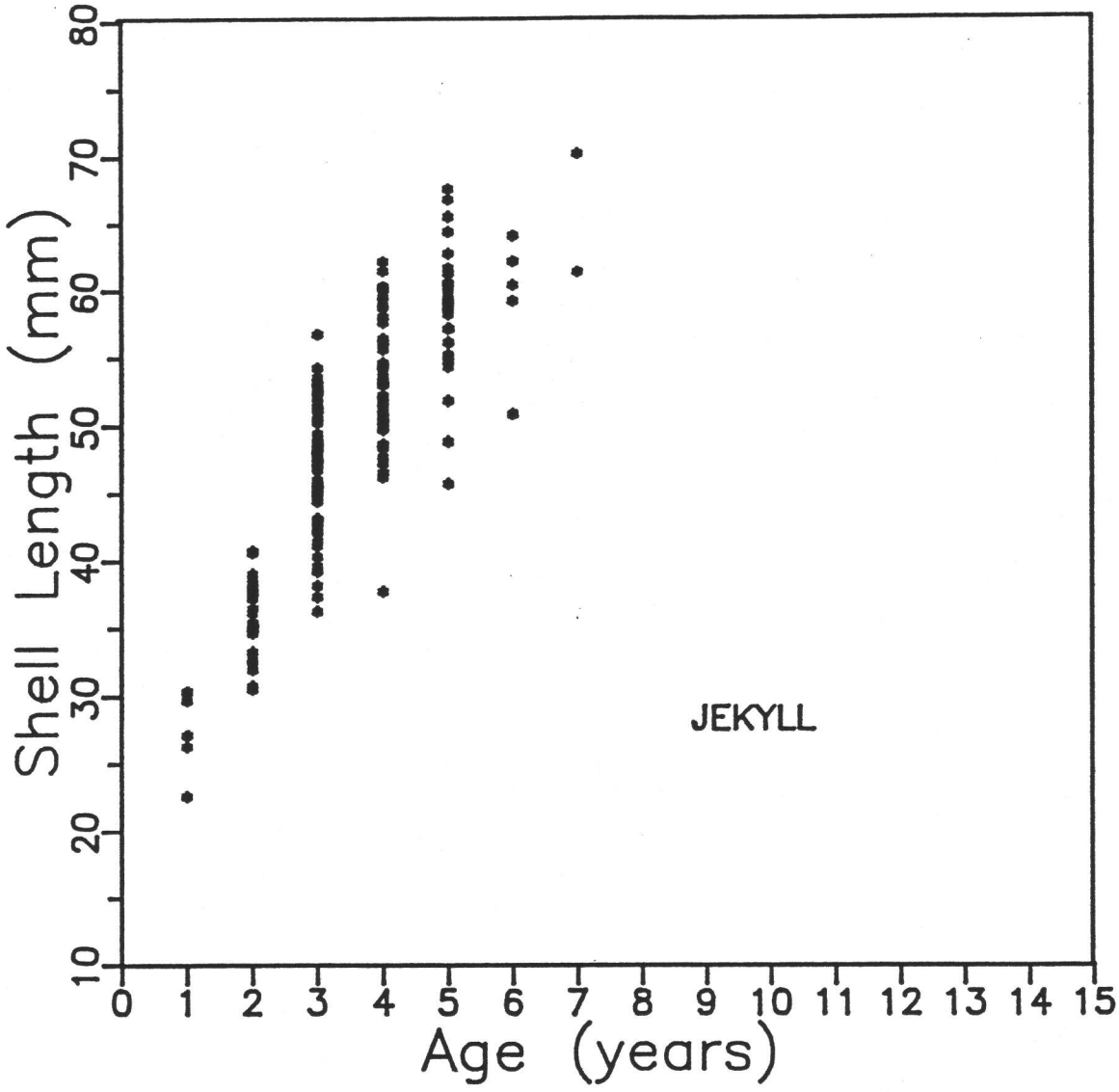


Figure 5c. Age - size comparisons of clams collected from Jekyll Island in October 1989.

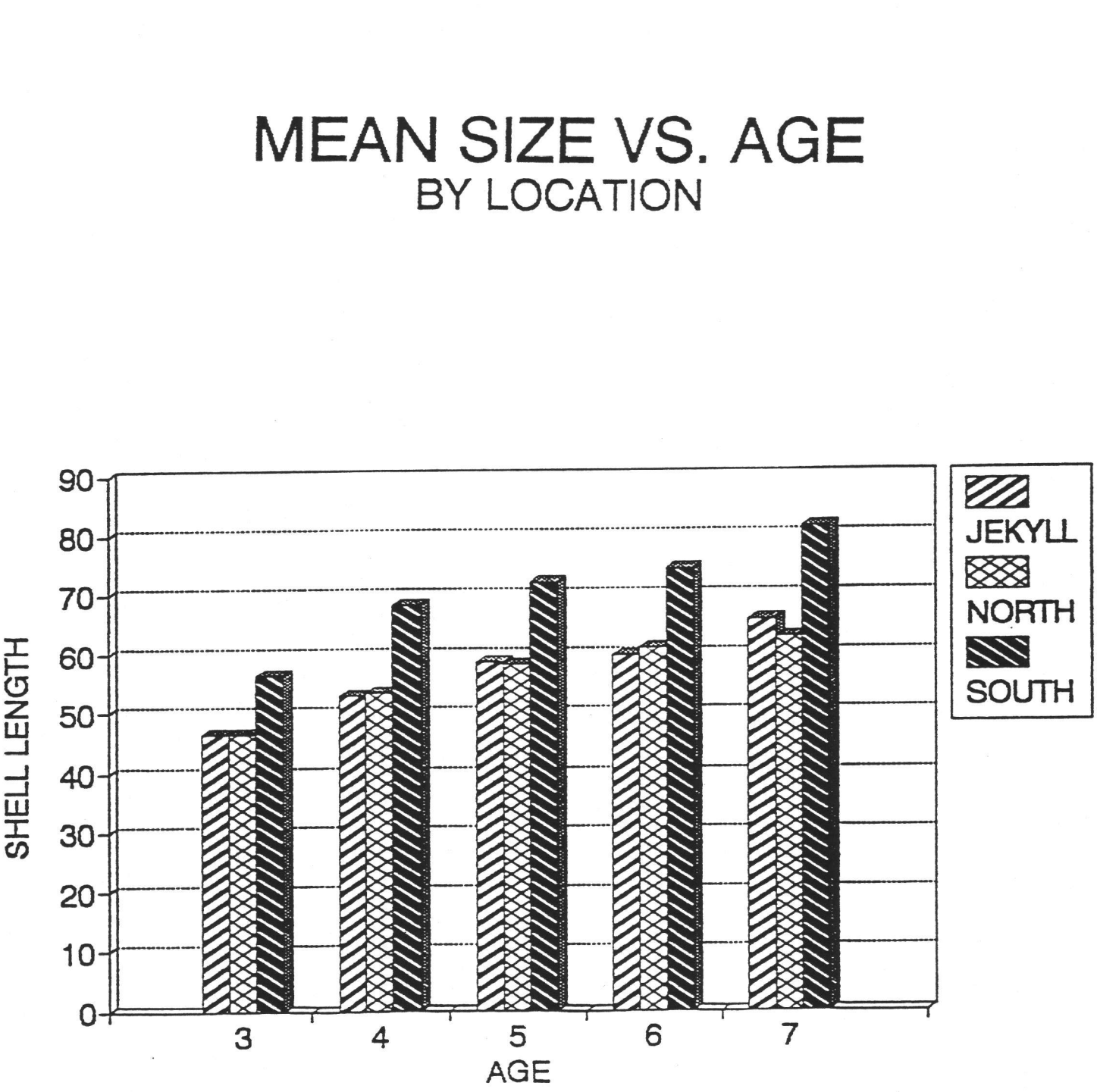


Figure 6. Mean shell length versus age for clams collected from southern and northern Cumberland Island and from southern Jekyll Island in 1989 and 1990.

of clams from southern and northern Cumberland Island suggest that clams from the southern "impact" site might be more energetically limited than northern clams, although this result was not substantiated by comparisons of clam growth.

The measurement of reproductive effort in bivalve molluscs can be used as an indirect assessment of environmental quality, because organisms under "stress" may be constrained energetically, devoting most, if not all of their available energy to basic maintenance, and not to reproduction (e.g., Browne and Russell-Hunter 1978). Reproductive effort in clams that were collected from the southern end of Cumberland Island was significantly lower and more variable than that measured in northern Cumberland clams, indicating that most southern clams are devoting less of their available energy to reproduction (as measured by gonadal tissue mass). The lower O:N ratios in clams transplanted to southern Cumberland Island may therefore reflect a true difference in energy availability between sites, and serve as the explanation for the lower reproductive effort ratios in clams collected from southern Cumberland Island. However, it appears that only the relative proportion of body mass devoted to reproduction differs between clams collected from southern and northern Cumberland Island, since total flesh (tissue) weight versus shell length of clams used in the determination of reproductive effort was comparable between locations. Relatively lower tissue weight for a given shell length would indicate that any constraints in energy availability were affecting overall clam tissue growth (e.g., Lauritsen 1986).

RECOMMENDATIONS FOR FURTHER STUDY

There were some expected and unexpected drawbacks to using enclosures in this study. Loss of enclosures demonstrated the difficulty of working in relatively high energy environments; the sites most likely to be affected by dredging were often not suitable locations for the type of enclosures that were used (although it is also possible that vandalism may have accounted for some of the losses). Age-size comparisons of collected clams also indicated the difficulty in finding a truly comparable control site. The best way to utilize enclosures would probably have been to do before-, during-, and after-dredging comparisons at the impact site, thus making temporal rather than spatial comparisons of clam growth. Unfortunately, this project was not funded until after the bulk of the dredging was completed.

It is possible to obtain this information in another way, however. Examination of clam shells collected for age-size comparisons indicated that historical growth rates could be determined by measuring the distances between annual growth lines. Growth rates could then be measured for the periods including before-, during-, and after-dredging by back-calculating from the last annual line to the annual lines which encompass these periods. The statistical methodology for making temporal comparisons in hard clam growth (by calculating a standardized growth index) has recently been developed (Jones et al. 1989); an alternative method for comparison is to calculate annual regression equations of clam size versus growth (Lauritsen in press). These methods are being utilized in the second phase of this study.

Other future research possibilities include assessing dredging effects by transplanting clams to an area where maintenance dredging is ongoing (such as parts of Kings Bay). Physical/chemical factors could also be monitored, giving insight as to how dredging might affect clam growth or physiology.

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Appendix

Appendix Table 1

Mean shell lengths (mm) of clams collected from southern Cumberland Island, northern Cumberland Island, and southern Jekyll Island in 1989 and 1990. Ranges of values are indicated in parenthesis.

Age	South	North	Jekyll
3	56.4 (52.1-59.5)	46.4 (36.1-52.6)	46.6 (36.2-56.7)
4	68.4 (58.9-70.5)	53.4 (47.3-59.8)	53.0 (46.2-62.2)
5	72.1 (61.7-80.9)	58.1 (50.5-65.2)	58.6 (45.7-67.6)
6	74.3 (65.6-86.5)	60.9 (55.0-68.3)	59.8 (50.8-64.1)
7	81.3 (71.8-90.4)	62.8 (57.2-67.4)	65.8 (61.4-70.2)