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Growth Studies of the Ocean Quahog, *Arctica islandica*

Steven A. Murawski, John W. Ropes, and Fredric M. Serchuk

National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts 02543 USA

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ABSTRACT

In situ growth rate of the ocean quahog, *Arctica islandica*, was investigated at a site 53 m deep off Long Island, New York, during 1970-1980. Specimens notched during summer 1978 and recaptured one calendar year later, yielded information on shell growth and the periodicity of supposed annual marks. Growth of recaptured specimens (59-104 mm, shell length) was described by: $SL_{t+1} = 2.0811 + 0.9802\ SL_t$, where SL is shell length in mm at age, t. Evidence is presented indicating that external bands on small quahogs (<ca. 60 mm) were formed annually during autumn - early winter. Internal banding in shell cross-sections of small quahogs correlated in number and position with external features. An equation representing back-calculated growth based on 1978 data was: $SL = 75.68 - 81.31\ (0.9056)^t$. Growth rates implied from progressions of length frequency modes in 1970 and 1980 samples from the area of marking were similar to those computed from mark-recapture and age-length equations. Annual increases in shell length were 6.3% at age 10, 0.5% at age 50, and 0.2% at an estimated age of 100 years.

RÉSUMÉ

Le taux d'accroissement, in situ, du "quahog" d'océan, *Arctica islandica*, fut étudié à un endroit de 53 m de profondeur au large de Long Island, New York, pendant 1970-1980. Spécimens encochés pendant l'été de 1978 et reprits un ans plus tard ont rendu renseignments sur l'accroissement de coquille et la périodicité de marque annuelle supposé. Croissance de spécimens reprits (59-104 mm, longueur de coquille) était décrite par: $SL_{t+1} = 2.0811 + 0.9802\ SL_t$, où SL est la longueur de la coquille en mm à âge t. Évidence est présenté indiquant que les bandes exterieur sur petites "quahogs" (<ca. 60 mm) ont été formé chaque ans pendant automne-au début d'hiver. Bandes interieur dans les profils transversals de petites "quahogs" se trouvaient en corrélation en nombre et position avec les traits exterieur. Une équation représentant croissance calcullé-d'arrière basé sur les données de 1978 etait: $SL=75.68-81.31\ (0.9056)^t$. Taux d'accroissement sous entendu des progressions de modes de fréquence de longueur des échantillons de 1970-1980 de l'aire de marquage ressemblaient ceux computés des équations de marque-reprise et âge-longueur. L'accroissement annuel de longueur de coquille était 6.3% à âge 10, 0.5% à âge 50, et 0.2% à âge estimé à 100 ans.

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INTRODUCTION

Research on the population dynamics of the ocean quahog, Arctica islandica, has become increasingly important in recent years. An intensive fishery for the species developed off New Jersey and the Delmarva Peninsula during the mid-1970's. The resulting increases in USA landings were dramatic: from 588 mt of shucked meats in 1975 to a record 15,748 mt by 1979. Estimates of the growth rate and longevity of ocean quahogs inhabiting the Middle Atlantic Bight are necessary to assess potential impacts of various harvesting strategies on the resources (Murawski and Serchuk 1979a; Mid-Atlantic Fishery Management Council 1979), but these data have not been heretofore presented.

Several published studies have alluded to the age and growth rate of Arctica, yet citations are largely anecdotal and generally do not reflect critical evaluations of the rate of growth or the validity of aging criteria. Turner (1949) reported an observation by G. Thorson that *"European investigators who have studied the chemical composition of the shell found reason to believe that it took six years or more for mahogany (ocean) quahaugs (quahogs) to reach average size."* Loosanoff (1953) stated that quahogs he examined for reproductive studies *"were adults, several years old, and averaged 3½ to 4 inches (89-102 mm) in length."* Jaeckel (1952) noted Cyprina (=Arctica) could perhaps attain ages up to 20 *"Sie kann hohes Alter (Vielleicht bis zu 20 Jahven) erreichen."* Skuladottir (1967) did not elaborate on aging methodologies but claimed *"the oldest clams were up to 18 years and about 9 cm long. The bulk was in the 10-14 year group and 7-8.7 cm long."*

The external color of large quahogs (>ca. 60 mm shell length) is usually solid black, however, the periostracum of small individuals is variable in color, grading from pale yellow to deep brown (Lovén 1929; Hiltz 1973). Concentric dark bands appearing in the shell surface of small specimens have thus been interpreted as annuli by several authors. Although Lovén did not present age-size relationships explicitly, he did note the presence of external *"annual rings" ("Jahresringe")* and presented photographs of a size range of small quahogs illustrating the relationship between numbers of rings and shell lengths. Chandler (1965) measured the maximum diameters of concentric rings and derived growth relationships based on eight specimens (96 total measurements). The largest number of such rings appearing on an individual quahog was 21; the corresponding shell length was 58.5 mm. Caddy et al. (1974) presented growth curves, based on external markings, for small quahogs from the Northumberland Strait and Passamaquoddy Bay. Average length at age was consistently greater for the more southern area.

Unpublished manuscripts by Chéné[1] and Meagher and Medcof[2] document recent efforts to establish quahog growth rates. Mark and recapture experiments were conducted in Brandy Cove, New Brunswick. Notched specimens (n=14) averaging 57.4 mm (shell length) when recaptured, grew an average of 0.6 mm (shell height) between September 1970 and September 1971. Sequential observations of eight small quahogs (mean length 20.16 mm) was undertaken to assess growth rates and seasonal changes in the color patterns of the periostracum. These individuals were held in cages and grew an average 17% in length from 4 June to 31 August 1971. Periostracum formed during the interval was brown, contrasting with yellow material formed before the study was begun. However, this banding pattern may not have been indicative of a normally occurring annual event since *"the caged clams were sensitive to experimental treatments and produced disturbance rings each time they were air-exposed for observation"* (Meagher and Medcof[2]).

Most previous investigation has thus been restricted to small sized individuals. Results of recent unpublished work suggest relatively slow rates for the species but extrapolation of experimental findings to field data may not be warranted (Chéné[1]; Meagher and Medcof[2]).

We initiated a project during summer 1978 to assess in situ growth rates of ocean quahogs at a deep water site off Long Island, New York. Objectives of the study were to obtain growth increment data directly from mark-recapture, evaluate the potential of banding patterns (both external and in shell cross-section) as indicators of age, and correlate growth measurements with a time-series of length frequencies collected in the vicinity of the marking site. Length-weight relationships have been established for the Middle Atlantic, based on a synoptic winter survey (Murawski and Serchuk 1979b), however, no data have been published on seasonal variations. An additional objective of the project was to compare winter and summer length-weight relations at the marking site.

FIELD STUDIES

Intermittent surveys of offshore clam resources of the Middle Atlantic Bight have been conducted since 1965 by the National Marine Fisheries Service (Merrill and Ropes 1969; Serchuk et al. 1979; Murawski and Serchuk 1979a). Cruises were designed to yield information on temporal and areal aspects of distribution, size composition, and relative abundance of both surf clam, Spisula solidissima, and ocean quahog, Arctica islandica. Stations were sampled in a grid array prior to 1978; surveys from 1978-1980 employed a stratified random scheme. Commercial type hydraulic clam dredges were modified to retain small individuals and used as

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[1]Chéné, P. L. 1970. Growth, PSP accumulation, and other features of ocean quahog (Arctica islandica). Fisheries Research Board of Canada, St. Andrews Biological Station, Original Manuscript Report Number 1104, 34 pp.

[2]Meagher, J. J., and J. C. Medcof. 1972. Shell rings and growth rate of ocean clams (Arctica islandica). Fisheries Research Board of Canada, St. Andrews Biological Station, Original Manuscript Report Number 1105, 26 pp.

survey gear; dredge specifications and vessels varied somewhat among cruises (Serchuk et al. 1979; Table 1).

We selected an area for intensive field study of quahog growth, based on an evaluation of pre-1978 survey data and knowledge of commercial fleet activities. Specific criteria for the site were: (1) sufficient clam densities for rapid capture of individuals used in the marking experiment, (2) abundant numbers of clams over a wide size range, (3) clam densities similar to sites frequented by fishing vessels, and (4) lack of previous exploitation and low probability of near future use. These specifications were met at a site 48 km SSE of Shinnecock Inlet, Long Island, New York, at 40°25.1'N, 72°23.7'W. Water depth was 53 m, and substrata consisted of coarse sand and shell, primarily ocean quahog and sea scallop, Placopecten magellanicus.

The probability of recapturing individual marked quahogs at the site was considered to be relatively low because of water depth, width of sampling gear, difficulties in positioning the vessel at a precise location, and the accuracy of the LORAN-C navigation system. Hence it was decided to mark and re-distribute large numbers.

Notching techniques have successfully been used to study growth rate and to validate the periodicity of mark formation in a number of bivalve species including soft shell clam, Mya arenaria (Mead and Barnes 1904), hard shell clam, Mercenaria mercenaria (Belding 1912), oyster, Crassostrea virginica (Loosanoff and Nomejko 1949), sea scallop (Stevenson and Dickie 1954; Merrill et al. 1966), and surf clam (Ropes and Merrill 1970; Jones et al. 1978). Accordingly, we marked ocean quahogs by cutting shallow grooves from the ventral margin up the shell surface using thin carborundum discs mounted on an electric grinder (Ropes and Merrill 1970). Two parallel grooves, 2 mm apart, were cut into each shell to distinguish our marks from shells scratched by natural processes or during dredging (Figure 1).

Marking operations were conducted from 26 July to 5 August 1978 (Table 1). A total of 41,816 quahogs was notched by the previously described technique. Batches of 3-5 thousand clams were dredged from within 9 km of the planting site, marked, and re-distributed. The method of marking and planting clams was rapid; about 1,600 clams were marked per hour. A grid system based on LORAN-C coordinates, was used to indicate the location of each batch. Length frequency samples were obtained during the marking phase (Table 1), and 134 small quahogs (19-60 mm) were retained for maturity studies and analyses of exterior and cross-sectional banding.

An intensive effort to recapture marked individuals was undertaken, one calendar year after planting, during 8-21 August 1979 (Table 1). Forty-three hydraulic dredge tows, each of about 5 minutes duration, were completed at the site. A total of 14,043 quahogs was examined; 74 (0.5%) had been marked. Recaptured specimens were photographed, measured, and frozen intact at sea. A random sample of 126 unmarked quahogs was frozen for length-weight comparison with marked individuals.

Length-frequency measurements were obtained from the site during routine assessment surveys in January 1979 and February 1980. Sampling within 10 km of the site was historically serendipitous; catch data were available from four surveys between 1970 and February 1978 (Table 1). Lengths of quahogs taken near the site exhibited a consistent bimodal frequency distribution throughout the time-series. Growth rate information from the mark-recapture and shell banding experiments was thus compared to that generated from modal progression in sequential length frequencies.

A random sample of 278 quahogs taken from the site during January 1980 was frozen whole for length-weight-comparison with an August 1979 sample. Small quahogs ($\leq$60 mm) were also frozen intact for analysis of the timing of periodic band formation in the shells.

LABORATORY STUDIES

Mark-Recapture

Recaptured specimens were thawed but kept moist during all phases of analysis to prevent shell cracking and disintegration of the periostracum. A total of 67 of the 74 recaptured specimens was suitable for growth analysis, the remaining samples were either shell fragments or from quahogs obviously dead when recovered. Shells were measured to the nearest 0.01 mm using calipers or a dissecting microscope equipped with an ocular micrometer. Periostracum obscured the shell edge of most specimens and was subsequently removed from the vicinity of the mark prior to measurement. Shell lengths were obtained by pressing the periostracum against the valves with calipers.

Growth increments of recaptured quahogs were determined as the linear increase in shell dimension along an imaginary line passing through the umbo and equidistant between grooves that formed the mark (Figure 1). The linear distance between the umbo and shell edge at the mark was designated as h'; shell length at marking was computed for each quahog by:

$$SL_t = SL_{t+1} - \left[\left(\frac{SL_{t+1}}{h'_{t+1}} \right) \cdot (h'_{t+1} - h'_t) \right] \qquad (1)$$

where: SL_t = shell length (longest linear dimension) at marking,

SL_{t+1} = shell length at recapture,

h'_t = linear measurement between umbo and edge of the shell equidistant between grooves, at marking,

h'_{t+1} = linear measurement between umbo and edge of the shell equidistant between grooves, at recapture.

Marginal growth in shell length was thus equivalent to the bracketed term.

Implicit in equation (1) is the assumption that ratios between the linear parameters SL and h' did not change between marking and recapture (isometric growth). The assumption is supported by comparisons of various standard shell

dimensions (i.e., shell length, height, and width, Chandler 1965; NMFS unpublished data), particularly considering the relatively small percent changes in shell size between marking and recapture (Table 2).

Two methods were used to fit growth equations to mark-recapture data. Quahogs were recovered one calendar year after marking; length at recapture was related to length at marking using Ford-Walford and annual increment plots described by Gulland (1969; Figure 2). The von Bertalanffy parameters L_∞ and K were also estimated using the BGC4 computer program (Abramson 1971). The program was designed specifically for determining growth parameters when lengths of unaged individuals are known at two points in time, and is based on the algorithm of Fabens (1965).

Equations derived from mark-recapture data can be used to describe relative growth from an arbitrary point in time (i.e., SL_{t+1}, SL_{t+2},...SL_{t+n}) but without at least one independently derived age-length observation, absolute growth curves cannot be established. Accordingly, analyses of external banding patterns of small quahogs were critical in "fixing" growth curves from mark-recapture.

Shell Banding

Small quahogs retained from the July-August 1978 cruise were analyzed for external and internal shell banding patterns. Sequential growth of individual quahogs was followed by measuring the maximum dimension (shell length) of exterior bands appearing on the periostracum, using calipers (Figure 1). Maximum shell length beyond the last band was also recorded. The opposite valve was sectioned from the umbo to the ventral margin and polished (Saloman and Taylor 1969; Jones et al. 1978). An acetate impression of the polished surface was made and mounted between glass slides. Images were enlarged with a microprojector to reveal internal banding patterns.

Internal lines present in shell cross-sections correlated in number and position with external bands when the latter were distinct. The periostracum on some shells was eroded near the umbo obscuring external bands. In these cases "annuli" nearest the umbo were located on the peels, but measurements of shell size could not be made (Table 3). External marks present near the shell margins on some larger specimens also could not be discerned; internal banding was again used to estimate age. Shell length statistics were computed for each age/annulus sub-class, weighted lengths at annuli for all ages and lengths at capture were also determined (Table 3).

Recaptured specimens ranged in shell length from 59-104 mm; most had a deep brown or black periostracum. Several specimens did, however, exhibit the characteristic external banding pattern (Figure 1), and were useful in validating the presumed annual periodicity of marks.

Marginal shell growth beyond the last external mark was strikingly different among small quahogs from August 1979 and February 1980 samples. Mean lengths at capture for individual age classes from summer 1979 (particularly ages 1-9) were

substantially greater than lengths at the last annulus, and were nearly equivalent to mean lengths at the last annulus for the next age class (Table 3). Quahogs from winter 1980 invariably had formed or were forming an annulus at the shell margin (Figure 1). A similar pattern was noted in shell cross-sections.

Growth equations were fitted to mean back-calculated lengths at age, from the summer 1979 samples, using the asymptotic regression computer program BMD06R (Dixon 1977; Figure 3). Few aged shells were as large as those recaptured (Tables 2 and 3). Growth functions generated from aging data were thus extrapolated to the size range of recaptured specimens and results compared to annual growth increments predicted from mark-recapture (Figures 2 and 3). An age-size point necessary to initialize the mark-recapture growth function was computed as: SL_{20} = 64.49 mm from the equation given in Figure 3; the mark-recapture equation was then iterated to encompass most shell lengths present at the marking site (Figures 4 and 5).

Length-Weight

Shell length-drained meat weight relations were computed for samples taken during August 1979 and February 1980. Laboratory and statistical methods are given in Murawski and Serchuk (1979b). Equations for recaptured and unmarked specimens from August 1979 were compared with covariance analysis to assess effects of marking on this index of relative condition (Table 4). Presumably if physiological processes of the animal were significantly disrupted by the marking procedures the adjusted mean of the length-weight equation might be statistically lower than that of controls. Seasonal variability in length-weight was investigated by comparing summer and winter equations (Table 5).

RESULTS AND DISCUSSION

New shell growth of recaptured individuals was clearly discernible in small specimens (<70 mm) not only at the mark, but all along the ventral margin when the periostracum was removed (Figure 1). A growth interruption was produced at the previous shell edge of small specimens; new material was formed slightly posterior to the earlier shell margin and was shingle-like in appearance (Figure 1). Growth of larger quahogs was less distinct and thus more difficult to measure. Where clear growth interruptions were not present, a faint yellowish band contrasting with white shell material was interpreted as a marking-induced check and growth was measured from that point. Shell growth was assessed midway between grooves that formed the mark since, in the case of larger specimens, the depth of the grooves was actually greater than the amount of new shell deposited (Figures 1 and 2).

A total of 9,759 quahogs was measured directly from dredge catches at the marking site during 1970-1980 (Table 1; Figures 5 and 6). Although minimum spacing of bars or rings in the rear portion of dredges varied somewhat (Table 1), size selectivity was apparently not significantly altered. Repeated tows were made at the marking site during August 1979 with 25 mm x 25 mm and later 51 mm x 51 mm wire mesh in the after portion of the dredge. Size distributions of quahogs were nearly identical before and after the alteration. A possible

explanation for the lack of differential selectivity is that shell, sand, and live invertebrates may have clogged the dredge at the beginning of tows, negating further filtering ability.

Two discrete length-frequency modes were exhibited in all eight sets of samples (Figures 5 and 6). Few small quahogs (<50 mm) were encountered from 1976-1980 (Figure 5) and, considering uniformity of modes over time, recruitment was probably equally poor during 1971-1976. Thus, corresponding modes in the 1970 and 1980 samples were probably composed of the same year classes (Figure 6). Average size of the small mode increased about 13 mm during the $9\frac{1}{2}$-year interval, while the large group shifted about 3 mm (Figures 5 and 6; Table 1). Size progression of modes was minimal during 1976-1980; intersample variation may be primarily related to differential sample sizes (Table 1). The effects of a 7-fold increase in sampling intensity can be seen by comparing August 1979 and February 1980 frequencies. Modes are smoothed in the latter sample, yet respective peaks are at precisely the same 1 mm intervals in both (65 and 90 mm). Average shell sizes ranged from 71-77 mm, however, trends in shell length among samples were not apparent (Table 1).

The average length of recaptured quahogs (Table 2) was similar to that of the concurrent length-frequency sample (Table 1), although length extremes of the marked individuals were not as great. Recaptured quahogs also exhibited the bimodal length-frequency distribution (Figure 4), indicating recaptured specimens represented a relatively unbiased sample of marked individuals and the ocean quahog population in the immediate vicinity of the study area. Calculated increments of shell growth from recaptured quahogs ranged from 0.08-1.38 mm, and averaged 0.56 mm (Table 2). Growth increments generally declined with increasing shell length, although there was substantial variation about a linear fit (Figure 2). The equation for predicting increment of growth from initial length is given in Figure 4; the Ford-Walford equation is: $SL_{t+1} = 2.0811 + 0.9802\ SL_t$, where SL is shell length (mm) at age t. Estimates of the asymptotic length (L_∞) and growth coefficient (K) from two fitting methods are:

	BGC4	Annual increment
L_∞ (mm)	107.06	104.95
K	0.0195	0.0200

Values of L_∞ from the two methods are greater than 99.5% (BGC4) and 98.5% (Annual Increment) of the cumulative 1980 length-frequency distribution at the study site. Estimates of K are relatively low and characteristic of slow-growing, long-lived species (Beverton and Holt 1959).

Analyses of shell banding features present in small specimens suggest that both external and internal marks are produced once during the biological year in these sizes. Several of the small recaptured quahogs exhibited concentric external rings, and these specimens formed one such band during the interval between marking and recapture (Figure 1a). Studies of small unmarked individuals retained from summer and winter sampling demonstrate that external and internal marks generally correspond in number and position. Internal marks were particularly useful in age determination when external marks were eroded near the umbo or closely spaced at the shell margin. Small quahogs captured during the summer

exhibited wide marginal increments of shell growth from the last external and internal marks to the shell edge, whereas winter samples had recently formed annuli (Figure 1c; Table 3). Thus, mark formation probably occurs during the last half of the calendar year.

Age analyses were limited to quahogs that exhibited suitable contrast on the shell surface to discern external concentric rings. Thus, the oldest aged quahogs (particularly ages 14-18) may represent the smallest, slowest growing individuals of their year classes; faster growing individuals may have reached sizes associated with color changes of the periostracum. Nevertheless, back-calculated mean lengths at age for 14-18 year old quahogs did not tend to be progressively smaller than means for ages 9-13, perhaps indicating that size selectivity of older individuals was not a significant bias (Table 3). A series of asymptotic regression equations were fitted to: (1) weighted mean back-calculated lengths at age for all quahogs, (2) weighted mean lengths at age for ages 2-8, and (3) mean lengths at the last completed annuli (right-most diagonal vector) for ages 2-10 and 2-13. For our purposes, the applicability of a particular model fit was judged not only by the total amount of variance between length and age explained by the equation, but by predicted annual growth increments in the 59-65 mm range. An appropriate model would fit as much of the age-sample data as possible and yield calculated annual growth increments consistent with those observed from recaptured specimens.

Equations utilizing weighted mean back-calculated lengths for ages 2-8, and lengths at the last complete annulus for ages 2-13 yielded unacceptable fits by our criteria. The former equation was calculated with information from the linear portion of the growth curve, predicted lengths beyond age 8 were unrealistically high. The latter equation incorporated one negative growth increment (between ages 11 and 12) and thus the calculated asymptote was only 62.8 mm; predicted annual growth near the asymptote was considerably less than observed increments for that size (Figure 2).

Asymptotic regression equations computed from weighted mean lengths at age for all quahogs and mean lengths at the last annulus for ages 2-10 were: $SL = 75.68\text{-}81.31\ (0.9056)^t$ and $SL = 72.20\text{-}75.22\ (0.8935)^t$, respectively. Mean lengths at age predicted from the two equations generally reflect differences among data sets over the range of shell sizes used to fit the functions, however, estimated lengths at age converge near the sizes of the smallest recaptured specimens. Estimated lengths at age 20 were 64.49 mm and 64.29 mm, respectively. Corresponding growth increments from age 20-21 were 1.06 mm and 0.84 mm, well within the range of observed growth for those sizes (Figure 2). If calculated lengths at age 20 are assumed to be the starting points for the Ford-Walford equation ($SL_{t+1} = 2.0811 + 0.9802\ SL_t$), the two acceptable asymptotic regression equations yield virtually identical growth curves when the Ford-Walford relationship is iterated. Additional growth analyses were conducted using the regression equation fitted to weighted mean back-calculated lengths for all ages because the maximum amount of information was used and the equation's behavior in the vicinity of marking data was consistent with empirical observations. However, further research on the growth patterns of small quahogs is indicated in order to resolve differences between various data subsets in Table 3.

The plot of observed mean back-calculated lengths at age appears logistic in shape when compared to the fitted asymptotic regression equation, however, differences between predicted and actual lengths were small (Figure 3). A composite growth curve incorporating the aged samples and mark-recapture data is given in Figure 4. The Ford-Walford equation was iterated to age 100 and a predicted shell length of 96.91 mm. Although ocean quahogs reach a size of at least 117 mm in the vicinity of the marking site (Table 1), ages substantially in excess of 100 are not necessarily implied because of the statistical variability in the marking data used to fit the predictor (Figure 2). Annual growth in shell length is rapid during the first 20 years of life, but declines significantly thereafter. Average yearly shell growth is 6.3% age age 10, 0.5% at age 50, and 0.2% at age 100.

Estimates of the von Bertalanffy parameter t_0 (age at zero length) were computed as -27.29 years and -27.62 years for the BGC4 and Annual Increment equations, respectively, with SL_{20} = 64.49 mm (Gulland 1969, Equn. 3.5). Although predicted lengths at ages greater than 20 are similar to those in Figure 4, a relatively poor fit to younger ages results from both von Bertalanffy equations.

The validity of using the age-length functions given in Figure 4 to describe ocean quahog growth at the marking site can be assessed by comparing predicted growth to that from modal progressions in length-frequency samples. Frequency distributions from 1976-1980 exhibit intersample variability in the position of major modes but no progressive shifts are discernible (Figure 5). However, expected growth during the 5-year period (Figure 4) was smaller than could probably be identified given the precision of length-frequency sampling (Table 1; Figure 5). Length modes can be used to compute growth at the site between August 1970 and February 1980 (Figure 6). Average growth of the smaller mode (52 mm in 1970) was about 13 mm, and the larger mode (87 mm in 1970) added about 3 mm shell length during the $9\frac{1}{2}$-year interval (Figures 5 and 6). Quahogs 52 mm in length are about 12 years old and average 21 years old at 65 mm; the estimated age of 87 mm individuals is 60 years and 90 mm quahogs average 70 years old (Figures 3 and 4). Thus, predicted growth during the period 1970-1980 is strikingly similar to that inferred from length mode progressions, implying that age analyses and mark-recapture data adequately describe historical ocean quahog growth at the site.

The age-length relationships presented herein have been computed for shell sizes in excess of 95 mm and ages up to 100 years. However, computed relationships for large sizes (>65 mm) are based on average growth rates from mark-recapture results and not from aging of individual specimens. It is likely, based on these analyses, that ocean quahogs do reach 100 years in age, however, direct age determination of large individuals awaits the development and validation of suitable methodologies. Internal banding patterns present in shell cross-sections were useful in aging small specimens since formation of the bands apparently occurs once annually. Extension of this technique to larger quahogs is promising but as yet remains unvalidated. Analysis of shell cross-sections of large recaptured specimens may be useful in determining the periodicity of internal banding in these large sizes, and study of this material continues.

The regressions of shell length vs. drained meat weight for marked and unmarked quahogs taken during August 1979 were not significantly different in slope or adjusted mean (Table 4). If, in fact, soft tissue robustness is a valid index of relative condition, then marked individuals apparently suffered no lasting effects from the stress of dredging and handling. This observation is supported by the conclusion that incremental shell growth of marked specimens was similar to that computed from progressive length frequencies of the population as a whole.

The adjusted means of length-weight equations for January 1980 and August 1979 samples were significantly different; winter samples were slightly heavier in drained meat weight at a given shell length than summer samples (Table 5). However, the magnitude of predicted differences in weight at length was small (4-11% for 65-115 mm quahogs) suggesting that significance may be a statistical artifact or related to sampling bias, and does not necessarily reflect the seasonal pattern of weight fluctuation at the marking site. Samples from winter and summer were combined to predict average weight for a given length during the year (Table 5). The resulting length-weight equation was applied to computed lengths at age to derive an age-weight relationship (Figure 4). Initial weight gains are proportionally greater than concomitant length increases, but growth rates are nearly identical at the oldest predicted ages. Average annual increases in drained meat weight are 18.1% at age 10, 1.6% at age 50, and 0.2% at age 100 (Figure 4).

Growth rates determined from the examination of concentric external banding patterns indicate small quahogs may grow faster off Long Island than in the Northumberland Strait and in Passamaquoddy Bay (Caddy et al. 1974). However, data are insufficient to conclude that a latitudinal cline in quahog growth exists. Factors influencing growth rates in a particular area are speculative, however density dependence must be considered. Murawski and Serchuk (1979a) noted relative population stability and poor recruitment for ocean quahogs in the Middle Atlantic during 1965-1977. Stable population size, poor recruitment and slow growth are characteristic of populations under density dependent regulation. Investigation of ocean quahog growth rates at various densities may help to elucidate their interrelationship and indicate the population consequences of cropping high density areas.

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Table 1. Characteristics of survey gear and length frequency statistics of ocean quahogs collected near 40°25'N, 72°24'W, 1970-1980.

Vessel	Dates	Hydraulic Dredge Blade Width (cm)	Spacing Between[a] Bars or Rings (mm)	SHELL LENGTH (mm)			
				$\bar{X}$	SD	Range	n
R/V DELAWARE II	8/13/70	122	30	74.1[b]	20.1	25-105	107
"	4/24/76	122	30	74.1	16.6	40-115	271
"	2/27/77	122	30	73.4	14.5	45-104	234
"	1/31-2/2/78	122	30	74.5	14.3	34-113	211
F/V DIANE MARIA[c]	7/26-8/5/78	254	13	74.5	15.4	31-112	1,262
R/V DELAWARE II	1/9/79	152	25	71.4	14.5	33-116	1,317
"[d]	8/14-21/79	152	25-51	76.5	15.2	38-111	811
"	2/8/80	152	51	74.2	13.8	38-117	5,546

a - dimension in the portion of the dredge where catch is accumulated

b - samples measured to the nearest 0.5 cm

c - initiation of marking study

d - recapture of marked individuals

Table 2. Growth statistics for 67 ocean quahogs marked during August, 1978, and recaptured during August, 1979, at 40°25'N, 72°24'W.

Parameter	Mean (mm)	S D (mm)	Range (mm)
shell length at recovery	77.31	14.67	59.12-104.40
calculated growth increment in shell length	0.56	0.38	0.08 - 1.38
calculated length at marking	76.76	14.97	58.15-104.09

Table 3. Backcalculated growth (shell length, mm) of small ocean quahogs. Samples taken from 40°25'N, 72°24'N, 26-29 July 1978.

Number of Annuli		Length at Capture	Length at Annulus 1	2	3	4	5	6	7	8	9	10	11	12	13
2	$\bar{x}$	18.00	7.00	12.30											
	SD	0.00	0.00	0.00											
	n	1	1	1											
3	$\bar{x}$	23.36	4.59	10.59	18.01										
	SD	3.42	0.78	2.66	3.14										
	n	9	9	9	9										
4	$\bar{x}$	29.73	4.39	10.04	16.99	24.38									
	SD	2.00	0.73	2.13	2.38	1.96									
	n	14	14	14	14	14									
5	$\bar{x}$	34.58	4.43	8.80	14.45	21.72	29.72								
	SD	3.19	0.07	1.50	2.29	3.08	3.41								
	n	26	26	26	26	26	26								
6	$\bar{x}$	38.49	4.07	7.77	13.40	19.13	26.09	33.88							
	SD	2.73	0.59	1.57	2.49	2.58	2.73	2.92							
	n	27	25[a]	27	27	27	27	27							
7	$\bar{x}$	41.66	4.16	7.66	12.10	17.42	23.87	30.81	37.61						
	SD	2.00	1.10	1.34	1.72	1.57	1.87	1.98	2.05						
	n	29	27[a]	29	29	29	29	29	29						
8	$\bar{x}$	46.24	3.92	7.59	12.29	16.92	23.64	29.95	36.63	42.76					
	SD	1.78	0.98	1.44	2.39	2.77	2.38	2.52	2.22	1.99					
	n	10	10	10	10	10	10	10	10	10					
9	$\bar{x}$	47.60	3.10	7.50	11.00	15.90	21.30	27.40	33.50	39.20	44.90				
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	n	1	1	1	1	1	1	1	1	1	1				
10	$\bar{x}$	48.23	3.67	6.47	11.77	15.97	20.80	25.57	31.17	36.90	40.40	45.30			
	SD	0.59	0.29	0.50	1.19	2.48	2.31	2.35	1.89	2.07	0.36	0.30			
	n	3	3	3	3	3	3	3	3	3	3	3			
11	$\bar{x}$	54.35	3.90	5.70	9.35	13.80	20.30	27.60	34.20	40.20	44.45	48.50	51.95		
	SD	2.05	0.00	0.42	0.78	0.28	3.68	4.81	2.83	1.41	1.06	0.71	1.20		
	n	2	1[a]	2	2	2	2	2	2	2	2	2	2		
12	$\bar{x}$	53.87	3.73	7.23	10.07	12.97	19.13	27.00	31.60	35.67	39.50	43.50	44.75	49.55	
	SD	3.95	0.35	1.38	2.30	3.28	4.15	9.37	8.56	7.90	8.42	8.23	1.91	2.90	
	n	3	3	3	3	3	3	3	3	3	3	3	2	2	
13	$\bar{x}$	53.90	-	5.20	9.70	12.80	17.50	22.20	28.00	34.70	38.30	43.70	46.40	50.00	52.00
	SD	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	n	1	-[a]	1	1	1	1	1	1	1	1	1	1	1	1
14[b]	$\bar{x}$	51.15	3.85	7.30	10.65	15.30	22.40	29.10	33.75	38.75	43.40	48.10			
	SD	5.16	0.50	2.26	2.19	0.42	0.57	1.56	1.34	0.07	1.98	0.00			
	n	2	2	2	2	2	2	2	2	2	2	1			
16[b]	$\bar{x}$	57.93	4.00	6.95	12.05	18.50	24.80	31.53	37.25	42.60	46.57	50.30	55.30		
	SD	2.90	0.00	1.11	2.24	2.49	3.95	3.75	2.91	2.60	1.59	1.84	0.00		
	n	4	2[a]	4	4	4	4	4	4	4	3	2	1		
18[b]	$\bar{x}$	57.10	3.60	7.55	10.95	16.40	24.60	29.85	40.10	43.40	46.80	49.00			
	SD	0.99	0.00	2.05	3.89	5.80	5.37	4.46	0.00	0.00	0.00	0.00			
	n	2	1	2	2	2	2	2	1	1	1	1			
ALL	$\bar{x}$	38.94	4.21	8.27	13.59	19.17	25.44	31.13	36.23	40.40	42.82	46.52	49.18	49.70	52.00
	SD	8.65	0.85	1.95	3.03	3.69	3.95	3.75	3.47	4.01	4.41	4.32	4.58	2.07	0.00
	n	134	125	134	133	124	110	83	56	27	16	13	6	3	1
	Min	18.7	2.5	5.1	7.8	9.3	14.5	18.6	24.5	29.3	32.4	36.0	43.4	47.5	52.0
	Max	60.4	7.0	15.8	22.5	26.7	36.4	38.1	41.9	46.2	48.8	52.3	55.3	51.6	52.0

[a] External mark eroded but mark present in shell cross-section

[b] Number of annuli exceeds the number of lengths at annulus because marks could be distinguished in shell cross sections that were too closely spaced to discern on shell surfaces.

Table 4. Ocean quahog shell length-meat weight regression equations, and analysis of covariance for marked and unmarked individuals sampled at 40°25'N, 72°24'W during August 1979 .

	Regression Parameters			
Sample	Intercept (a)	Slope (b)	r	n
marked	-9.8373	2.9530	.975	55
unmarked	-9.0170	2.7637	.953	126

	Test of Adjusted Mean			Test of Slope	
Sample	Adjusted mean	d.f.	F	d.f.	F
marked	2.8702				
vs.		1,178	.001 n.s.	1,177	2.13 n.s.
unmarked	2.8714				

n.s. - Non-significant at the 5% level

Table 5. Ocean quahog shell length-meat weight regression equations, and analysis of covariance for August 1979 and February 1980 samples taken near 40°25'N, 72°24'W.

	Regression of Parameters			
Sample	Intercept (a)	Slope (b)	r	n
August 1979	-9.2901	2.8274	.961	181
January 1980	-8.6865	2.7086	.976	278
All Data	-9.0627	2.7871	.967	459

	Test of Adjusted Mean			Test of Slopes	
Sample	Adjusted Mean	d.f.	F	d.f.	F
January 1980	3.0302	1,456	58.86**	1,455	3.22 n.s.
vs.					
August 1979	2.9398				

** - Significant at the 1% level

n.s. - Non-significant at the 5% level

LIST OF FIGURES

Figure 1: (a) Ocean quahog (65 mm, shell length) marked during July-August 1978 and recaptured during August 1979 near 40°25'N, 74°24'W. Arrow indicates external growth band formed during the interval between marking and recapture. (b) Arrow indicates shell growth of a 68 mm ocean quahog from July-August 1978 to August 1979 with periostracum removed. (c) Arrows indicate positions of most recently formed external growth bands on small ocean quahogs from August 1979 (right, 43 mm), and February 1980 (left, 45 mm) samples.

Figure 2: Relation between calculated increment of growth in shell length (mm) and initial length for ocean quahogs marked during July-August 1978 and recaptured during August 1979 near 40°25'N, 74°24'W.

Figure 3: Observed and predicted shell lengths at age for small ocean quahogs sampled during July 1978 at 40°25'N, 72°24'W.

Figure 4: Predicted shell lengths (mm) and drained meat weights (g) at age for ocean quahogs at 40°25'N, 72°24'W. Dot indicates separation between curves derived from external banding of small specimens, and mark-recapture data.

Figure 5: Length frequency distributions (1 mm intervals) of ocean quahogs sampled near 40°25'N, 72°24'W, 1976-1980.

Figure 6: Length frequency distributions (5 mm intervals) of ocean quahogs sampled near 40°25'N, 72°24'W, August 1970 and February 1980.

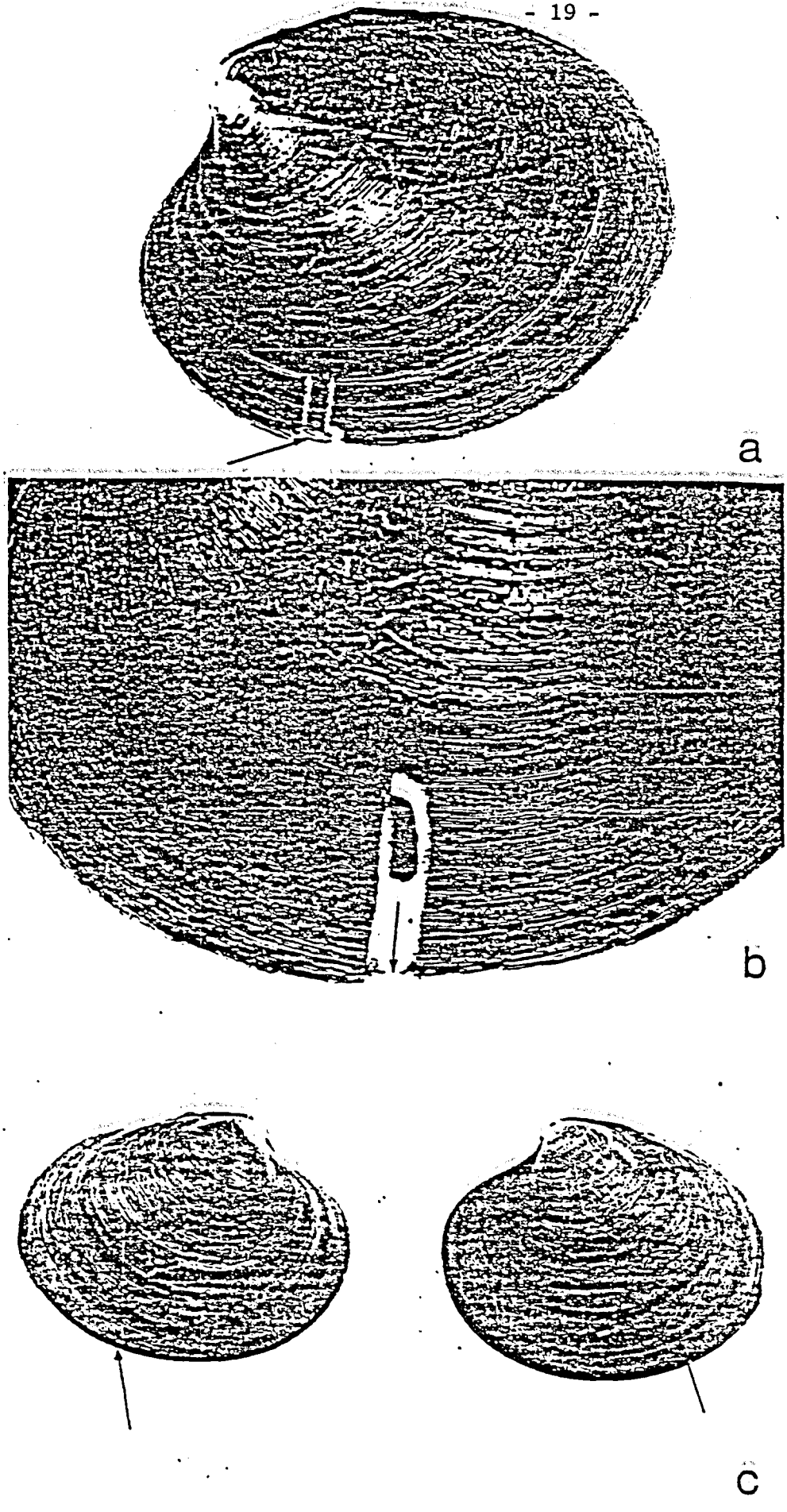

Figure 1.

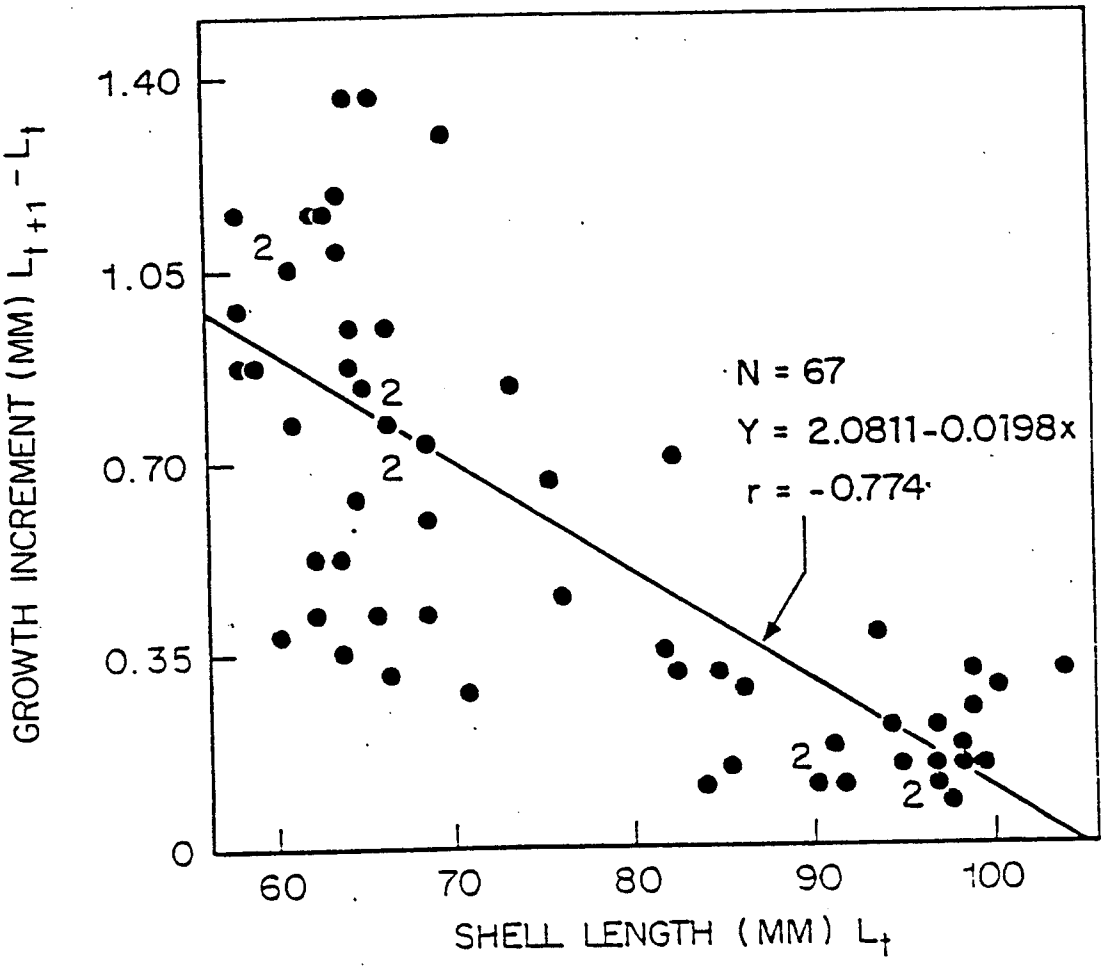
GROWTH INCREMENT (MM) $L_{t+1} - L_t$
1.40
1.05
0.70
0.35
0
60
70
80
90
100
SHELL LENGTH (MM) L_t
N = 67
Y = 2.0811-0.0198x
r = -0.774

Figure 2.

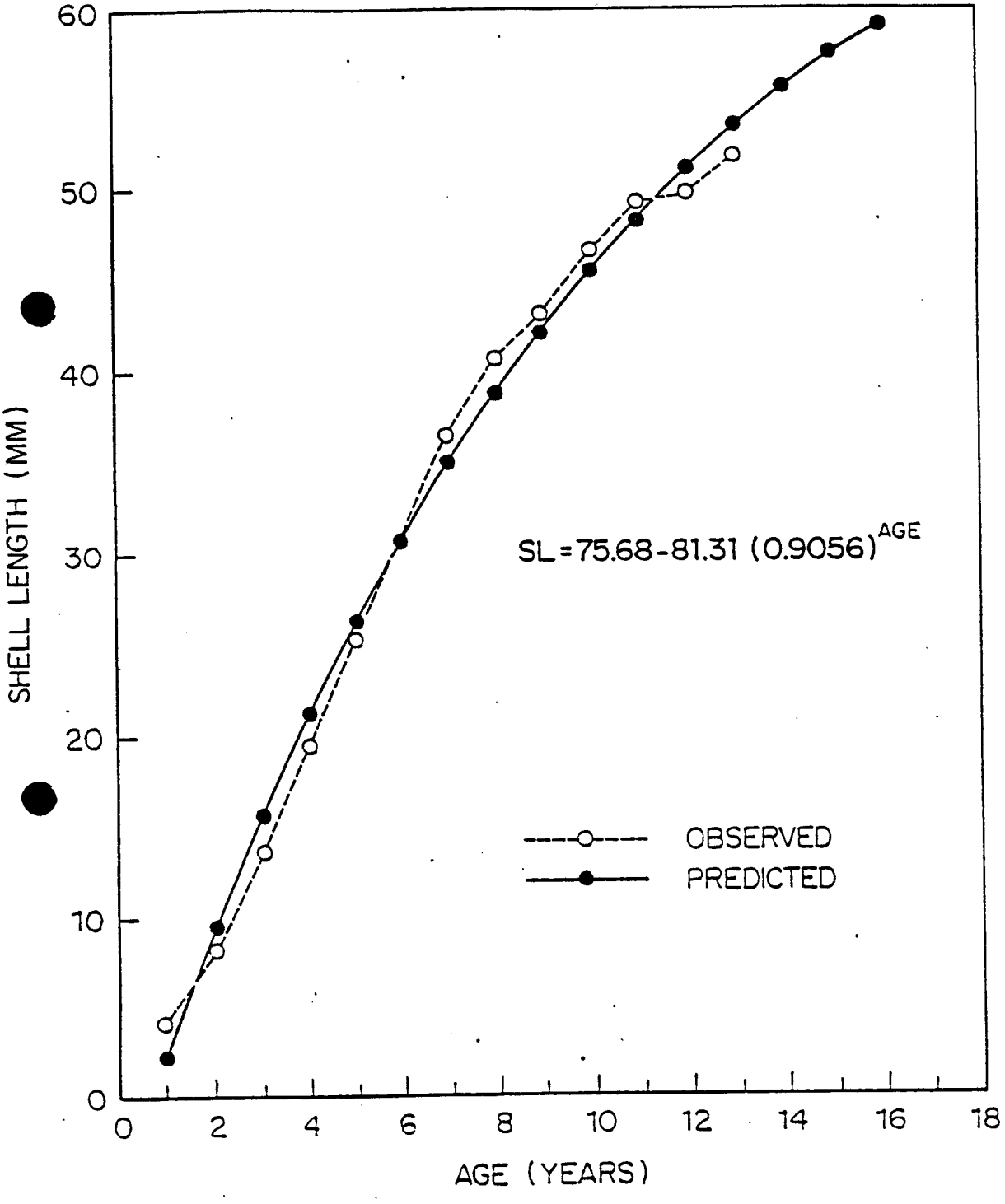
60
50
40
30
20
10
0
SHELL LENGTH (MM)
0
2
4
6
8
10
12
14
16
18
AGE (YEARS)
SL=75.68-81.31 (0.9056)^AGE
OBSERVED
PREDICTED

Figure 3.

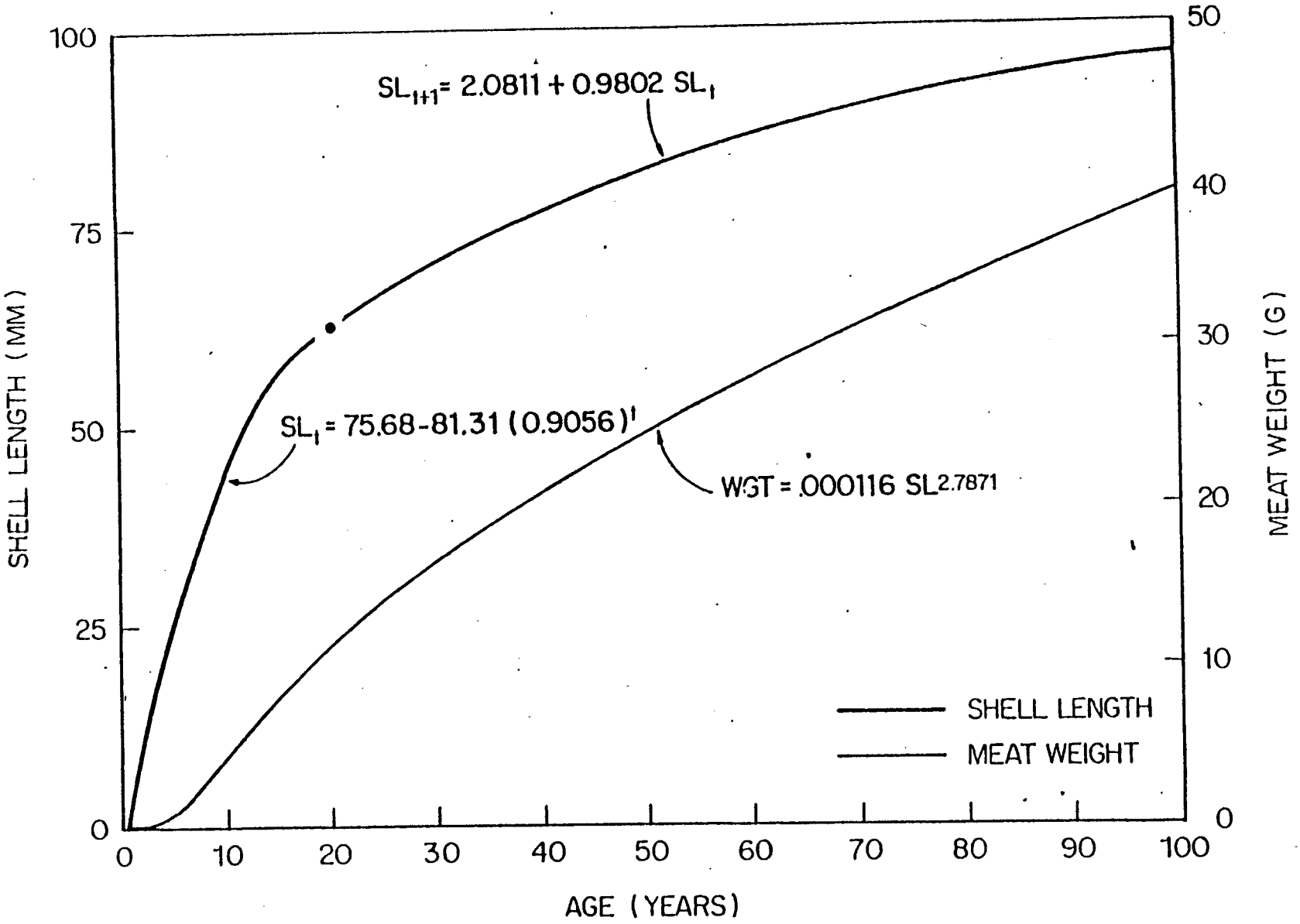
100
75
50
25
0
SHELL LENGTH (MM)
50
40
30
20
10
0
MEAT WEIGHT (G)
$SL_{t+1} = 2.0811 + 0.9802\ SL_t$
$SL_t = 75.68 - 81.31\ (0.9056)^t$
$WGT = .000116\ SL^{2.7871}$
SHELL LENGTH
MEAT WEIGHT
0
10
20
30
40
50
60
70
80
90
100
AGE (YEARS)

Figure 4.

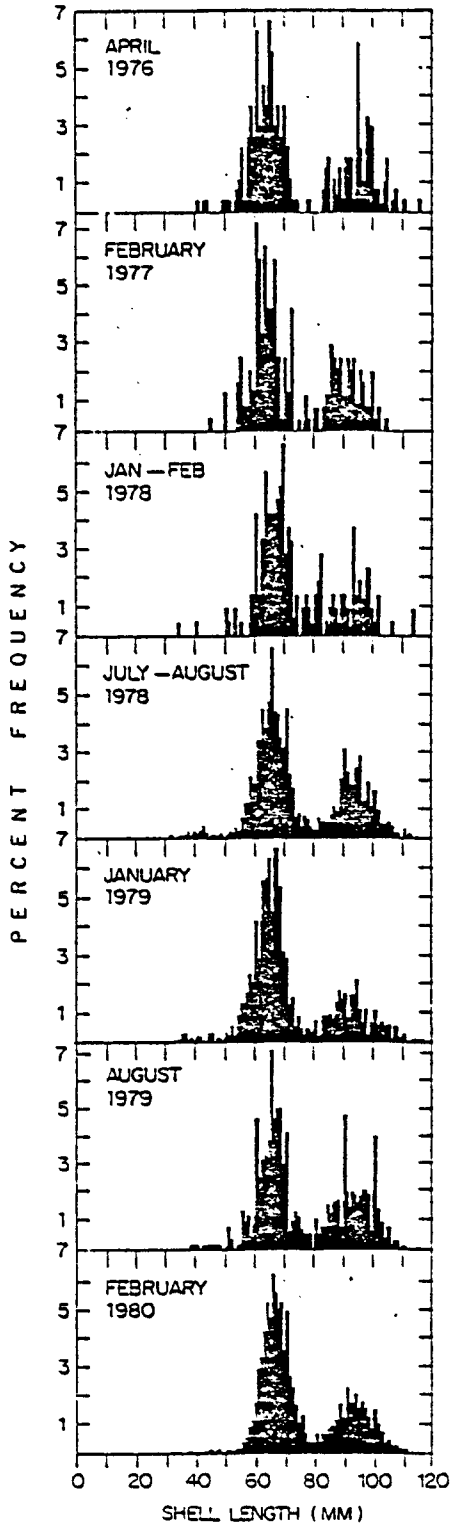
APRIL
1976
FEBRUARY
1977
JAN—FEB
1978
JULY—AUGUST
1978
JANUARY
1979
AUGUST
1979
FEBRUARY
1980
PERCENT FREQUENCY
0 20 40 60 80 100 120
SHELL LENGTH (MM)

Figure 5.

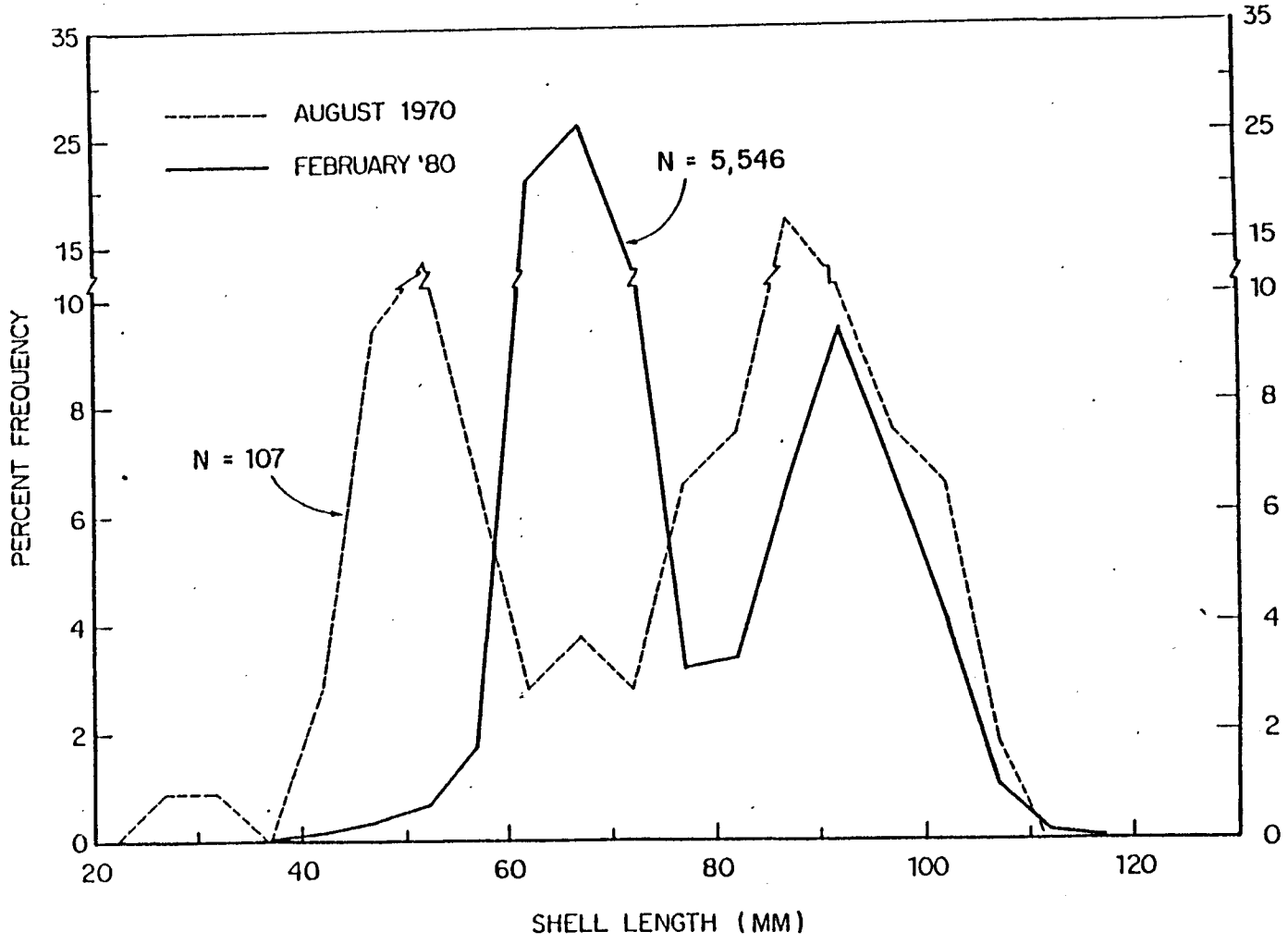
AUGUST 1970
FEBRUARY '80
N = 5,546
N = 107
PERCENT FREQUENCY
SHELL LENGTH (MM)
0
2
4
6
8
10
15
25
35
20
40
60
80
100
120

Figure 6.