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Length-weight relationships of surf clam (*Spisula solidissima*) from Georges Bank

by

C. T. Gledhill

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Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Massachusetts 02543

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SUMMARY

Shell length (L, mm)- meat weight (W, g) regressions were calculated on 613 surf clams (Spisula solidissima) sampled from depths of 19 to 73 meters on George's Bank during July, 1984. Regressions were fitted grouping by depth, by bottom type and for all groups combined. The combined equation for George's Bank was: $\log_e W = -7.9967 + \log_e L \cdot 2.5772$ ($r = 0.981$). The length-weight relantionship varied between depths. Significant differences of the slopes and adjusted means of the regressions were noted between depth zones. The clams from the 19-26 meter zone had a regression slope of 3.05. Surf clams from this depth range had higher meat weights for similar lengths than clams from deeper water. No differences were noted by bottom type.

The combined George's Bank regression was compared with regressions fitted for surf clams from Southern New England and the Mid-Atlantic. An increase in meat weight for similar length surf clams along a south to north cline was noted. This may be relanted to the different thermal regimes of the northern and southern areas.

INTRODUCTION

An organized commercial fishery of surf clams, Spisula solidissima (Dillwyn) has existed since the 1870's (Yancey and Welch 1968). The fishery started on Cape Cod and moved south along the Middle Atlantic coast. Recent landings have primarily come from the Mid-Atlantic regions of Delmarva and northern New Jersey (Murawski and Serchuk 1984). The Mid-Atlantic surf clam fishery is managed under a Fishery Management Plan (FMP) with restrictions on catch, areal closures, and a prohibition of entry of additional vessels (Mid-Atlantic Fishery Management Council 1981). The fishery has therefore expanded into the New England area again, with landings of surf clams from Nantucket Shoals in 1983 (Murawski and Serchuk 1983). A new bed of surf clams was discovered in the spring of 1984 in the Cultivator Shoals area on the western side of Georges Bank. A total of 14 different vessels have fished this bed with a catch of 276,640 bushels through 7 September (Murawski and Serchuk 1984). The fishery is scheduled to close on 31 October.

Surf clam biology has been reviewed by Ropes (1979, 1980) and Yancey and Welch (1968). The population dynamics of surf clams has been studied by Murawski and Serchuk (1979a, 1981, 1984) and length-weight relationships have been determined by Chang et al. (1976), Caddy and Billard (1976) and Murawski and Serchuk (1979a, 1980, 1983). No survey directed for surf clams has been conducted by the Northeast Fisheries Center (NEFC) on Georges Bank, therefore information on the Georges Bank surf clam population is incomplete. A survey of Georges Bank was conducted to provide more information on the stock of surf clams. The objectives of this study were to: (1) calculate shell length-drained meat weight regressions for the Georges Bank surf clams, (2) investigate variation in the length-weight relationships due to depth, and (3) make comparisons with the length-weight data from the Mid-Atlantic and Southern New England areas.

METHODS

Surf clam samples for length-weight analysis were collected on Georges Bank during the shellfish assessment survey of the R/V DELAWARE II from 9 July to 1 August 1984. Sampling gear and survey procedures have been described elsewhere (Murawski and Serchuk 1981). The initial stratified random design and sampling procedures were modified during the cruise. Changes were made in the location of some stations and in tow duration after the dredge was damaged during the initial tows on Georges Bank. In order to minimize further damage to the dredge, stations with rock substrate were either dropped or moved to an adjacent site. The "hardness" of the bottom was assessed by an echo-sounding before the dredge was set. The tow duration was reduced from 5 min. to 1 min. and springs were added to the knife assembly to further reduce the risk of damaging the dredge. Sampling stations were added to the survey at intervals of one quarter the distance between the randomly chosen stations that were 18 km or more apart, if the substrate was not "hard." The overall sampling scheme was therefore not completely random.

Procedures for sampling the catch follow Murawski and Serchuk (1979b). Five intact surf clams in each 10 mm length interval were selected at each station. Shell dimensions were recorded to the nearest millimeter and all soft parts were shucked into individual plastic bags. Frozen samples were returned to the laboratory, thawed, rinsed to remove sand, drained on towelling, and weighed to the nearest 0.1 g.

Linear regressions were fitted with length-weight data transformed to natural logarithms. The form of the length-weight equation was assumed to be:

$$W = cL^b \qquad \text{equation 1.}$$

where W is the drained meat weight, L is the shell length and c and b are fitted coefficients. Covariance analyses were conducted to determine the significance of difference between the slopes and adjusted means of various length-weight equations. Length-weight regressions were fitted by depth zone and by sediment type. All calculations were performed by the computer programs BMDPIR and BMDPIV (Dixon 1975). T-tests were used to determine if surf clams exhibit isometric growth (slope = 3.0, Paulik and Gales 1964). Empirical weights were compared to weights derived from the length-weight equation fitted with all data from Georges Bank (combined equation). A paired t-test was used to test for difference between empirical and calculated weights (Sokal and Rohlf 1969).

Length-weight equations have been reported for the Mid-Atlantic and Southern New England areas (Murawski and Serchuk 1981, 1983). The data to fit the Mid-Atlantic equations were obtained during the R/V DELAWARE II shellfish survey from 3 January to 10 February 1980. Southern New England data were collected on the commercial vessel F/V Shinnecock on 31 March 1983. The data from these areas were obtained to compare length-weight relationships with the Georges Bank area. Some outliers were detected and deleted from the data sets for Southern New England (1 point), New Jersey (15 points) and Delmarva (2 points). Length-weight regressions were fitted and analysis of covariance used to make comparisons between areas.

RESULTS

A total of 144 stations were sampled on Georges Bank (Figure 1). Surf clams from 61 stations ranging in depth from 19 to 73 meters were used for length-weight analysis. Stations were grouped into depth zones that represented

the depth contour boundaries used to define strata. The data were also grouped by sediment type, "sand" or "not sand", based on material brought up in the dredge haul at each station. If the dredge contained no substrate material or sand, the bottom was classified as "sand." If the dredge contained some gravel, cobbles, or rocks, the bottom was classified as "not sand." A total of 613 clams were weighed and measured, the majority (327) from the 27-45 meter depth zone.

Summary Statistics

The surf clams from Georges Bank used in the length-weight analysis ranged in length from 30 to 190 mm (mean = 100.47 mm) and in weight from 1.5 to 286.7 g (mean = 62.8 g, Table 1, Figure 2). The smallest mean length (67 mm) was found in the 19-27 m depth zone, and the largest mean (115 mm) in the 27-45 m zone.

Analysis by Depth Zone

Length-weight regressions were calculated by depth zone and for all data combined (Table 2). The overall slope was 2.58, which was significantly different from 3.0 ($P < 0.001$), indicating allometric growth. Allometric growth was also exhibited for the 27-45 m, 46-54 m, and the 55+ m depth zones. The slope for the 19-26 m area, 3.05, was not significantly different from 3.0. Surf clams in this depth range showed isometric growth. The clams from the 19-26 m area weighed more at a given length than clams from other depth ranges (Figure 3).

Regression equations for each depth zone were tested for equality of slopes and adjusted means by an analysis of variance (Table 3). Tests among all 2-way comparisons between depth zones indicated nonsignificant differences

between slopes and adjusted means for the 27-45 m vs 55+ m, and the 45-54 m vs 55+ m groups. All other comparisons showed inequality of slopes. The 19-26 m depth zone equation had the highest slope, and the smallest mean sized clams. Growth equations for surf clams show that smaller/younger clams grow at a faster rate than larger/older clams (Murawski and Serchuk 1981; Ropes 1980). The 19-26 m group contained no clams larger than 135 mm. Regressions were, therefore, refitted for the deeper depth ranges with clams larger than 135 mm excluded and compared with the 19-26 m equation. The slopes of the equations from the deeper areas changed little. The smaller size of clams in the 19-26 m range, therefore, is probably not an explanation for its larger slope. Based on the data from Georges Bank, depth of occurrence of surf clams seems to affect the length-weight relationship.

Analysis by Sediment Type

Each station was grossly classified as having either a "sand" or "not sand" substrate type. This enabled a preliminary investigation of the influence of sediment type on the length-weight relationships. Sediment type has been shown to affect the growth of soft-shell clams, *Mya arenaria* (Pfitzenmyer and Drobeck 1963). Length-weight regressions were fitted by least-squares for the two sediment groups (Table 4). The slopes for the "sand" and "not sand" classification were 2.5664 and 2.5808, respectively. Weights at length calculated from the regression equation were very similar (Figure 4). An analysis of covariance showed no significant differences between the slopes ($F=0.099$, $P>0.75$) and between adjusted means ($F=3.06$, $P>0.05$).

Precision of Computed Weights

The regression equations calculated from the Georges Bank data accounted for greater than 94% of the variation between shell length and meat weight ($r^2 \cdot 100$). Predicted mean weight (mean of weights from combined equation) was 1.2% smaller than the empirical mean weight (Table 5). A paired t-test between empirical and calculated weights showed no significant differences. The overall regression equation is a relatively precise approximation of the empirical data. This equation was used for comparisons with the data from the Southern New England and Mid-Atlantic areas.

Comparisons with Southern New England and Mid-Atlantic Areas

Length-weight regressions were fitted for the Southern New England and Mid-Atlantic areas (Table 6). Seasonal variations may confound any comparisons with the Georges Bank data. Surf clams spawn in August and drop in meat weight after a spawn occurs. The surf clams on Georges Bank were collected just prior to the peak spawning period. Surf clams from the other areas were collected in the winter.

Surf clams from Southern New England had the highest meat weight at a given length (Figure 5). The slope from this area was not significantly different from all the other areas (Table 7). This lack of significance is probably due to the variability around the fitted regression line, $r = 0.77$ (Table 6). The adjusted mean of the Southern New England area was different from all other areas, and with the exception of the Delmarva area, larger (Table 7).

A general trend of higher meat weight at length from Virginia-North Carolina to New England occurs (Figure 5). The Georges Bank clams weight at length are similar to those for the Southern New England-Long Island area.

The surf clams from the 19-27 m depth zone on Georges Bank had the highest overall slope (3.05) and showed the highest weight at a given length (Figures 4 and 6).

DISCUSSION

Analyses of Georges Bank surf clam data indicate that the meat weight for similar sized clams is highest at the 19-26 m depth range. Various physical and biological factors may influence the growth of clams; temperature, salinity, nutrients, and food supply. Density may also influence growth rates (Caddy 1975, Kristensen 1957). The water column over Georges Bank is well mixed throughout the year (Butman et al. 1982, Cohen and Wright 1978, Bumpus 1976). There is a lack of any stratification so the flow of nutrients is not restricted. On a gross scale, therefore, temperature, salinity, and nutrient supply may not account for differences in surf clam growth on Georges Bank. The distribution of plankton varies in abundance and species composition by depth, area of the Bank, and season (Pavshtiks and Gogoleva 1964, Riley 1941). Such changes may affect the food abundance and quality in localized areas.

Although factors affecting differences in the length-weight relationships between areas is confounded by season, variation induced by area may be real. A general increase in weight at similar length was observed from the southern to the New England areas. This pattern of growth may be related to the water temperature variation in each area. Murawski and Serchuk (1979b) attributed variation in the length-weight relationship of ocean quahogs (*Arctica islandica*) to thermal stability. Differences in the temperature regimes of areas may affect the length of period of activity (feeding) of surf clams.

Surf clams become inactive at 4°C (Savage 1976). Ambrose (1977) indicated that minimum water temperature may be related to slower growth rates of surf clams along the Middle Atlantic Bight. Feeding is also suspended at higher temperatures below the upper lethal temperature. As the temperature approaches the upper limit for surf clams, the shell valves close and the clams become inactive (Hendersen 1929). The lethal upper temperature for surf clams is 26°C to 28°C (Saila and Pratt 1973). The southern limit of the range for surf clam distribution corresponds with a 23°C maximum water temperature (Saila and Pratt 1973, Merrill and Ropes 1969). The differences in growth of surf clams may be explained by the length of the period of inactivity, defined as the time when the temperature is 4°C or lower and 23°C and higher. The annual variation in bottom water temperature on the continental shelf from New England to Cape Hatteras has been reported (Colton and Stoddard 1973, Walford and Wickland 1968). Based on these data for the depth range of surf clams, the number of months of surf clam inactivity is two on Georges Bank, two off the New Jersey coast, and four off Norfolk, Virginia. Off New Jersey and on Georges Bank, the bottom temperature falls below 4°C in February and March. Off Virginia, in the months of June through September, temperatures exceed 22.5°C. Further study is necessary to determine if length-weight relationships differ between seasons, years, or condition of the gonads.

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Table 1. Summary of statistics of surf clam length-weight data by depth for Georges Bank, July, 1984.

		LENGTH				WEIGHT			
Depth	n	$\bar{x}$	s	MIN	MAX	$\bar{x}$	s	MIN	MAX
Combined	613	100.47	35.90	30.00	190.00	62.80	53.25	1.50	286.70
19-26 m	84	67.33	17.97	33.00	135.00	24.04	21.56	2.20	146.70
27-45 m	327	115.43	34.56	30.00	190.00	83.16	59.22	1.70	286.70
46-54 m	172	93.64	29.77	30.00	158.00	47.32	33.55	1.50	147.90
> 55 m	30	69.47	25.48	31.00	124.00	23.36	20.31	2.00	70.60

Table 2. Statistics describing regression equations between shell length (mm) and drained meat weight (g) for surf clams on Georges Bank.

Depth (m)	Intercept (a)	Slope (b)	S.E.(b)	Antilog$_e$ of a	r
Combined	-7.99667	2.57722	0.02042	0.0003365816	0.9814
19-26 m	-9.88133	3.05003	0.08072	0.0000511202	0.9725
27-45 m	-8.31826	2.64219	0.02969	0.0002440201	0.9801
46-54 m	-7.54909	2.47549	0.41450	0.0005265891	0.9770
55 + m	-8.11634	2.60080	0.09153	0.0002986196	0.9831

Table 3. Covariance analysis of surf clam length-weight equations between depth zones on Georges Bank.

Comparison	Test of Adjusted means				Test of Slopes		
	Adj. mean	F-ratio	df	Sig. Level	F-ratio	df	Sig. Level
(19-26) vs. (27-45)	NOT APPLICABLE				25.63	407	p<0.001
(19-26) vs. (46-54)	NOT APPLICABLE				42.08	252	p<0.001
(19-26) vs. (55+)	NOT APPLICABLE				12.77	110	p<0.001
(27-45) vs. (46-54)	NOT APPLICABLE				10.99	495	p<0.001
(27-45) vs. (55+)	3.976 4.003	0.52	354	n.s.	0.19	353	n.s.
(46-54) vs. (55+)	3.436 3.398	0.94	199	n.s.	1.49	198	n.s.

p<0.001 = significant at the 0.1% level.
n.s. = non-significant

Table 4. Regression equations between shell length and meat weight for surf clams from Georges Bank by sediment type.

Sediment	n	Intercept (a)	Slope (b)	Antilog$_e$ of a	r
Sand	429	-7.95710	2.56644	0.0003301671	0.9798
Not Sand	184	-7.99257	2.58079	0.0003379644	0.9830

Table 5 Mean weight and predicted mean weight of Georges Bank surf clams (Predicted mean weight = $0.0003365816L^{2.57722}$).

Mean Weight	Mean Predicted Weight	Mean Difference	paired-t statistic	Sig. Level
62.08	61.33	0.75	1.42	n.s.

Table 6. Length-weight regression statistics from the Southern New England (1983) and Mid-Atlantic (1980) management areas.

Area	n	Intercept a	Slope b	Correlation r
Georges Bank (1984)	613	-7.9967	2.5772	0.981
Southern New[1] England (1983)	128	-7.8550	2.5801	0.768
Southern New England-Long Island (1980)	132	-7.9837	2.5802	0.924
New Jersey	446	-9.3049	2.8448	0.988
Delmarva	525	-9.1076	2.7676	0.986
Virginia-North Carolina	25	-7.0583	2.3033	0.985

[1]All clams were >140 mm in length.

Table 7. Covariance analyses of surf clam length-weight equations between areas.

Comparison	Tests of Adjusted Means			Tests of Slopes		
	Adj. mean	F	Sig. level	Error d.f.	F	Sig. Level
Georges Bank vs.	3.944					
Southern New England	4.1005	56.47	<0.001	737	0.0008	n.s.
Georges Bank vs.	3.917					
So. New England-Long Island	3.944	1.91	n.s.	741	0.0036	n.s.
Georges Bank vs. New Jersey	NOT APPLICABLE			1055	68.92	<0.001
Georges Bank vs. Delmarva	NOT APPLICABLE			1132	41.78	<0.001
Georges Bank vs. Virginia-No. Carolina	NOT APPLICABLE			634	4.15	<0.05
So. New England vs.	5.155					
So. New England-Long Island	5.027	53.83	<0.001	250	0.000	n.s.
So. New England vs.	4.629					
New Jersey	4.523	52.16	<0.001	570	1.60	n.s.
So. New England vs.	4.590					
Delmarva	5.290	297.80	<0.001	647	0.53	n.s.
So. New England vs.	5.005					
Virginia-No. Carolina	4.425	102.29	<0.001	149	0.19	n.s.
So. New England-Long Island vs. New Jersey	NOT APPLICABLE			574	7.81	<0.01
So. New England-Long Island vs.	4.439					
Delmarva	4.252	120.80	<0.001	651	2.58	n.s.
So. New England-Long Island vs. Virginia-No. Carolina	NOT APPLICABLE			153	4.41	<0.05
New Jersey vs. Delmarva	NOT APPLICABLE			965	6.27	<0.01
New Jersey vs. Virginia-No. Carolina	NOT APPLICABLE			467	31.76	<0.001
Delmarva vs. Virginia-No. Carolina	NOT APPLICABLE			544	14.80	<0.001

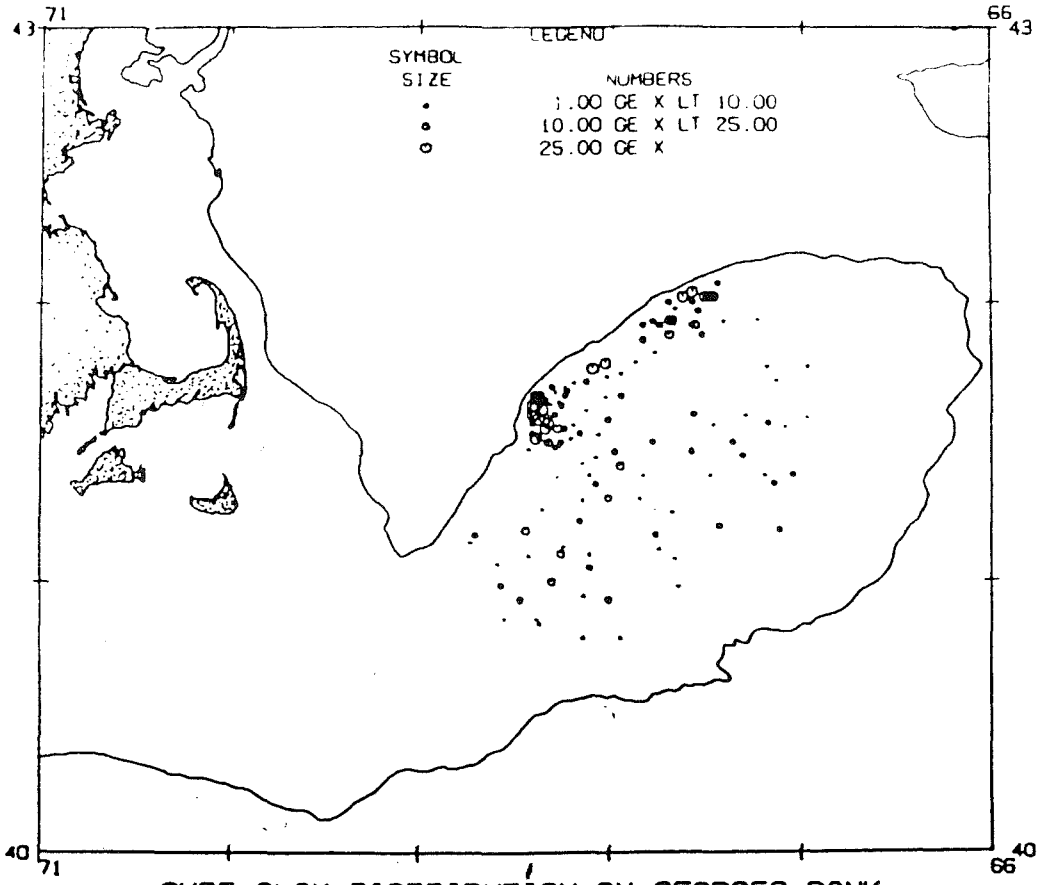

Fig. 1. SURF CLAM DISTRIBUTION ON GEORGES BANK
NMFS CLAM SURVEY 1984

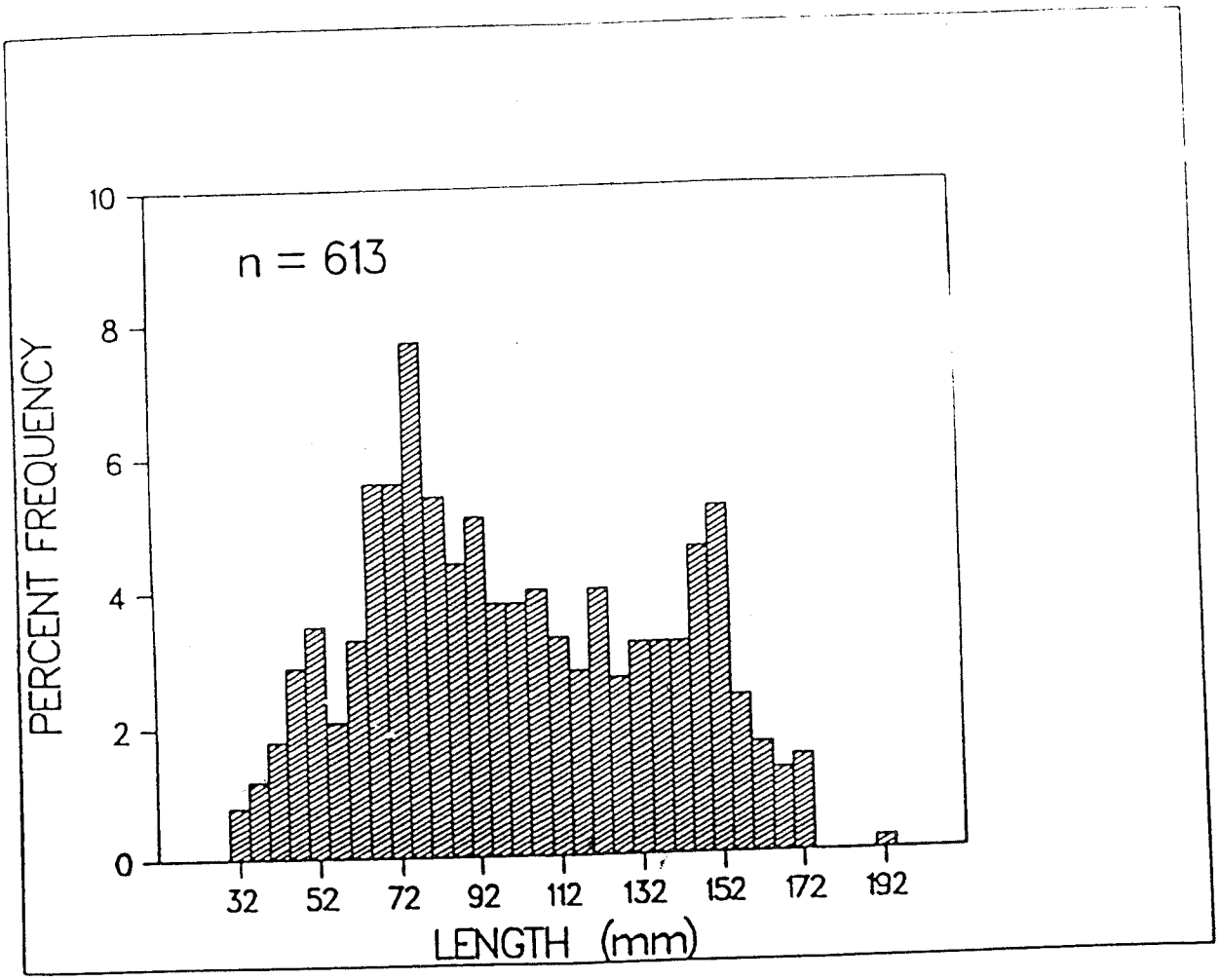

Fig. 2. Length frequencies of surf clams from George's Bank sampled for length-weight analysis.

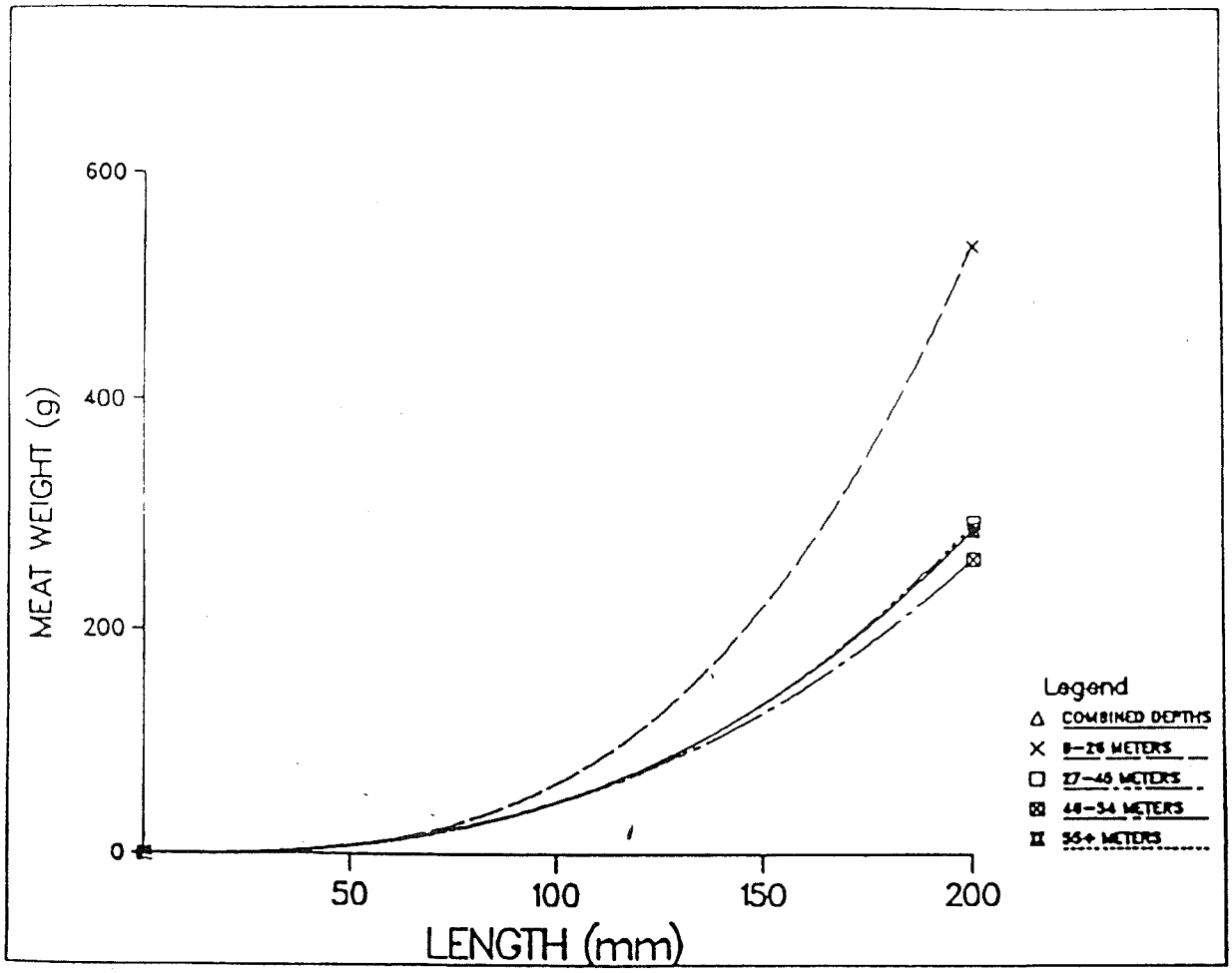

Fig. 3. Surf clam length-weight regressions - George's Bank by depth.

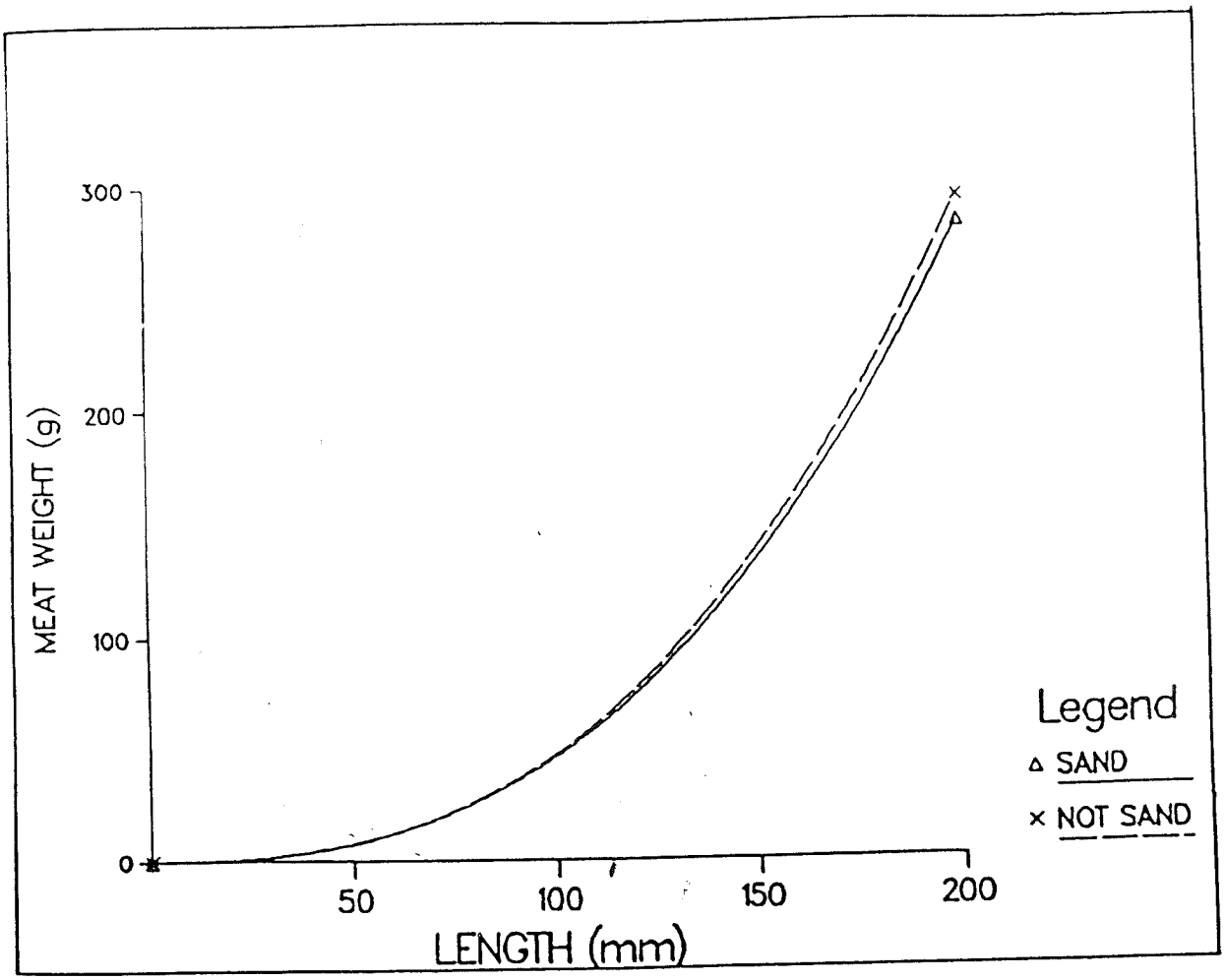

Fig. 4. Surf clam length-seight regressions - George's Bank by sediment type.

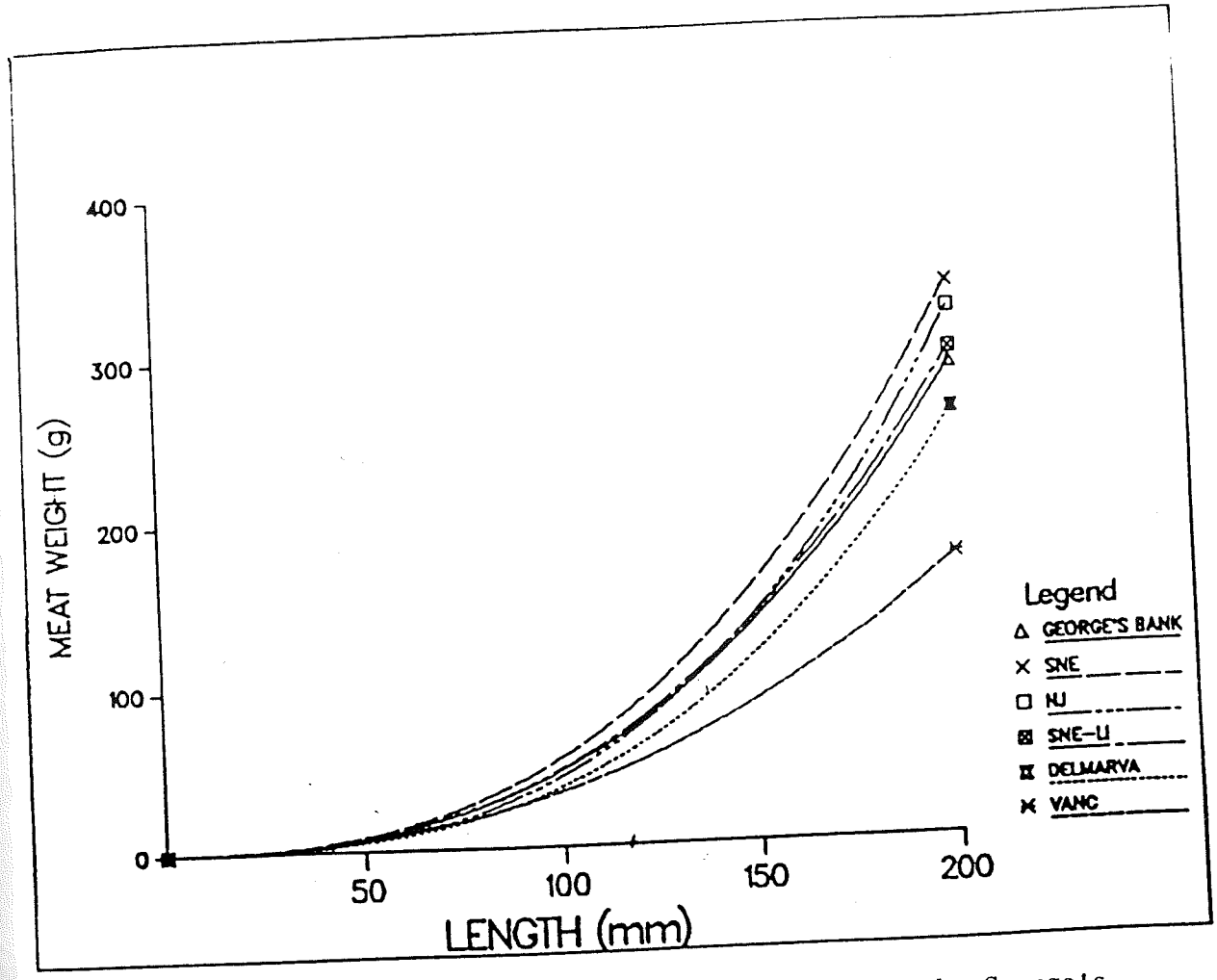

Fig. 5. Surf clam length-weight regressions from the George's Bank and Mid-Atlantic Areas.