Dynamics of Ocean Quahog, *Arctica islandica* Populations off the Middle Atlantic Coast of the United States

Steven A. Murawski

Fredric M. Serchuk

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

Laboratory Reference No. 79-16
April 1979

ABSTRACT

Abundance and size composition estimates of Middle Atlantic ocean quahog, *Arctica islandica*, populations were derived from seven federal (BCF-NMFS) research survey cruises conducted from Cape Cod to Cape Hatteras during 1965-1977. Sampling was performed with a hydraulic shellfish dredge utilizing a transect grid-type survey design, post-stratified to area/depth strata. Standardized tows of four minutes duration using a 121.92 cm (48 in) wide dredge sampled approximately 83 m^2 of bottom per station.

Minimum population size in numbers and biomass (meat weight) was calculated using mean quahog densities (1965-1977) expanded by strata areas. Within the surveyed regions, a standing crop of approximately 56.6 x 10^9 ocean quahogs was estimated, having a biomass of 1.5 x 10^6 metric tons (mt). The largest proportion of the resource (46%) was located off Long Island, with 44% off New Jersey and 10% off the Delmarva Peninsula. Estimates of equilibrium yields for the Middle Atlantic quahog resource (Long Island through Delmarva) ranged from 3,022 to 45,332 mt, assuming rates of instantaneous natural mortality (M) between 0.01 and 0.10, and mortality of unharvested quahogs due to gear encounters between 40-60% of the amount caught. If $M \leq 0.05$, (implying that $\geq$0.7% of the population survies to age 100), total annual equilibrium yield for the area Long Island - Delmarva is less than 23,000 mt.

Commercial offshore landings in 1977 and 1978 were 7,295 and 9,163 mt, respectively with the bulk of the FCZ landings from off New Jersey and the Delmarva Peninsula. While the accumulated Middle Atlantic ocean quahog population biomass can support substantial increases in annual harvests, present data suggest that the current landings may be near the equilibrium capacity of the resource and the current distribution of fishing effort is disproportionate to the spatial distribution of stock biomass.

INTRODUCTION

Commercial utilization of Middle Atlantic (Cape Cod to Cape Hatteras) ocean quahog, *Arctica islandica*, populations has increased rapidly in recent years. Total USA landings in 1977 were 8,412 metric tons (mt), a 235% increase from 1976 and 12-fold greater than the 1967-1976 average annual catch of 687 mt (Table 1). Landings from the Fishery Conservation Zone (FCZ) during 1978 were about 9,163 mt, a 26% increase from 1977. Prior to 1976, virtually all USA landings were derived from a small fishery off Rhode Island (Merrill et al. 1969; Parker and McRae 1970; Serchuk et al. 1979a). The development of a fishery off New Jersey in 1976 and the Delmarva Peninsula in 1977 resulted in a sharp increase in annual landings; catches from these areas comprised 0% of the USA total in 1975 but accounted for 87% in 1977. Population declines in Middle Atlantic surf clams, *Spisula solidissima*, exacerbated in 1976 by a massive kill of the clam stocks in the traditional New Jersey fishing grounds stimulated increased fishing for ocean quahogs (Ropes et al. 1979). The implementation of management measures enacted to conserve and rebuild offshore surf clam populations (Mid-Atlantic Fish. Mgmt. Council 1977; Murawski and Serchuk 1979a; Serchuk et al. 1979b) further encouraged continued expansion of the Middle Atlantic ocean quahog fishery.

Studies of ocean quahog population dynamics, resource abundance and distribution, and life history are generally lacking. Merrill and Ropes (1969; 1970), Parker and McRae (1970) and Merrill et al. (1969) summarized Middle Atlantic research vessel survey cruise data collected by the Bureau of Commercial Fisheries (BCF) during 1963-1967; however, quahog data obtained

from the synoptic research surveys conducted during 1965-1977 have not been heretofore quantitatively analyzed. In this paper we review recent research and commercial information on the distribution, relative abundance, and size composition of Middle Atlantic ocean quahog populations. In addition estimates of resource equilibrium yields are derived from data on population biomass, age and growth, and assumptions of the rates of natural and fishing induced mortality.

SURVEY DESIGN AND SAMPLING PROCEDURES

Ocean shellfish research vessel surveys were initiated in 1963 by the National Marine Fisheries Service's predecessor, the Bureau of Commercial Fisheries, primarily to elucidate the distribution and production potential of offshore Middle Atlantic surf clam populations. However, complete region-wide cruises were not begun until 1965 (Parker 1966; Merrill and Ropes 1969). Sufficient ocean quahog samples were taken in seven cruises from 1965-1977 which were useful for population assessment (Table 2).

A grid-type sampling design was employed during all seven surveys with pre-determined dredge stations located at either 9 or 19 km (5 or 10 nautical mile) intervals along transects coinciding with either LORAN lines or latitude-longitude bearings. Stations deeper than 80 m were rarely occupied due to gear limitations and sampling emphasis on shallow-water surf clam beds. Standard tow data were post-stratified to appropriate area and 20 m depth strata (Figure 1). Survey strata were designed to represent relatively homogeneous areas of bottom type, depth, and ecological conditions (Emery and Uchupi 1972). For the analyses in this paper, grid samples within these strata were treated as if they were random since quahog beds within these zones were not thought to be systematically aggregated.

During most cruises survey coverage extended from Long Island through Delmarva; in some cruises southern Virginia-North Carolina and southern New England waters were also sampled. The southern-most boundary of the southern Virginia - North Carolina strata (not illustrated in Figure 1) extends southeast from Cape Hatteras to the 100 m isobath.

Research vessels and sampling gear used in each of the recent surveys are listed in Table 2. In the first four surveys (1965-1973) an hydraulic clam dredge with 76.20 cm (30 in.) wide knife was used while the latter three cruises used a 121.92 cm (48 in.) wide dredge. Details of the construction and operation of the dredges are described and illustrated in Parker (1966; 1971), Standley and Parker (1967), Ropes et al. (1969), and Parker and McRae (1970).

After each tow, contents of the dredge were dumped, sorted by species and enumerated. Volume determinations were made and if the catch exceeded 35 ℓ (1 U.S. bu.) the usual practice was to take a 35 ℓ subsample for length frequency analysis. Total shell length (longest dimension) was recorded to the nearest cm for quahogs that were whole or broken but measurable. Total live weight of the catch was not routinely recorded because of the variability in weights of quahogs due to contamination with substrate from the dredging process. Hence, catch weights were derived by applying appropriate areal length-weight equations (Table 3; Murawski and Serchuk 1979b) to the prorated length frequency distribution of each tow, viz:

$$\hat{B} = \sum_{L=1}^{15} cL_i^{\,b} N_i$$

where $\hat{B}$ = total calculated catch in weight per tow
L_i = mean shell length of quahogs in 10 mm size groups i, expressed as the mid point of the size group (i.e., for size groups 0-9, 10-19,.... 140-149 mm, L_i = 4.5, 14.5...144.5 mm).

N = total number of quahogs caught within size group i
b = slope of the appropriate areal length-weight equation (Table 3)
c = antilog of the intercept of the appropriate areal length-weight equation (Table 3)..

The prorated length frequency distribution of each tow was derived from the measured subsamples by multiplying the number of quahogs in each size group by the ratio of the total number caught to the total number measured. For tows in which no length samples were taken, the appropriate strata cumulative length frequency distributions were applied to catch.

Since tow duration and gear varied slightly between survey cruises, individual tow catches (numbers and weight) were standardized to a 121.92 cm wide dredge and four minute tow. Thus, the 1965-1969 tow data were multiplied by 1.28; the product of the linear correction factors: 1.6 (the ratio 121.92/76.20), and 0.8 (the ratio 4 minutes/5 minutes). Odometer readings (n = 217) from the 1965 and 1969 surveys indicated that during a five mintue tow an average of 64.74 m^2 of bottom was covered by the 76.20 cm wide dredge. Thus, approximately 82.87 m^2 was sampled during a standardized tow.

ABUNDANCE INDICES

Standardized mean catch per tow data (numbers and meat weight) of ocean quahogs, by area/depth strata, for the 1965-1977 shellfish surveys are presented in Table 4. The relative distribution of biomass form the 1965 (spring) and 1977 surveys (Figures 2 and 3) are indicative of the time series of data.

A total of 10% (171) of the stations sampled between 1965 and 1977 were located within the southern Virginia - North Carolina area. Yearly strata catch per tow indices exhibited marked variation reflecting the sporadic distribution of quahogs in this region. However, 95% confidence limits about the mean catches per tow ($\pm 2\sqrt{\frac{\sigma 2}{n}}$) suggest that differences over time within strata were not significant. Abundance indices for southern Virginia - North Carolina were the lowest of all areas for each depth range from 20.1-80.0 m.

The ocean quahog resource off the Delmarva Peninsula occurs in waters deeper than 20 m. Survey indices for depths greater than 20 m were significantly higher than corresponding strata to the south. The 40.1-60.0 m strata usually exhibited the highest relative abundance of quahogs. Differences in catch per tow values over time were generally not significant, although means were highly variable, particularly in the 40.1-60.0 m interval. Approximately 31% (552) of the stations sampled during the period were from this area.

The relative abundance of quahogs off New Jersey in waters greater than 40.0 m deep was similar to that off Delmarva. However, indices for the 20.1-40.0 m depth stratum were significantly greater than off Delmarva. The largest percentage (36%) of the stations sampled during the period were off New Jersey.

Average catch rates from Long Island strata were generally greater than corresponding strata in other areas. The 40.1-60.0 m depths exhibited the highest mean catches per tow, consistent with trends for southern

Virginia - North Carolina, Delmarva, and New Jersey. Abundance indices did not apparently vary significantly during the time period. The increased shoreward abundance of quahogs off Long Island may reflect generally cooler waters there than further to the south especially during the summer. A total of 22% of the stations were located off Long Island.

Limited data for the southern New England area were collected during cruises in 1970 and 1977. The lack of an extensive time series precludes assessment of the significance of changes in abundance over time. Data for the 1977 survey do, however, indicate that trends in relative abundance by depth are consistent with other areas.

SIZE COMPOSITION

Survey catches of ocean quahogs were comprised of individuals ranging in size from 2-14-cm shell length (longest dimension). Dredge specifications and shell morphometry data indicate that minimum shell lengths at full selection ranged from 6-7 cm for the two survey dredges used (Table 2). Shell length frequency distributions for most area/depth strata were unimodal; modal sizes usually ranged from 6-10 cm. Little change in frequency distributions within strata occurred during 1965-1977, suggesting relative resource stability. Substantial differences in length composition, however, were evident between strata and areas. The largest quahogs sampled were from off New Jersey with few individuals greater than 11.9 cm taken off southern New England, Long Island, Delmarva, or southern Virginia - North Carolina. Most of the New Jersey quahogs greater than 12 cm were from 20.1-40.0 m depths, with progressively fewer large quahogs in deeper waters. The

greatest proportion of small *Arctica* (<5 cm) were from Long Island with fewer small quahogs in other areas. Individuals less than 4 cm were rarely taken from depths shallower than 40 cm in any area, perhaps indicating poor recruitment to those strata during the study period.

MINIMUM POPULATION SIZE

Statistical analyses of relative abundance indices (Table 4) revealed little significant change in quahog populations over time. Stable population size is further suggested by the lack of significant fluctuation in length frequency composition, and the relative scarcity of small individuals. Hence, we combined catch per tow data for all years to compute single indices for those area/depth strata with sufficient information (Long Island-Delmarva). The highest abundance in numbers and meat weight per tow was in waters 40.1-60.0 m deep off Long Island and New Jersey (Table 5).

Estimates of population density - the absolute number and weight per m^2 - were calculated assuming the dredge sampled an average of 82.87 m^2 per tow. These estimates must be considered minimum because the dredge is not thought to be 100% efficient in sampling clam populations. Also, only clams above a certain size will be fully retained by the dredge. Population size estimates were derived for quahogs of all sizes taken in the research sampling. Estimated densities ranged from 0.02 - 2.70 individuals and 0.02 - 60.18 g/m^2.

The minimum population size of quahogs inhabiting the area from Long Island through Delmarva was computed utilizing minimum density calculations and corresponding stratum areas (Figure 1). Population size for each stratum was derived by multiplying number and weight per m^2 by the number of m^2 of

ocean bottom in each. Total population size is hence the sum of the strata estimates (Table 5). A total Middle Atlantic resource of 56.6×10^9 quahogs and 1.5×10^6 mt of meat was estimated. The distribution of total biomass was greatest off Long Island (46%) followed by New Jersey (44%) and Delmarva (10%). Average meat weights were largest off New Jersey (32 g) followed by Delmarva (28 g) and Long Island (23 g).

EQUILIBRIUM YIELDS

The amount of resource available for sustainable harvesting has been generally thought of as the production in excess of that needed to maintain the population at a certain stock size, and has thus been termed surplus production (Schaefer 1954; Gulland 1971; Sissenwine 1978). For populations exhibiting logistic growth, the point of maximum surplus production occurs at the inflection of the population growth function, corresponding to a level of 50% of the virgin stock size (Schaefer 1954). Methodologies to compute surplus production are based on historical catch and effort data for established fisheries; however, the available data for the Middle Atlantic ocean quahog resource are not sufficient for these purposes. Gulland (1971) proposed a simplistic model for calculating maximum sustainable yield (MSY) when adequate data for more sophisticated analyses are lacking. Maximum sustainable catch (C_{max}) is related to the optimum relative stock size ($X = \frac{1}{2}$ virgin stock size, B_0) and the instantaneous natural mortality rate (M) by:

$$C_{max} = X \cdot M \cdot B_0$$

It is recognized that the actual population will not follow the formula precisely but it is likely some deviations may compensate each other (Gulland

1971). We have included an additional term in this formula to reflect fishing mortality caused by the dredge damaging quahogs that are not harvested. The actual rate of additional mortality is not precisely known but has been tentatively estimated at between 40 and 60% of the amount harvested (Mid-Atlantic Fish. Mgt. Council 1977). Calculations of the natural mortality rate of ocean quahogs have not been reported. However, recent studies (Dr. I. Thompson, Princeton University, personal communication) have suggested that a significant proportion of the resource may live longer than 100 years. We have incorporated values of the instantaneous natural mortality rate (M) into our calculations of MSY ranging from 0.01 (36.8% of the population living to 100 yr) to 0.10 (<0.1% of the population living to 100 yr). The latter value is similar to the calculated mortality rate of the sea scallop, *Placopecten magellanicus*, which inhabits much of the quahog's range in the Middle Atlantic (Merrill and Posgay 1964).

Calculations of MSY for the ocean quahog resource from Long Island - Delmarva are presented in Table 6. Estimates of virgin biomass are those expanded from stratified catch per tow information from surveys, and therefore, must be considered minimum. Values of MSY vary considerably depending primarily on the assumed natural mortality rate. The natural mortality rate of quahogs is probably less than that of scallops considering the more dynamic nature of the sea scallop resource (Serchuk et al. 1979c). If $M \leq 0.05$ for quahogs ($\geq$0.7% survive to 100 yrs), then MSY for the area Long Island - Delmarva would be expected to be less than 23,000 mt per year. The ocean quahog fishery operating in the FCZ harvested 6,808 mt in 1977, and an estimated 9,163 mt

in 1978. However, most of the offshore Middle Atlantic landings were derived from the New Jersey and Delmarva areas, which account for 54% of the total calculated biomass from Long Island - Delmarva. Thus, if the relative areal distribution of landings does not change, MSY for the area being fished is probably less than 12,000 mt (22,666 · 0.54).

Further refinement of MSY estimates will be possible as additional information on age and growth, breakage of unharvested quahogs and catch/effort data become available. However, it should be noted that the Schaefer model implies that maximum surplus production will occur when the standing stock is reduced to one-half of the virgin level. Therefore, harvests above MSY in the initial fishing years should not cause irreparable harm to the resource. If, however, subsequent evidence suggests rapid resource depletion and little concurrent recruitment to the population, appropriate constraints on the fishery should be considered.

REFERENCES

Emery, K.O., and E. Uchupi. 1972. Western North Atlantic Ocean: topography, rocks, structure, water, life, and sediments. Am. Assoc. Petrol. Geol. Tulsa, Oklahoma. 532 pp.

Gulland, J.A. 1971. The fish resources of the ocean. Fishing News (Books) Ltd., Surrey, England. 255 pp.

Merrill, A.S., and J.A. Posgay. 1964. Estimating the natural mortality rate of the sea scallop (*Placopecten magellanicus*). Int. Comm. N.W. Atl. Fish. Res. Bull. 1:88-106.

Merrill, A.S., and J.W. Ropes. 1969. The general distribution of the surf clam and ocean quahog. Proc. Nat. Shellfish Assoc. 59:40-45.

_____ 1970. The distribution and density of the ocean quahog, *Arctica islandica*. Amer. Malacol. Union Bull. 36:19.

Merrill, A.S., J.L. Chamberlin, and J.W. Ropes. 1969. Ocean quahog fishery. In: F. Firth (ed.). Encyclopedia of Marine Resources. Reinhold Publ. Corp., N.Y. 125-129.

Mid-Atlantic Fish. Mgt. Council. 1977. Fishery Management Plan for surf clam and ocean quahog fisheries. Mid-Atlantic Fish. Mgt. Council. Fish. Mgt. Plan. 136 pp.

Murawski, S.A., and F.M. Serchuk. 1979a. An assessment of offshore surf clam, *Spisula solidissima*, populations off the Middle Atlantic Coast of the United States. Nat. Mar. Fish. Serv. Woods Hole Lab. Ref. 79-13. 36 pp.

_____ 1979b. Shell length-meat weight relationships of ocean quahogs, *Arctica islandica*, from the Middle Atlantic Shelf. Proc. Nat. Shellfisheries Assoc. 69 (in press).

Parker, P.S. 1966. Ocean clam survey off U.S. Middle Atlantic coast -- 1963. U.S. Fish. Wildl. Serv., Commer. Fish. Ref. 28(3):1-9.

_____ 1971. History and development of surf clam harvesting gear. Nat. Mar. Fish. Serv., Circ. 364. 15 pp.

Parker, P.S., and E.D. McRae. 1970. The ocean quahog, *Arctica islandica*, resource of the Northwestern Atlantic. Fishery Industrial Research 6: 185-195.

Ropes, J.W., J.L. Chamberlin, and A.S. Merrill. 1969. Surf clam fishery. In: F. Firth (ed.). Encyclopedia of Marine Resources. Reinhold Publ. Corp., N.Y. 119-125.

Ropes, J.W., A.S. Merrill, S.A. Murawski, S. Chang, and C.L. MacKenzie, Jr. 1979. Chapter XI. Impact on clams and scallops associated with anoxic bottom water in the Middle Atlantic Bight during the summer of 1976. Part I. Field survey assessments. In R.L. Swanson and C.J. Sindermann (eds.). Oxygen depletion and associated mass mortalities in the New York Bight, 1976. NOAA, ERL-MESA Spec. Publ. (In press.)

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bull. Inter. Am. Trop. Tuna Comm., 1(2):26-56.

Serchuk, F.M., S.A. Murawski, and J.W. Ropes. 1979a. Ocean quahog, *Arctica islandica*, (Linnaeus). In: Grosslein, M.D., and T. Azarovitz, (eds.) Fish distribution MESA New York Bight Monograph No. 15. New York Sea Grant Institute, Albany, New York.

Serchuk, F.M., S.A. Murawski, E.M. Henderson, and B.E. Brown. 1979b. The population dynamics basis for management of offshore surf clam populations in the Middle Atlantic. Proc. of the Northeast Clam Industries-Management for the Future. Coop. Ext. Serv. Univ. of Mass. - MIT Sea Grant.

Serchuk, F.M., P.W. Wood, J.A. Posgay, and B.E. Brown. 1979c. Assessment and status of sea scallop (*Placopecten magellanicus*) populations off the Northeast Coast of the United States. Proc. Nat. Shellfisheries Assoc. (In press.)

Sissenwine, M.P. 1978. Is MSY an adequate foundation for optimum yield. Fisheries 3(6):22-24, 37, 38, 40-42.

Standley, M.L., and P.S. Parker. 1967. Development of a submersible pumping system for hydraulic surf clam dredge. U.S. Fish Wildl. Serv., Commer. Fish. Rev. 29(6):50-55.

Table 1. Landings of ocean quahogs (mt of meat) derived from State waters and the Fishery Conservation Zone (FCZ), 1967-1978.

Year	State waters	FCZ	Total
1967	20[1]	-	20
1968	102[1]	-	102
1969	290[1]	-	290
1970	792[1]	-	792
1971	921[1]	-	921
1972	635[1]	-	635
1973	661[1]	-	661
1974	365[1]	-	365
1975	569[1]	-	569
1976	656[1]	1,859[2]	2,515
1977	1,118[2]	7,295[2]	8,412
1978		9,163[3]	

[1]Landings from Rhode Island, principally derived from within 3 miles of the coast.

[2]Data presented in "Fisheries of the United States, 1977", Current Fisheries Statistics No. 7200.

[3]Based on log book records submitted to NMFS.

Table 2. Ocean shellfish survey cruises used in the analysis of the dynamics of ocean quahog populations.

Year	Cruise dates (Month/Day)	Research vessel	Dredge knife width (cm)	Minutes per tow	Ring size or cage bar space (mm)	Minimum shell length at full selection (mm)
1977	1/26-3/17	Delaware II	121.92	4	30.0[b]	70
1976	4/6-5/13	Delaware II	121.92	4	30.0[b]	70
1970[a]	8/13-8/24	Delaware II	121.92	4	30.0[b]	70
1969	6/20-7/2	Albatross IV	76.20	5	50.8[c]	63
1966	8/14-8/27	Albatross IV	76.20	5	50.8[c]	63
1965(2)	10/27-11/14	Undaunted	76.20	5	50.8[c]	63
1965(1)	5/26-6/23	Undaunted	76.20	5	50.8[c]	63

[a]Submersible pumping system used.

[b]Terminal cage used.

[c]Terminal ring bag used.

Table 3. Statistics describing regression equations between shell length (mm) and drained meat weight (g) for ocean quahogs (from Murawski and Serchuk 1979b).

Area	Intercept(a)	Slope(b)	S.E. of b	Correlation coefficient(r)
Southern New England - Long Island	-9.124283	2.774989	0.0199	0.9670
New Jersey	-9.847183	2.949540	0.0294	0.9546
Delmarva - So. VA-NC	-9.042313	2.787987	0.0800	0.9172

Table 4. Catch per tow data ($\overline{X}$ = mean, σ = standard deviation, n = number of tows) of ocean quahogs, by area/depth strata for ocean shellfish surveys 1965-1977[a].

Area depth(m) cruise	n	Catches in Numbers $\overline{X}$	Catches in Numbers σ	Catches in Meat Weight(kg) $\overline{X}$	Catches in Meat Weight(kg) σ
So. New England					
20.1-40.0					
1977	11	20.00	34.83	0.5326	0.9315
1970	4	183.50	337.03	4.5183	8.2074
40.1-60.0					
1977	15	77.87	97.10	1.7288	2.2351
60.1-80.0					
1977	10	15.80	37.14	0.3615	0.8231
Long Island					
0.1-20.0					
1977	2	0.00	0.00	0.0000	0.0000
1976	6	4.00	9.80	0.0785	0.1923
1970	4	8.00	16.00	0.1940	0.3880
1969	4	0.64	1.28	0.0246	0.0492
1966	3	0.00	0.00	0.0000	0.0000
1965(2)	17	0.00	0.00	0.0000	0.0000
1965(1)	10	0.13	0.40	0.0031	0.0098
20.1-40.0					
1977	14	32.64	48.21	0.9444	1.2397
1976	26	103.72	185.80	2.9419	5.2644
1970	14	265.36	320.49	6.3862	7.2196
1969	25	149.20	242.99	3.5362	5.2225
1966	21	130.07	266.08	3.5116	7.0453
1964(2)	20	139.71	320.66	3.3973	7.4062
1965(1)	29	114.45	215.13	2.8899	5.7174
40.1-60.0					
1977	17	243.24	171.43	5.2236	3.3971
1976	36	293.54	206.08	6.1944	4.2529
1970	21	214.81	203.15	5.2784	5.2987
1969	23	136.63	197.19	2.9080	3.9825
1966	1	0.00	0.00	0.0000	0.0000
1965(1)	26	208.29	179.88	4.9551	4.8447
60.1-80.0					
1977	15	134.40	195.73	2.6715	4.2497
1976	18	100.83	169.15	2.2175	3.7895
1970	6	13.17	20.59	0.1925	0.2415
1969	21	39.13	104.30	0.8946	2.4139
80.1-100.0					
1976	2	0.00	0.00	0.0000	0.0000
New Jersey					
0.1-20.0					
1977	7	0.00	0.00	0.0000	0.0000
1976	12	0.00	0.00	0.0000	0.0000
1970	11	0.18	0.40	0.0048	0.0115
1969	12	0.00	0.00	0.0000	0.0000
1966	17	0.00	0.00	0.0000	0.0000
1965(2)	23	0.11	0.53	0.0032	0.0156
1965(1)	19	0.00	0.00	0.0000	0.0000

Table 4 (continued)

Area depth(m) cruise	n	Catches in Numbers $\bar{X}$	Catches in Numbers σ	Catches in Meat Weight(kg) $\bar{X}$	Catches in Meat Weight(kg) σ
20.1-40.0					
1977	24	24.62	63.79	0.8451	1.9455
1976	34	55.53	186.12	1.6464	4.4192
1970	45	28.69	72.11	1.7182	4.3060
1969	52	51.15	229.65	1.2896	4.5480
1966	82	30.02	103.60	1.1279	3.4761
1965(2)	49	5.12	10.15	0.1933	0.3682
1965(1)	58	67.82	278.01	1.7108	5.1558
40.1-60.0					
1977	26	114.00	190.43	3.4920	5.7138
1976	20	146.55	261.82	4.3251	7.5912
1970	23	148.04	160.00	7.5929	8.3864
1969	14	65.92	78.73	1.8244	2.1585
1966	29	116.17	203.41	4.2543	7.0372
1965(2)	3	322.56	527.84	8.6975	13.9972
1965(1)	33	179.86	232.02	5.1960	6.9847
60.1-80.0					
1977	12	49.92	74.97	1.3656	2.2556
1976	9	71.56	69.96	2.1488	2.2201
1970	4	307.75	263.91	8.9548	7.6338
1969	17	98.03	191.75	2.3772	3.9401
80.1-100.0					
1977	1	8.00	0.00	0.1441	0.0000
1966	6	1.67	2.58	0.0572	0.0888
1969	1	2.56	0.00	0.1067	0.0000
DELMARVA					
0.1-20.0					
1977	9	0.00	0.00	0.0000	0.0000
1976	13	0.00	0.00	0.0000	0.0000
1970	13	0.00	0.00	0.0000	0.0000
1969	23	0.00	0.00	0.0000	0.0000
1966	14	0.00	0.00	0.0000	0.0000
1965(2)	27	0.00	0.00	0.0000	0.0000
1965(1)	21	0.00	0.00	0.0000	0.0000
20.1-40.0					
1977	32	0.75	3.71	0.0360	0.1795
1976	31	9.16	35.84	0.3269	1.2531
1970	34	1.79	5.45	0.0838	0.2706
1969	48	2.32	12.23	0.0787	0.4176
1966	63	1.85	6.23	0.0674	0.2318
1965(2)	41	1.65	6.74	0.0592	0.2318
1965(1)	64	3.18	9.31	0.0890	0.2581
40.1-60.0					
1977	11	137.73	351.38	3.6329	8.2199
1976	13	38.23	42.77	1.4657	1.4248
1970	9	105.78	242.62	2.4654	4.4750
1966	11	69.35	87.64	2.8033	3.6442
1965(2)	4	7.36	11.37	0.2124	0.2579
1965(1)	30	125.65	222.56	3.1341	4.5993

Table 4 (continued)

Area depth(m) cruise	n	Catches in Numbers $\bar{X}$	Catches in Numbers σ	Catches in Meat Weight(kg) $\bar{X}$	Catches in Meat Weight(kg) σ
60.1-80.0					
1977	6	51.00	49.67	1.3620	1.1011
1976	9	48.44	80.56	1.4827	1.8768
1970	4	17.75	30.40	0.6263	1.0347
1969	19	6.20	12.48	0.2145	0.4296
1965(1)	2	14.72	19.01	0.4570	0.6007
80.1-100.0					
1977	1	0.00	0.00	0.0000	0.0000
So. VA-NC					
0.1-20.0					
1976	6	0.00	0.00	0.0000	0.0000
1970	5	0.80	1.79	0.0069	0.0153
1969	5	0.00	0.00	0.0000	0.0000
1965(2)	9	0.00	0.00	0.0000	0.0000
1965(1)	6	0.00	0.00	0.0000	0.0000
20.1-40.0					
1976	18	0.33	1.41	0.0128	0.0544
1970	5	0.20	0.45	0.0101	0.0226
1969	13	0.00	0.00	0.0000	0.0000
1965(2)	16	1.04	3.54	0.0320	0.0991
1965(1)	59	0.00	0.00	0.0000	0.0000
40.1-60.0					
1970	1	8.00	0.00	0.3077	0.0000
1969	1	3.84	0.00	0.1202	0.0000
1965(2)	6	6.19	6.60	0.1692	0.1809
1965(1)	15	4.01	11.01	0.1520	0.4418
60.1-80.0					
1970	2	5.50	7.78	0.1728	0.2444
1965(2)	2	0.00	0.00	0.0000	0.0000
1965(1)	2	0.00	0.00	0.0000	0.0000

[a]Standardized to catch of 121.92 cm wide dredge, towed for 4 minutes.

Table 5. Mean catches per tow, average densities, and minimum population size estimates for ocean quahogs from Long Island - Delmarva sampled during NMFS shellfish surveys, 1965-1977.

Area depth (m)	# of tows	$\bar{X}$ Catch/Tow		$\bar{X}$ Density/m^2		Minimum Population Size Estimates	
		Numbers	Meat weight (kg)	Numbers	Meat weight (g)	Numbers	Meat weight (mt)
Long Island							
0.1-20.0	46	1.30	0.0300	0.02	0.3611	15,809.900	363
20.1-40.0	149	129.65	3.3089	1.57	39.9288	7,312,331,312	186,625
40.1-60.0	124	223.96	4.9868	2.70	60.1762	17,956,052,870	399,811
60.1-80.0	60	78.86	1.6655	0.95	20.0977	4,930,390,147	104,126
80.1-100.0	2	0.00	0.0000	0.00	0.0000	0	0
New Jersey							
0.1-20.0	101	0.05	0.0013	0.00	0.0151	1,792,174	50
20.1-40.0	344	38.01	1.2262	0.46	14.7967	4,296,491,970	138,604
40.1-60.0	148	138.48	4.7190	1.67	56.9446	11,129,064,200	379,249
60.1-80.0	42	98.59	2.6657	1.19	32.1673	5,585,360,331	151,023
80.1-100.0	8	2.57	0.0743	0.03	0.8960	35,202,305	1,016
Delmarva							
0.1-20.0	120	0.00	0.0000	0.00	0.0000	0	0
20.1-40.0	313	2.77	0.0968	0.03	1.1681	308,736,895	10,772
40.1-60.0	78	96.49	2.6527	1.16	32.0104	4,518,622,965	124,234
60.1-80.0	40	24.00	0.7253	0.29	8.7523	502,578,436	15,185
80.1-100.0	1	0.00	0.0000	0.00	0.0000	0	0
					TOTAL	56,592,433,505	1,511,058

Table 6. Calculations of maximum sustainable yield (MSY) for ocean quahogs from Long Island - Delmarva (M = instantaneous natural mortality rate, B_0 = biomass in meat weight available to the fishery, X = proportion of virgin stock size for MSY from Schaefer yield model, P = amount of additional biomass lost from dredge mortality of unharvested quahogs expressed as proportion of amount caught).

M	B_0 (mt)	X	P	MSY (mt)
0.01[a]	1,511,058	0.5	0.4	4,533
			0.5	3,778
			0.6	3,022
0.02[b]	1,511,058	0.5	0.4	9,066
			0.5	7,555
			0.6	6,044
0.027[c]	1,511,058	0.5	0.4	12,240
			0.5	10,200
			0.6	8,160
0.05[d]	1,511,058	0.5	0.4	22,666
			0.5	18,888
			0.6	15,111
0.10[e]	1,511,058	0.5	0.4	45,332
			0.5	37,777
			0.6	30,221

[a]Equivalent to 36.8% of the population living to 100 yr.

[b]Equivalent to 13.5% of the population living to 100 yr.

[c]Equivalent to 6.7% of the population living to 100 yr.

[d]Equivalent to 0.7% of the population living to 100 yr.

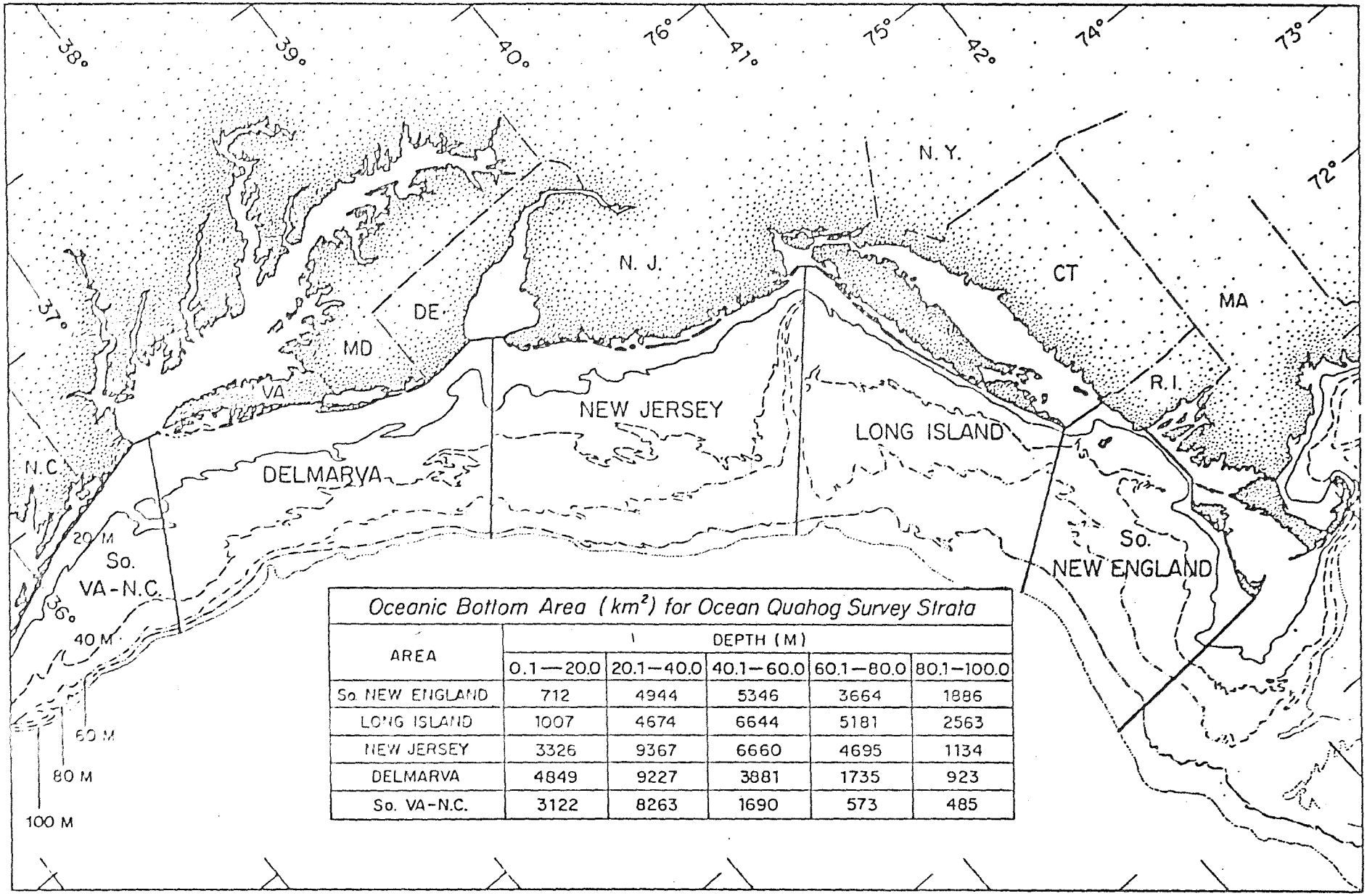
[e]Equivalent to <0.1% of the population living to 100 yr.

LIST OF FIGURES

Figure 1. Ocean quahog survey strata and associated bottom areas in the Middle Atlantic.

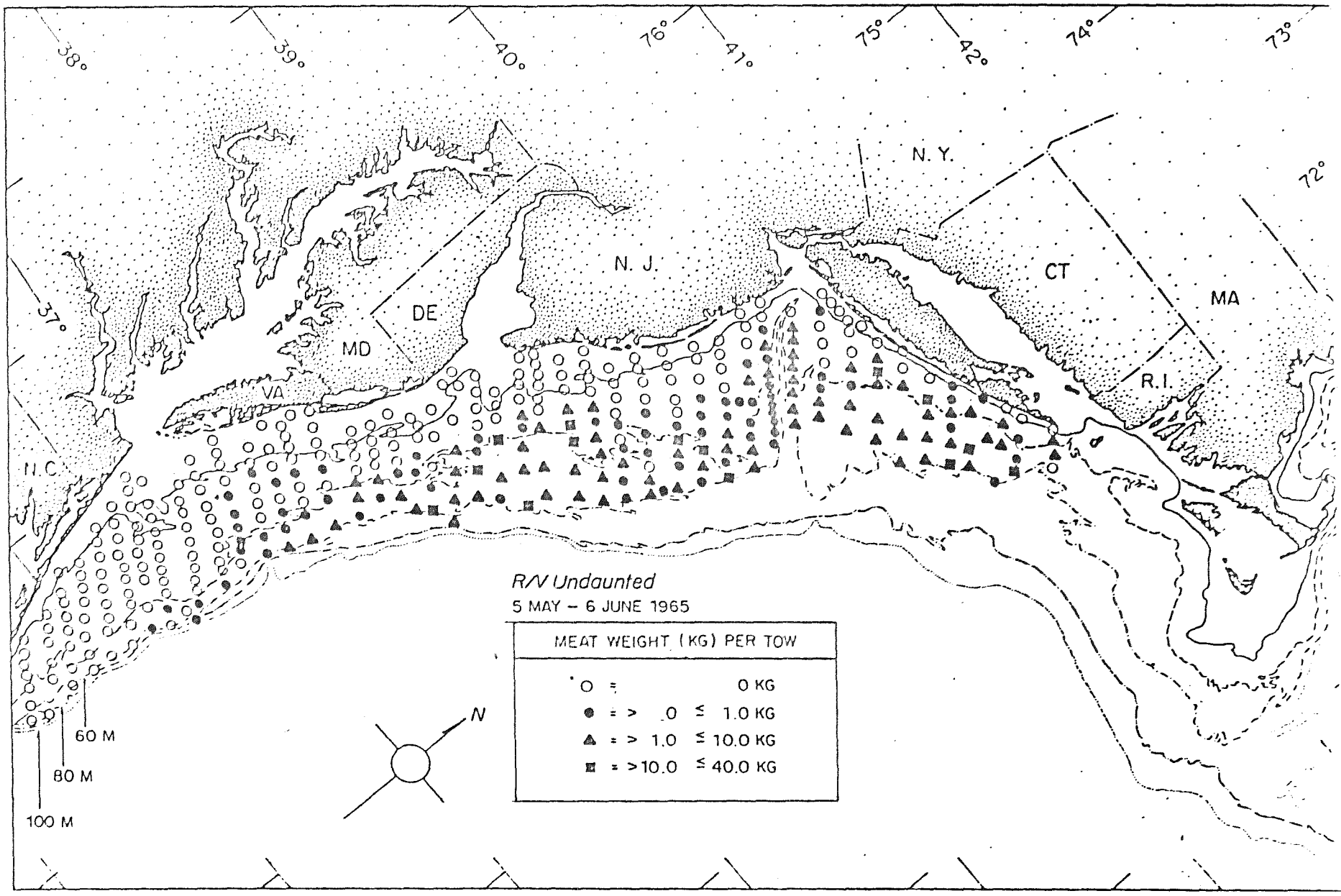
Figure 2. Station locations and ocean quahog catches in meat weight (kg) during the R/V UNDAUNTED cruise, 5 May - 6 June 1965. Several stations near Cape Hatteras in which no quahogs were taken are not illustrated.

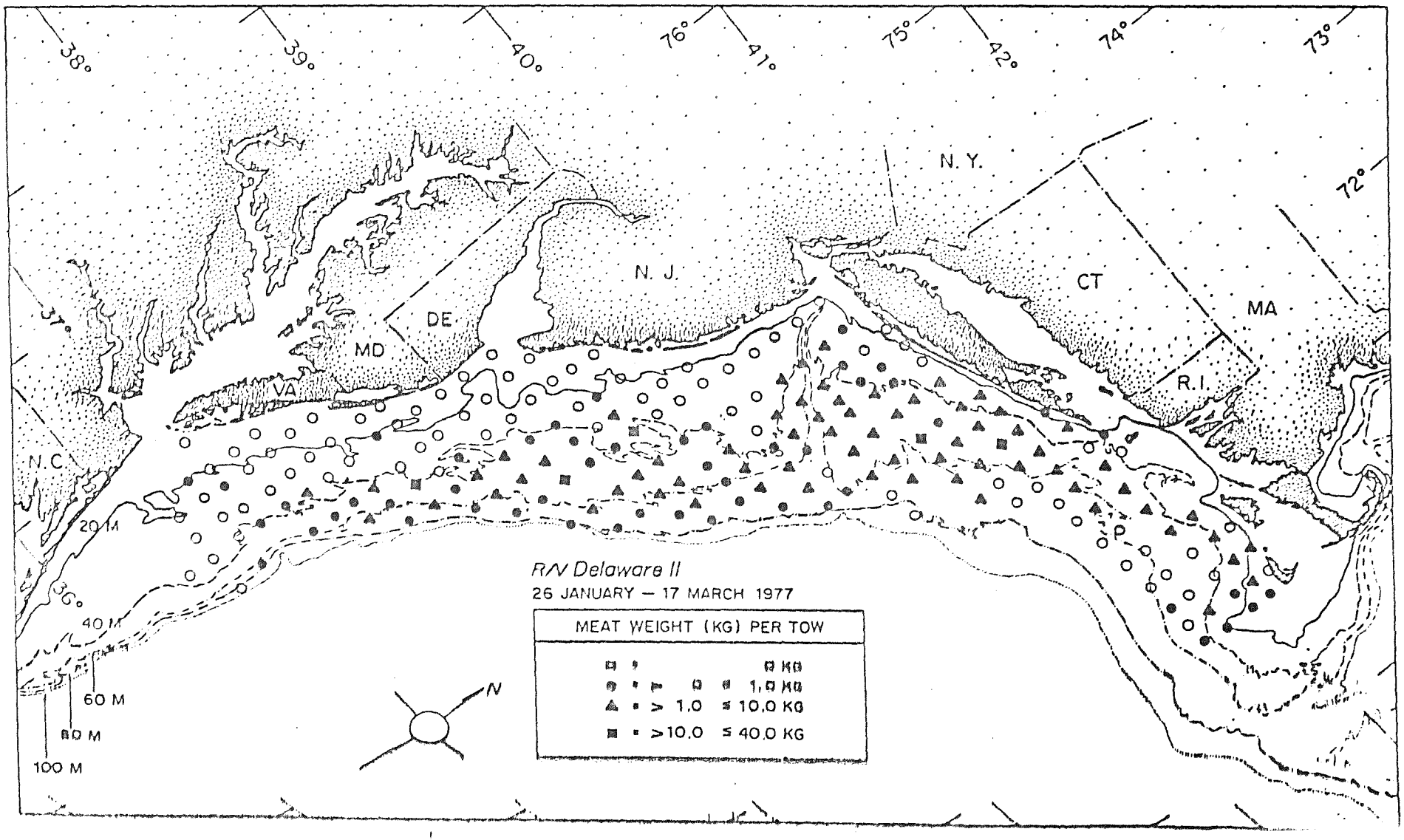
Figure 3. Station locations and ocean quahog catches in meat weight (kg) during the R/V DELAWARE II cruise, 26 January - 17 March 1977.



Oceanic Bottom Area (km^2) for Ocean Quahog Survey Strata

AREA	DEPTH (M)				
	0.1—20.0	20.1—40.0	40.1—60.0	60.1—80.0	80.1—100.0
So. NEW ENGLAND	712	4944	5346	3664	1886
LONG ISLAND	1007	4674	6644	5181	2563
NEW JERSEY	3326	9367	6660	4695	1134
DELMARVA	4849	9227	3881	1735	923
So. VA-N.C.	3122	8263	1690	573	485


38°
39°
40°
76°
41°
75°
42°
74°
73°
72°
37°
N. Y.
N. J.
CT
MA
DE
MD
R.I.
VA
N.C.
R/V Undaunted
5 MAY – 6 JUNE 1965
MEAT WEIGHT (KG) PER TOW
O = 0 KG
● = > .0 ≤ 1.0 KG
▲ = > 1.0 ≤ 10.0 KG
■ = >10.0 ≤ 40.0 KG
N
60 M
80 M
100 M


38°
39°
40°
76°
41°
75°
42°
74°
73°
72°
37°
36°
N. Y.
N. J.
CT
MA
R. I.
DE
MD
VA
N. C.
20 M
40 M
60 M
80 M
100 M
N
R/V Delaware II
26 JANUARY — 17 MARCH 1977
MEAT WEIGHT (KG) PER TOW
0 KG
> 1.0 ≤ 10.0 KG
>10.0 ≤ 40.0 KG