Gulf of Maine Ocean Quahog (*Arctica islandica*) Assessment

Completion report submitted to the Northeast Consortium

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Abstract

The Maine ocean quahog (*Arctica islandica*) fishery was fully integrated into the surfclam/ocean quahog ITQ system under the Mid-Atlantic Fisheries Management Council in 1998 with the ratification of Amendment 10 to the fisheries management plan. This fishery differs in many respects from the larger-scale ocean quahog fishery occurring in waters off southern New England and the Mid-Atlantic Bight. Initial allocation for the Maine fishery was 100,000 bushels based on historical landings since little data was available for the Gulf of Maine population. The biology of *A. islandica* is characterized by slow growth rates, low natural mortality, delayed age at maturity, and highly variable recruitment rates – making it potentially vulnerable to over-exploitation. In the spring of 2002, the Maine Department of Marine Resources undertook an industry-collaborative pilot survey of Maine's ocean quahog resource. We collected base-line information to begin to establish a biological basis for quota allocation. Objectives were to map the species' distribution to the 50-fathom depth contour and to obtain population structure, length-weight, relative abundance data and bycatch information. Work included a stratified random survey of the three PSP management zones where fishing is currently allowed (225 stations), a systematic survey of the main known beds between Cross Island and Petit Manan Island (46 stations), and a descriptive survey of an historically fished area in Passamaquoddy Bay (23 stations). Six permanent stations were also established to track temporal trends. Samples of shell were collected for later age and growth analyses. Few small patches of quahogs were discovered at random stations beyond known historically fished areas, but juvenile animals (<20 mm) found at some previously fished sites indicated at least some recent recruitment. The GOM population was characterized by younger/ potentially slower growing clams compared to populations found in commercially fished beds off southern Massachusetts and the Mid-Atlantic. Shell length of clams ranged from 10.17 mm to 77.8 mm with a mean of 46.3mm for the random survey. The overall meat weight to shell length relationship for clams over this size range was: $MW = 4.97x10^{-6}xSL^{3.5696}$. Average meat yield was 17.5%. The preliminary estimate of relative abundance for the currently fished bed was 1,288,564 "Maine" bushels (1 Maine bushel = 35.25 L). This number is not corrected for dredge efficiency, which is believed to be low for the dry dredge used in these surveys. Due to resource and habitat patchiness, standard errors for survey relative abundance estimates are wide. Parameter estimates and the distribution map obtained from this research will allow future surveys to be optimized. A dredge-efficiency study could not be accomplished in the days at sea allotted for this survey. Although such a study is complicated by the depths, currents, and often heterogenous bottom-types encountered over quahog beds in the Gulf of Maine, it will be needed before an absolute biomass for the resource can be calculated. Results of this survey and a literature review of key biological parameters associated with *A. islandica* demonstrate a substantial degree of variability depending on locality and environment. This points to the need for continued research on the Gulf of Maine population.

Introduction

Biology

The ocean quahog (*Arctica islandica*) is widely distributed on both sides of the Atlantic at depths from 30 to 800 feet, in sand and mud/sand sediments, where summer bottom temperatures remain below 20°C (NOAA/NMFS, 1999). In the western Atlantic, *A. islandica* is found from St. George's Bay, Newfoundland to north of Cape Hatteras. South of Cape Cod, beds occur progressively further offshore. Sexes are separate and the larval period may last up to 60 days (Landers, 1973). It is an extremely long lived bivalve and estimated natural mortality rates are low (Z = 0.04, Weinberg, 1993) though imprecisely known. Ropes (1984) reported a maximum documented age of 225 years based on internal shell growth lines with 100-year-old individuals commonly encountered on federal survey cruises in the Mid-Atlantic.

Growth rates of young animals are variable. Reports on the mean age of quahogs at 50 mm shell length range from 12 years (Kennish et al. 1994) to 30 years (Kraus et al., 1992) depending on environment, although more rapid growth rates have been obtained in the lab (Krauss et al. 1992). Growth rates of larger animals are very low. Maximum size is reached at approximately 140 mm (Ropes, 1985). Age and size at maturity is delayed in *A. islandica*, varies with location, and differs between males and females (Thompson et al., 1980, Ropes et al. 1984). This species also displays sporadic recruitment although it has not been determined whether this is due to a lack of larval supply or post-set mortality (MAFMC, 2000).

Fishery

Two distinct fisheries exist for ocean quahogs in the U.S. The larger fishery (4.5 million bushels in 2001) occurs mainly in the EEZ off southern New England and the mid-Atlantic Bight. It utilizes large vessels operating in offshore waters. Primarily large clams are harvested using hydraulic dredges (Figure 1). Quahogs are stored and offloaded via cranes in large 32-bushel metal cages and are processed into products such as clam chowder and minced clams. This fishery has been managed by the Mid-Atlantic Management Council's surf clam / ocean quahog FMP since 1976. In 1988 an ITQ system was implemented with Amendment 8 (MAFMC 1988).

The Maine fishery is pursued on a relatively small portion of bottom north of the 43 degree 50 minute latitude line. Most fishing activity occurs between Mt. Desert Rock and Cross Island. The animals harvested are smaller (1.5 to 2.5 inches) compared to (3.5 –5.5 inches) in the industrial fishery, and sold primarily to a half-shell market as a less expensive substitute for *Mercenaria mercenaria*. Ocean quahogs are known as "mahogany clams" in Maine after the golden brown color characteristic of the periostracum of these younger clams. Older quahogs have a black periostracum. Boats 35-45 feet in length use "dry" dredges, limited by regulation to a cutter bar width of 36", to harvest these smaller clams. Although a relatively small number of boats pursue the fishery year round, the market peaks on certain holidays (Memorial Day, July 4th, and Labor Day) during which time 30-40 vessels might fish to satisfy this demand.

The fishery originally occurred in Maine state waters, but began to expand into federal waters in the 1980's, in part because of paralytic shellfish poisoning (PSP) closures of several areas in state waters (see Chenoweth and Dennison, 1993, for a review of the fishery's development). Problems were created when this was discovered in 1990 because under the Magnuson-Stevens Fishery Management and Conservation Act, the MAFMC is obligated to manage a stock as a "unit throughout its range….to the extent practicable" and interrelated stocks "in close coordination". Management measures enacted for the federal fishery did not work well for the artisanal Maine fishery, so it was allowed to continue as an "experimental fishery" from 1990 to 1997. In 1998, the Maine fishery was fully integrated into the surfclam / ocean quahog FMP with approval of Amendment 10, and an initial maximum quota allocation of 100,000 bushels was granted. Annual quota, currently set yearly, may range between 17,000 and 100,000 bushels. This quota was based on historical landings since no stock assessment information was available for the Maine resource. Amendment 10 also restricted harvest to areas certified to be free of PSP and established an entry moratorium to the Maine EEZ zone.

Catch rates in the Maine fishery were relatively stable until the mid 1990's (Figure 2). With developing markets in recent years, landings have increased from 38,000 bushels in 1995 to over 97,000 bushels in 1999. Additional quota can be obtained by purchasing ITQ shares from mid-Atlantic fishermen. This occurred in 2000 when over 120,000 bushels were harvested from the Maine zone.

The only survey information for the eastern Gulf of Maine quahog stock was from a limited number of non-random samples collected on NMFS surf clam / ocean quahog cruises in 1992 and 1994. A number of considerations outlined above point to the importance of gaining more information on this resource: 1) The low natural mortality rates, delayed maturity, slow growth, and variable recruitment displayed by this species would make recovery difficult if over-exploitation occurred, 2) Variability in key biological parameters governing the population dynamics of *A. islandica* points to the need for local stock information and a better understanding of environmental effects on these processes, 3) optimal cost-effective sampling strategies must be developed to better estimate the abundance of ocean quahogs in the Gulf of Maine area and to establish a biologically sustainable quota for this zone, and 4) based on trends in recent landings there may be an industry need for more quota allocation in this area if future biomass estimates show that increased harvest can be sustainable.

In response to these needs, a pilot survey of the ocean quahog resource in eastern Maine was initiated in the spring of 2001 to develop assessment methodologies.

Methods

The objective of this work was to determine the relative abundance, distribution, size composition, and associated bycatch of the ocean quahog resource in the open fishing areas of eastern Maine. Three zones have been established for PSP monitoring purposes (Figure 3). From West to East, Zone 1 is bounded by a line running from the

Figure 1. Boat and gear typical of the larger scale ocean quahog fishery in Southern New England and the Mid-Atlantic. (From Murawski and Serchuk, 1989).

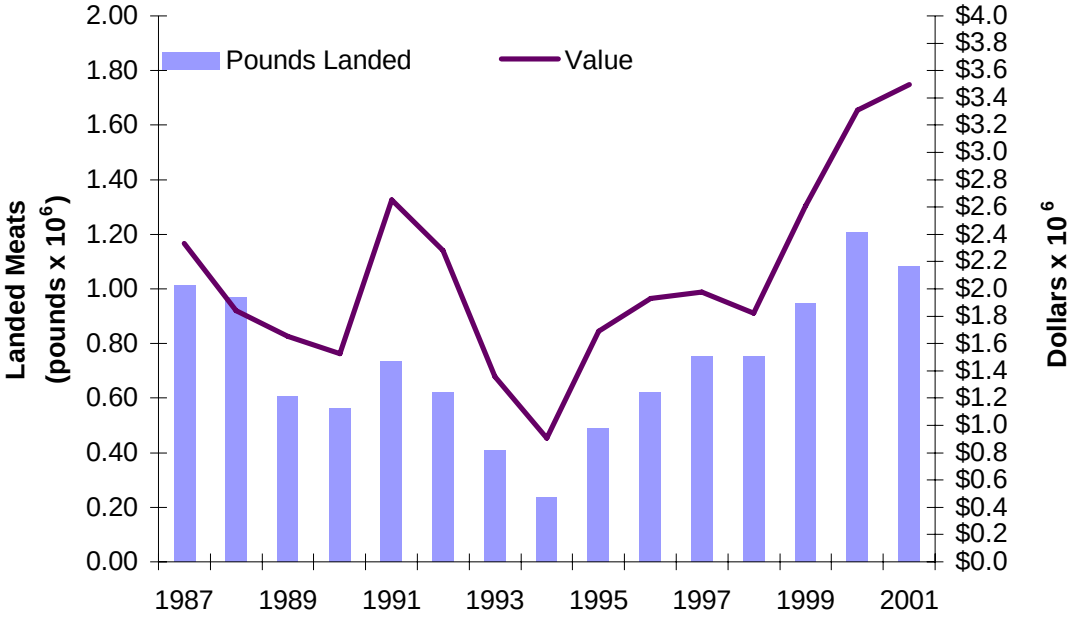

Figure 2. Ocean quahog landings and value in Maine 1984 –2001.

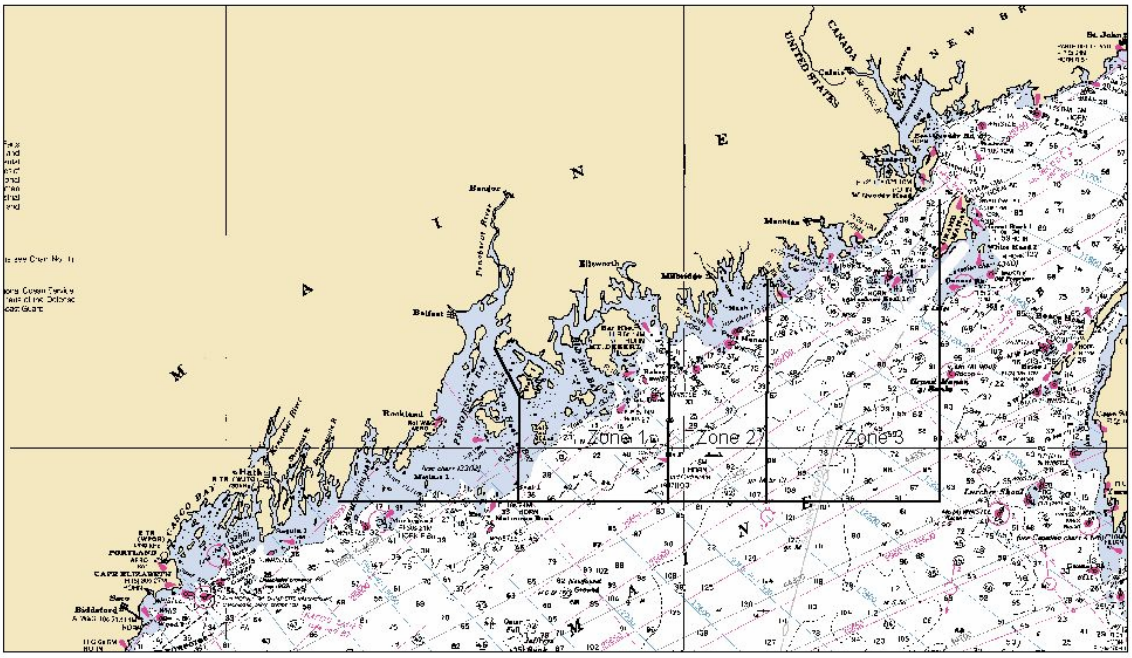

Figure 3. Overview of the three PSP management zones in the Gulf of Maine.

Western-most shore of Cape Rosier then southeast of the western-most shore of Deer Isle and then due south. The line between zones one and two runs due south from the tip of Schoodic point. Zones two and three are separated by a line due South from Beals Island. Zone three is bounded in the east by a line running due south from Eastern Head. By rule, the zones extend south to the 43 degree 50 minute latitude, but in practice boats rarely travel beyond 10 – 15 miles from shore. Because costs associated with PSP sampling preclude sampling the entire Maine coast, fishing activity is restricted to these harvest areas.

Ocean quahogs are known to extend beyond this range. Beds occurring in Southern Maine waters off Saco, Biddeford, and Ogunquit were documented by the Maine Fisheries Laboratory in 1976 (Card, 1976), but these concentrations consist mainly of larger animals unsuitable for the half shell market. Exploratory surveys outside of the harvest zones may be carried out in the future, but funding constraints limited the survey work to 12 days at sea. Thus, surveyed areas were similarly restricted to these three zones between depths of 10 and 100 meters - comprising an area of approximately 1325 nautical miles^2.

The primary fishing grounds straddle state and federal waters from the east side of Petit Manan Island to Cross Island south of Machias Bay. The usual first step of developing a direct survey is a complete understanding of the distribution of the target species. It is important that early surveys extend well beyond fished beds in order to gain a better understanding of distribution early on in a survey series (Hilborn and Walters, 1992). Suitable habitat for *A. islandica* in these zones is patchy and many areas are

unfishable. Harvester reports from the logbook database were plotted on GIS (Arcview 3.2) and fishermen interviewed to obtain information on actively and historically fished beds. It was difficult to use known fished areas as a stratifying variable in the survey because of scattered reports off the main beds, a lack of fishing effort data by location at the time the survey was planned, and insufficient knowledge on population densities likely to be encountered in more remote areas of the zones. A better map of quahog distribution was needed and we implemented a two-pronged approach to the work with the expectation that in future surveys strata boundaries and sampling effort would be refined.

Nine days at sea were used to perform the main survey of all three zones. This survey utilized a stratified random design using the PSP management zones (for administrative convenience) and depth as stratifying variables. In order to better map major known beds and to more intensively sample the main fished area, a second systematic survey of beds between Petit Manan and just east of Cross Island was carried out. Lastly, we conducted a separate haphazard survey of a small area in Passamaquoddy Bay and nearby Treat Island where quahogs were historically fished.

Random survey

The three PSP management areas and depth zones (10-40 m, 40-70 m, and 70-100 m) were plotted on a map of the Maine coast using ArcView 3.2 GIS software. Strata consisted of each depth zone divided north and south by the management area boundaries (nine strata total; Figure 4). Potential sampling plots consisted of a 500 m grid plotted over this view. The sampling grid size was chosen based on a tow length ranging from 100-200 meters. It was anticipated that tow direction could not be randomized due to fishing constraints caused by tidal currents, but a tow in any direction from roughly the center of a 500 m grid would stay within the bounds of the sample plot while also coming close to sampling the edges of the plot. An attempt was made to eliminate grid quadrats that were likely unfishable by overlaying a GIS-based bottom-type theme (compiled by Kelly et al., 1998). Based on plotted harvest locations that corresponded with areas designated as “rock” by this theme, data inadequacies cited by the authors, and a lack of coverage in regions of potential quahog habitat, it was deemed not to be reliable enough to be used to refine the survey grid.

Plot numbers were assigned to each square in the grid. Grid numbers corresponding to the area covered by each individual stratum were exported as separate columns into Systat. The total number of sampling stations (originally 255) was determined by the logistics of the survey. Funding was in place for a total of 12 survey days. It was desired to spend several days for ancillary studies (see below) and an estimated 25 tows per day could be completed considering steaming time between stations. Allocation of sampling effort was based on assigning an equal number of stations between each zone. Since zone one contained the largest overall area (586 nm^2 to the 50 fathom line) this had the effect of increasing the relative number of samples (per area) in zones two (328 nm^2 area) and three (411 nm^2) to some degree. This was desired since most of the recent fishing activity had occurred in zones two and three. For each depth strata within these zones sampling effort was assigned proportionally to the relative area each depth contributed to individual zones. Sample stations were selected randomly,

without replacement, within each stratum using Systat. Center points of these sample grids were plotted in ArcView and the coordinates of these points tabulated and exported into The Cap'n navigation software, which was used on board the survey vessel.

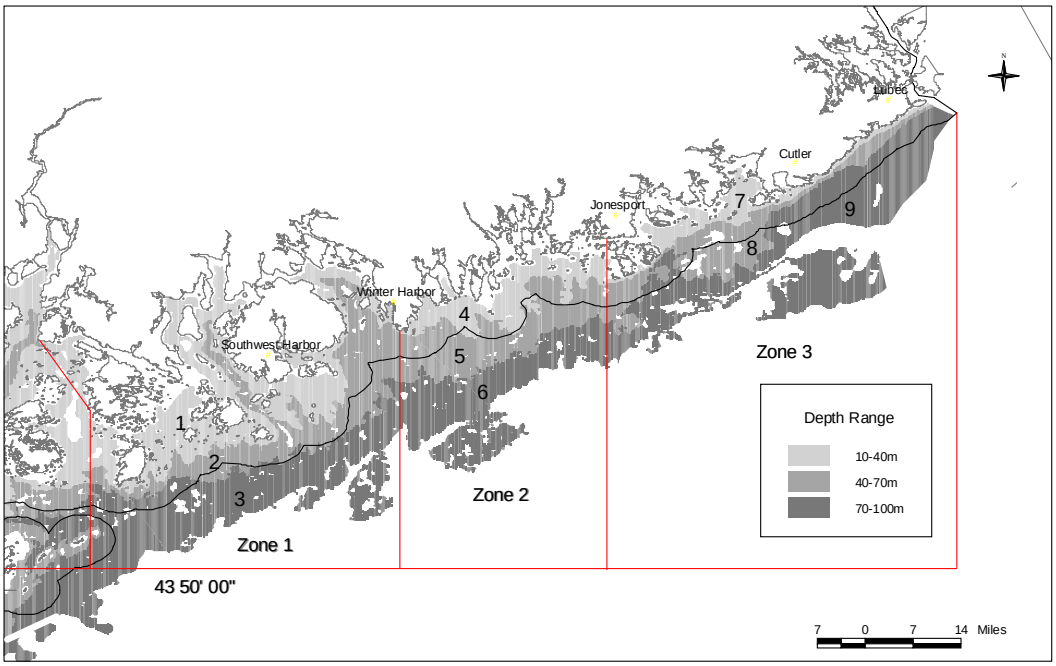

Figure 4. Strata designated for the main survey corresponding to each depth zone within separate PSP management zones (nine total). Ports in aHarbor, Winter Harbor Jonesport, Cutler, and Lubec were used in the survey.

Systematic survey

The sampling frame for the systematic survey of the main fished beds was established by plotting reported harvest locations, obtained from data in the Federal logbook database for the years 1995, 1997-1999, and 2001-2002, in ArcView. A minute square grid was overlaid over all of these locations in ArcView. Minute squares occurring within one nautical mile of any reported harvest location were selected. Potential sample squares not contained within the area between Cross Island and Petit Manan were eliminated. Sampling stations (47) were assigned in a grid pattern with one occurring every 2 nm in every direction over the bounds of the defined area. The number of sampling stations was again based on the two days at sea available to complete this work.

Descriptive survey

A number of sampling stations were also designated in general areas of interest. Five of these stations were assigned throughout the main and systematic surveys. One survey day was spent in an area of interest outside of the main areas, in the St. Croix

River on the U.S side of Passamaquoddy Bay, and Treat Island near Lubec. In the St. Croix, two transects in a historically fished area were chosen to sample. Stations were located at approximately 0.5 nm intervals. Four haphazardly selected stations near Treat Island were also sampled.

Survey gear

The sampling gear was a standard Maine dry dredge lined with lobster wire with an effective ¾" square mesh size (Figure 5). The Maine dry dredge resembles an iron cage on skis. The cutter bar measured 36" (0.91 m). Teeth spacing was 1 ¼" and they were set to a depth of 4 ½". All work was completed from the *F/V Whitney and Ashley* (36 feet; 320 HP). The bottom was surveyed at each station using the boat's sounder to determine if it was fishable. If the site was not fishable an area of approximately 0.3 nm was searched for suitable bottom. If fishable bottom was not found in this area, a notation was made and the boat continued on to the next site.

Tow duration was 2 minutes at approximately 2.5 knots. Average tow length was approximately 150 meters. The tow wire was marked off incrementally and wire out to depth was kept at a constant 3:1 ratio. After towing, dredge contents were washed out by steaming with the dredge at the surface until the wash trail ran clear. The dredge was dumped into a shallow plywood box on deck. For areas with extremely high catches containing a lot of shell, the catch was split by mixing and leveling the contents of the plywood dumping platform and then dividing the pile in half once or twice using 2x4 guides which could be inserted into the middle of each side of the platform.

A digital picture was taken of the dredge contents with the date and time imprinted. Live quahogs and bycatch were separated out. Bycatch species were noted and either enumerated or assigned a categorical abundance (1-3) corresponding to 'present', 'common', or 'abundant'. For small animals (such as astarte clams., the northern cardita, and brittle stars) these categories corresponded to less than approximately 10 animals, 10 – 50 animals, and > 50 animals per tow respectively. For other species (crabs, scallops, starfish), 'present' represented 1-2 animals, 'common' 3-4, and abundant >4. The amount of quahog shell present was also noted. Volume and weight of the entire catch of live quahogs was recorded. The entire catch or a 5-L subsample was measured for shell length (the maximum size of the shell), height (the dimension from the umbo to the maximum distance to the outer edge), and depth (the maximum distance from the outer surfaces of the left and right valves). Any shell damage was also noted. Another subsample consisting of a haphazard selection of clams representative of the entire size range of the catch was bagged and kept cool. Quahogs were shucked on shore and whole, meat, and shell weight determined. The bottom type was recorded based on the dredge contents in combination with sounder information.

Data collection

A Juniper Systems Allegro hand-held computer running on DOS was used for data collection. A data entry program was configured using Data-Plus Professional software. Six different data screens were set up to collect: trip information (date, port,

time out and in, weather and sea state), station information (station number, tow position and time, depth, speed, and bottom type), catch (volume, weight, number of animals, and

Figure 5. The Maine dry dredge – gear used in the survey with lined cage.

sample proportion), bycatch (species and abundance), length frequency (shell height, length, and depth), and weight information (individual whole, shell, meat weight, and shell length, height, and depth). A Garmin Map76 WAAS enabled hand-held GPS with a "Mighty-Mouse II" GPS active antennae fed NEMA time and position data into the Allegro via an RS232 connection. Accuracy of this GPS is within 10 m 95% of the time. Position coordinates were entered on dredge deployment, at the start of the tow, at the start of haul-back, and at the end of haul back when the dredge cable went vertical. Tows were also plotted, using the Cap'n software, on a separate PC laptop connected to the vessel's GPS receiver. As a back up, position data were also entered as 'waypoints' directly on the Garmin unit. An Onset temperature logger was mounted on the dredge to record bottom temperature.

Shell length, height, and depth were recorded, to the nearest 0.01 mm, using Fowler Mark IV digital calipers with RS232 output to the Allegro computer. Quahog catch was weighed on a spring scale to the nearest 0.1 kg and the volume determined to the nearest 0.1 L in a graduated bucket. Individual clams were bagged, labeled, and brought back to the Boothbay Harbor lab to weigh. Clams were measured as above and whole, shell, and meat weight determined on an Ohaus Navigator balance, also with RS232 output to the Allegro computer. A small number of gonad smears were examined

microscopically to assess maturity. Shells of shucked clams were washed, labeled with the station number and date, and archived for later growth and age analyses.

Data analyses

Systat and Excel were used for data analyses. Tow length was taken as the distance between the vessel's position when actual towing of the dredge began and the vessel's position at the start of haul back. Catches were standardized to an average tow length of 150 m (137.1 m^2 area coverage). For each stratum, the mean of catch number divided by catch volume and weighted by each sample's relative contribution to the total standardized catch of the stratum was calculated and multiplied by 35.25 L (volume of a standard 'Maine' bushel). This provided a conversion factor to convert relative abundance estimates to volume in bushels. Standardized catches at each sample station were plotted in ArcView 3.2 to examine the spatial distribution of the resource. The finite population correction factor was ignored in the relative biomass calculations since the proportion of area sampled was a very small fraction of the total area of each stratum. These abundance estimates were not corrected for dredge efficiency as no studies have been done to obtain a value. Bootstrap estimates of standard errors and confidence intervals were computed for the systematic survey (Efron and Tibshirani, 1998). Results were examined to determine if strata should be refined for future surveys. Optimal allocation of sampling effort for future surveys was determined assuming fixed sampling costs for all stations (Neyman allocation). A spreadsheet of stratum sizes, means, and variances was set up and Excel's "Goal seeker" tool used to determine optimal allocation and total number of samples needed for 90% and 95% confidence intervals with an accuracy between 10% and 25% of the relative biomass estimate.

Length frequencies for each strata and the overall survey weighted by their respective contribution to the total standardized catch are presented. The length-weight relationship for survey data is presented. Parameter estimates were obtained by plotting meat weight as a function of shell length and fitting a power equation trend line to the data. This equation was then optimized iteratively using Solver in Excel to minimize the sum of squares. Meat yield was calculated as the mean of individual meat weights divided by whole wet weight.

Results

Overview of resource distribution and abundance estimates

Main survey

Stations for the survey of all three management zones were completed over nine days from May 10 to June 12, 2002. From 19% to 92% of assigned stations in each stratum were fishable (Table 1). Only one station in stratum one (PSP zone 1 in depths from 10 – 40 m) could be sampled due to unfishable bottom or an abundance of lobster gear in the area (particularly Frenchman and Blue Hill Bays) so the stratum was dropped. Of the 226 remaining stations, 68% or 154 were fishable overall. Of these, 30.5% (47

stations) contained quahogs. While the greatest number of stations where quahogs were present was in the 71-110 m depth range, the proportion of stations where quahogs were present to the number of fishable stations in each strata showed no obvious trend with depth. However, not unexpectedly, the stations with the highest catches were all located at depths greater than 40 m. Catches ranged from 0 – 771 animals per standardized tow. The frequencies of catch ranges for individual strata and overall are presented in Figure 6.

Distribution of quahogs and catches showed patchiness (Figure 7). The largest catches were in the main fished beds in zones 2 and 3 between Cross Island and Petit Manan Island. Most large catches were between 41 and 100+ meters and this 'swath' in quahog distribution seemed to continue at these depths southwest to the border between zones 1 and 2. However, abundances tapered off here and catches in this area southwest of Petit Manan were relatively small. Survey catches in the shallowest depth zone were restricted to Machias Bay and areas around Libby Island. Quahogs were caught at only two stations in zone 1. While areas around Isle au Haut were fished in the past, beds are known to be small and patchily distributed in this area (K. Porter, personal communication). Twelve sites in zone 1 did contain old quahog shell indicating that quahogs were more widely distributed in this area many years ago. There were a few scattered patches of quahogs discovered away from the main fished areas, but no 'new' beds with great abundances found.

Relative abundance estimates are presented in Table 1. A total of 7.13E+08 (+/- 1.78E+08 SE) individuals or 776,442 (+/- 214,495 SE) "Maine" bushels were estimated for the entire area. As described above, most of the population was contained in stratums 5, 6 and 9 (zones 2 and 3 at depths 41-100+m).

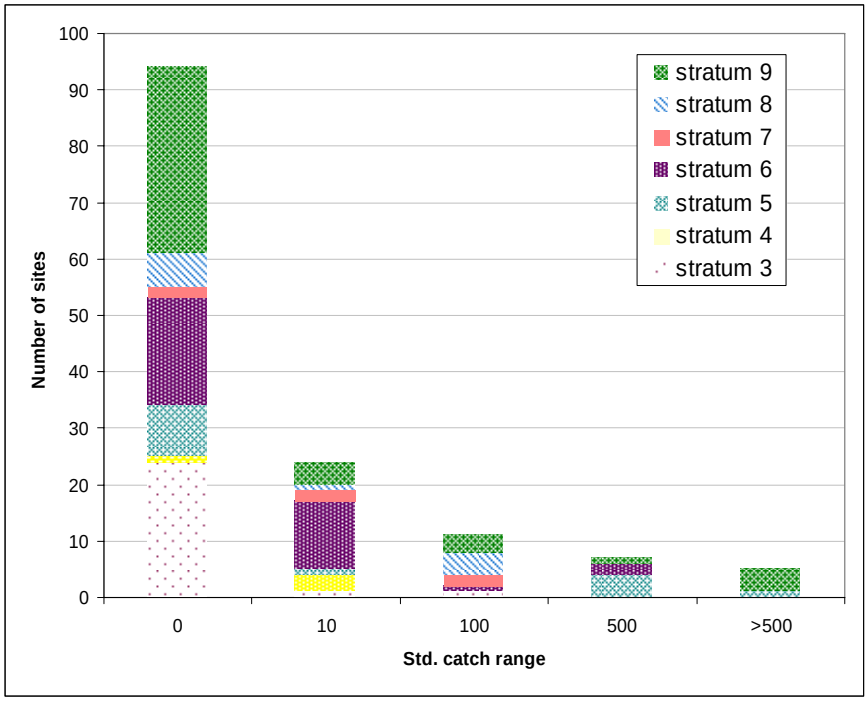

Figure 6. Frequency of standardized catch ranges in the stratified random survey.

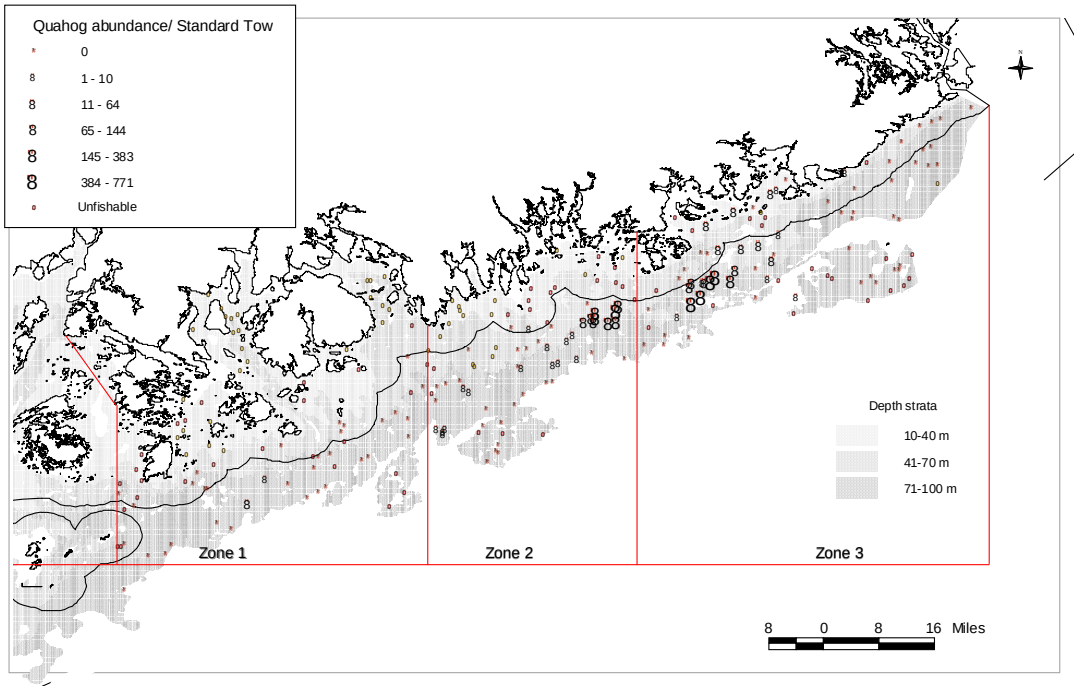

Figure 7. Quahog abundance (standardized catch) and unfishable sites for the random stratified survey.

Systematic survey

Sites in the systematic survey of the main beds were completed in two days on July 10 and 11, 2002. Standardized catch rates ranged from 0 to 2113 animals per tow with a mean of 226.3 (Figures 8 and 9). Out of the 46 assigned stations, 41were fishable and quahogs were present at 29 of the sites (71% of the total fishable sites). Relative quahog abundance was estimated at 1.13E+09 (+/- 3.4E+08 SE) or 1288533 (+/- 389,971 SE) "Maine" bushels (Table 1b). These standard error estimates assume a random assignment of stations, and this assumption may not be valid given the systematic design of the survey. However, the systematic grid did help to better establish the outline of the main beds (Figure 8). The largest catches corresponded roughly with reported harvest locations, but there were scattered pockets throughout the area. The population didn't extend all the way to the 50-fathom line and the area due South of Great Wass Island was largely unfishable.

Several permanent stations were also located in current and historically heavily fished areas (Figure 10).

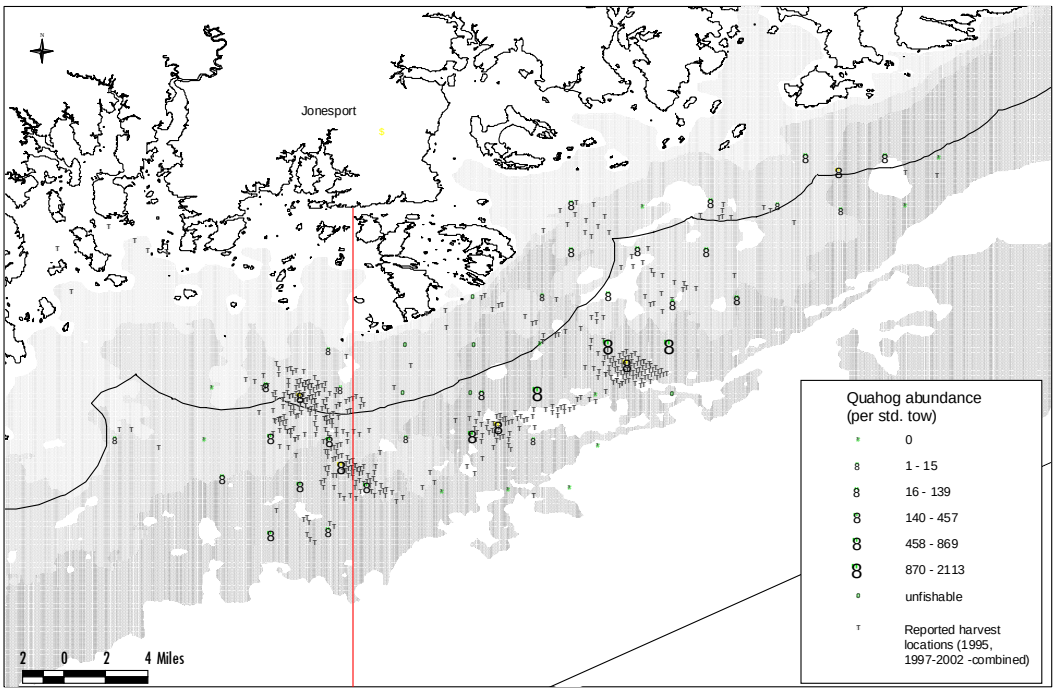

Figure 8. Standardized catch data from the systematic survey of fished beds, and 1995 and 1997-2002 reported harvest locations. Light colored circles are 'permanent stations' not part of the systematic grid.

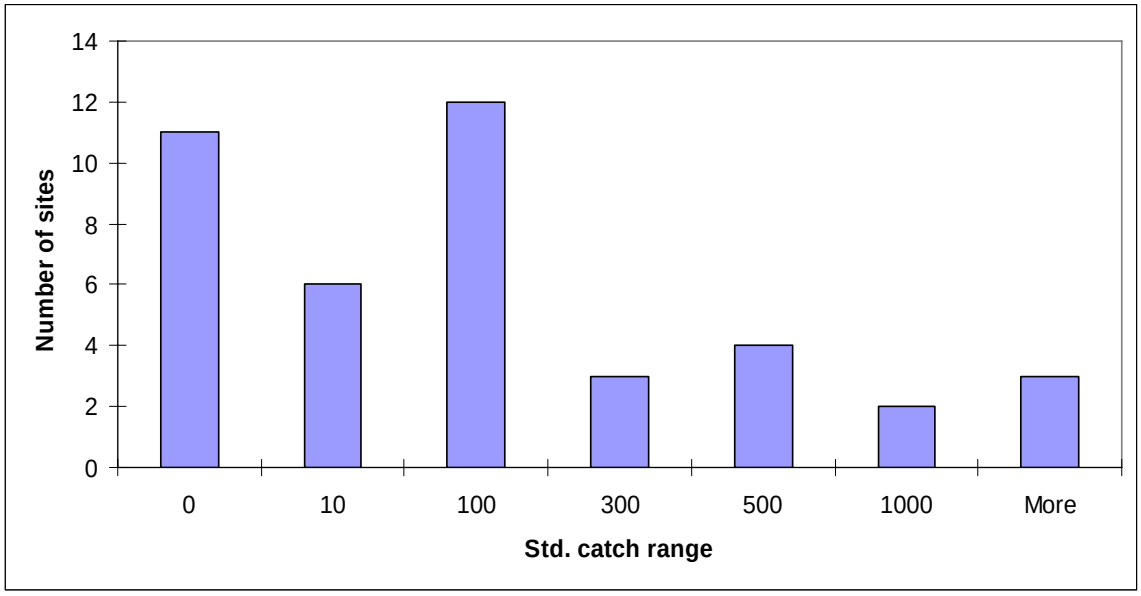

Figure 9. Frequency of standardized catch ranges in the systematic survey of major fished beds.

Table 1. A) top - Relative biomass estimates for the random stratified survey. B) bottom - relative biomass estimates for the systematic survey of main fished beds.

A)

Strata	Zone	Depth (m)	Area (NM)	Stations assigned (#)	Stations fishable (#)	Fishable Bottom (%)	Fishable Area (NM^2)	Total Possible Tows	Mean no. per std tow	Std. Error	Stratum Total (# animals)	Stratum Std. Error (# animals)	Bushel Conversion (#/ bushel)**	Stratum Total (# bushels)	Stratum Std. Error (# bushels)
1	1	10-40	208.2	30	1	3%	6.9	173566.3	0*						
2	1	41-70	123.1	18	6	33%	41.0	1026378	0.00						
3	1	71-100+	254.3	37	26	70%	178.7	4468160	2.58	2.45	11506328	10931718	891	12907	12263
subtotal			*585.6*	*85*	*33*	*39%*	*226.7*				*11506328*		*891*	*12907*	*12263*
4	2	10-40	82.1	21	4	19%	15.6	391001	0.74	0.25	288011	96127	1000	288	96
5	2	41-70	98.1	26	20	76%	74.6	1864503	117.35	42.71	218803562	79629805	1301	168217	61220
6	2	71-100+	148.2	38	35	92%	136.5	3412475	23.74	11.76	81015247	40147402	1382	58630	29054
subtotal			*328.4*	*85*	*59*	*69%*	*226.7*				*300106820*			*227135*	
7	2	10-40	54.1	11	6	55%	29.5	737353.4	8.66	4.23	6388276	3121363	578	6388	5399
8	2	41-70	71.1	15	11	73%	52.1	1303416	9.18	4.19	11971352	5456845	474	25250	11510
9	2	71-100+	286.3	59	46	77%	219.5	5489035	69.69	27.99	382546236	153652391	758	504762	202741
subtotal			*411.4*	*85*	*63*	*74%*	*301.1*				*400905864*			*536400*	
Total*			***1117.2***	***225***	***154***	***68%***	***759.7***				***712519012***	***178103365***		***776442***	***214495***

* strata dropped ** - Maine bushel (35.25 L)

B)

	Depth (m)	Area (NM)	Stations assigned (#)	Stations fishable (#)	Fishable Bottom (%)	Fishable Area (NM^2)	Total Possible Tows	Mean no. per std tow ***	Std. Error	Stratum Total (# animals)	Stratum Std. Error (# animals)	Bushel Conversion (#/ bushel)**	Stratum Total (# bushels)	Stratum Std. Error (# bushels)
Systematic fished area		**225**	**46**	**41**	**89%**	**200.5**	**5020326**	**226.30**	**68.49**	**1136099737**	**343837096**	**882**	**1288533**	**389971**

Std. Tow area = 137.16 m^2

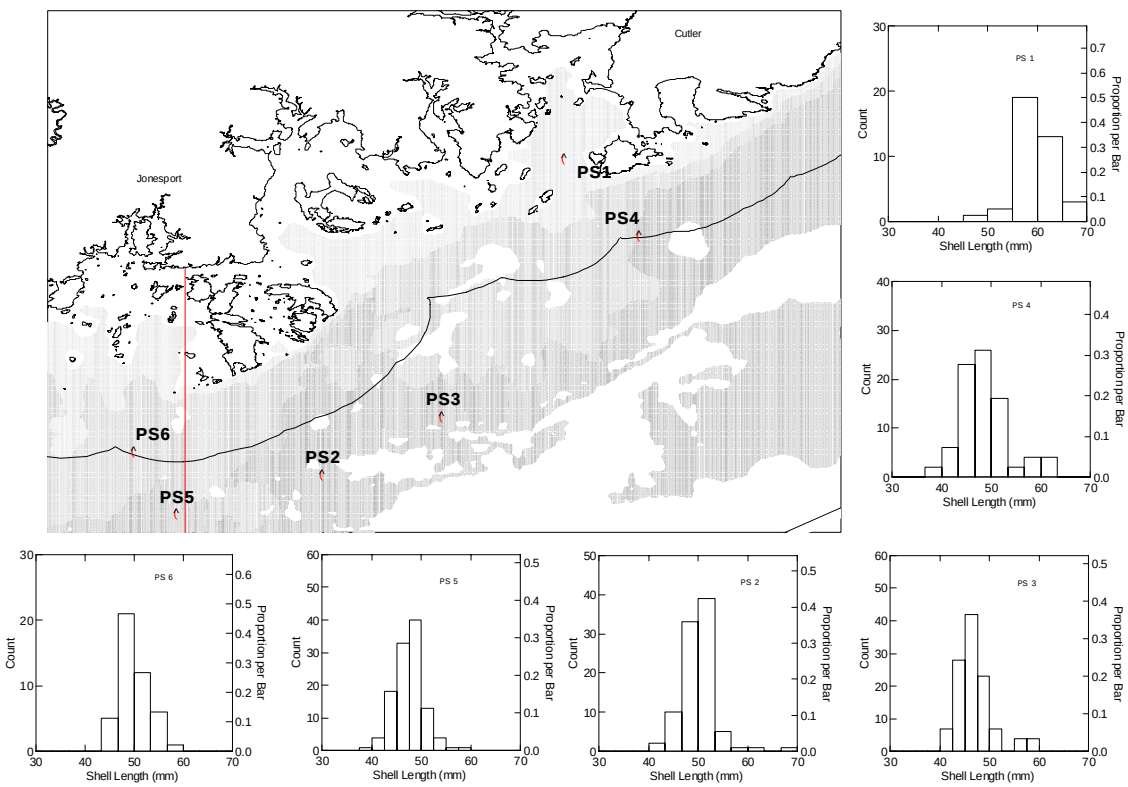

Figure 10. Permanent station locations and their respective length frequency histograms showing local variability in quahog size.

St. Croix and Treat Island

On July 3, 2002 we surveyed areas in Passamaquoddy Bay and by Treat Island in general locations reported to be fished a number of years ago. Standardized catches were smaller compared to those of the main fished beds between Cross Island and Great Wass Islands - ranging from 0 – 121 quahogs per tow. Average catch was 17 clams/ tow overall or 32.1 over stations where quahogs were present (10 of 19 stations). The main concentration of animals in the St. Croix was in a small area close to the U.S./ Canada boundary in 16 – 25 fathoms of water. Catches dropped off at shallower depths near shore (Figure 11). Stations were located at roughly 0.5 nm intervals, but no attempt was made to compute a relative abundance for this area. Three of the four haphazard stations located near Treat Island contained catches from 39 – 121 clams. These were located in shallower water of 11-14 fathoms. Individual station data are appended for all sites.

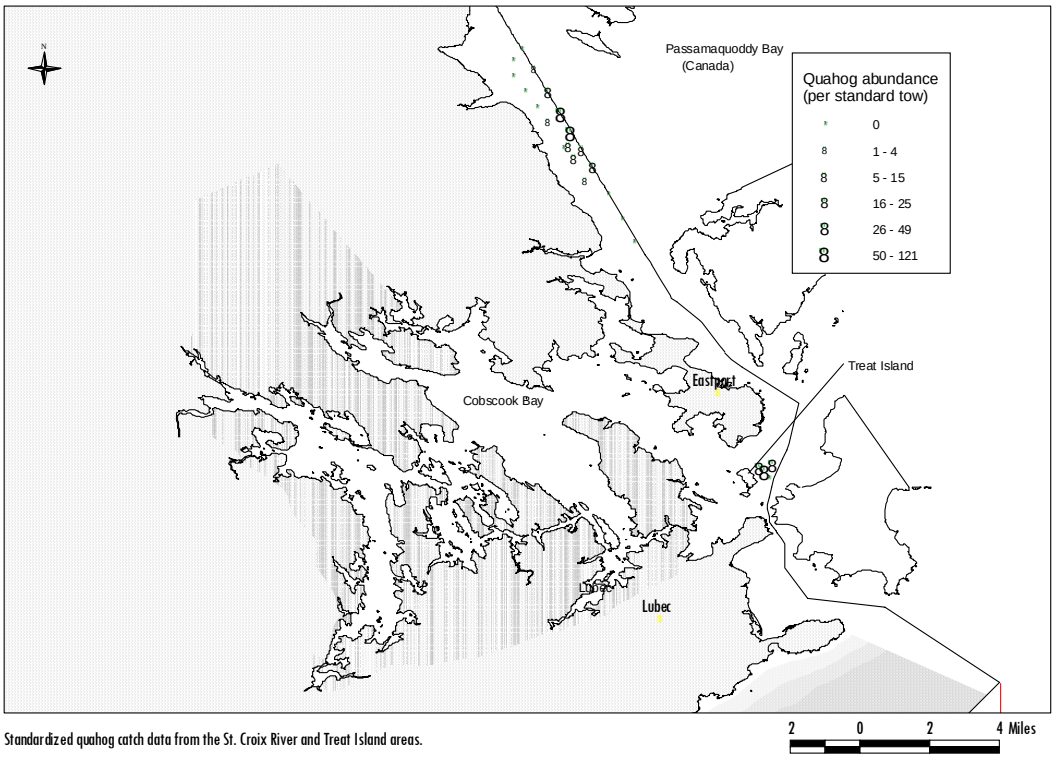

Figure 11. Standardized catch data from the St. Croix and Treat Island areas.

Bycatch and observations

Bycatch at survey stations where quahogs were present was generally low. Typical dredge contents from stations located in fished areas are shown in Figure 12. Data compiled from the systematic survey is presented in Table 2. This area is most

representative of bycatch likely to be encountered in the commercial fishery. Data is split arbitrarily into three categories by quahog abundance (sites with a standard catch of 1-10, 11-100, and greater than 100 quahogs) to indicate bycatch associated with high abundance areas likely to be fished as well as the entire range of species encountered

Figure 12. Typical catch in fished areas. Note the abundance of new and old quahog shell mixed in with live quahogs. Sea stars and Astarte spp. were most prevalent as bycatch in this tow.

where any quahogs are present in this area. The most commonly encountered animals were astartes (Astarte sp.) and the Northern Cardita (*Venercardia borealis*). These small bivalves were nearly omnipresent at stations containing quahogs and where quahog shell was present. Given their small size and the selectivity of the survey dredge, actual abundance of these species is presumed to be very high. Rock crabs (*Cancer irroratus*) were also commonly encountered, followed by several species of sea stars. Sea scallops were also occasionally present in dredge contents. Only one lobster appeared in the bycatch, and sponges were present at one station where quahogs were abundant. Other species encountered included the Ten-ridged whelk (*Neptunea lyrata decemcostata*), and hermit (*Pagarus* sp.) and Jonah crabs (*Cancer borealis*). One monkfish (*Lophius americanus*) was found, and anemones were sometimes associated with rocky areas.

Areas with the largest quahog catches were generally over mud and mud/fine sand bottom although quahogs were present on a wide variety of bottom types including rock/mud areas, areas with cobble, and on shell hash bottoms. Generally, non-target species were brought up in good condition and were released back into the water alive. Many sites also contained large amounts of quahog shell. This was especially true over

actively fished areas where an accumulation of shell has built up. Variable amounts of old (or ‘paleo-‘) quahog shell were also present. A number of sites where no live quahogs were found contained a fair amount of either old or more recent quahog shell. Quahog shells with drill holes were sometimes numerous – indicating a gastropod predator.

Table 2. Associated by-catch from the systematic survey of the main fished beds. Data are presented as the percent occurrence within each categiory of quahog abundance.

		Std. Catch = 1-10 quahogs			Std. Catch = 10-100 quahogs			Std. Catch = >100 quahogs		
Species Group	Species	Pres.	Com.	Abund.	Pres.	Com.	Abund.	Pres.	Com.	Abund.
Bivalves										
Astartes	*Astarte sp.*	44	33	22	50	50		6	29	29
Northern cardita	*Cyclocardia borealis*	33	33		10	50	10	29	29	6
Sea scallop	*Placopecten magellanicus*	11						18	6	
Whelks										
10 ridged whelk	*Neptunea lyrata decemcostata*	22								
Crustaceans										
Hermit crab	*Pagarus sp.*	11								
Rock crab	*Cancer irroratus*	33	22		10			12	24	6
Jonah crab	*Cancer borealis*	11								
Lobster	*Homarus americanus*							6		
Echinoderms										
Sun star	*Crossaster papposus*	11			10					
Common star	*Asterias forbesi*							6		
Brittle star	*Micropholis (=Amphiodia) atra**							6	6	
Northern star	*Asterias vulgaris*									6
Fish										
Monkfish	*Lophius americanus*				10					
Other										
Sponge	*Polymastia robusta* or *Isodictya palmata*	11			10	10		6		
Anenome	Species not identified	11								
Trash										
	Quahog shell	44	22		60	20	10	6	53	12
	V. Old Quahog Shell			22	10	10	10			6
	Scallop Shell -old					20				
	Shell Hash	33	11							
	Rocks							6		
	Cobble		22	11		10				
Total sites		9			10			17		

* = tentative ID

The area sampled in the St. Croix river and Treat Island showed a slightly different bycatch composition. Here animals present in sample tows included mud stars (*Ctenodiscus cripatus*), rat-tailed sea cucumbers (*Caudina arenata*), the sea mouse (*Aphrodita hastate*), the false quahog (*Pitar morrhuanus*), two species of sponge (probably *Polymastia robusta* and *Isodictya palmate*), a flounder (*Pleuronectes americanus*), green sea urchins (*Strongylocentrotus droebachiensis*), and anemones. Despite the diversity encountered at this site, bycatch was still generally low. The Treat Island site, which was in more shallow water, had greater amounts of sea scallops and urchins.

Length frequencies and recruitment.

Shell length frequency histograms are presented in Figure 13 for each survey and Figure 14 for individual permanent stations. Mean sizes and standard deviations for individual tows are appended. Market size ranges from 1 ½ to 2 ½ inches (38.1 mm – 63.5 mm) although smaller animals are generally preferred (40-50 mm). A count of about 450 quahogs per 'bag' is desired by many dealers (K. Porter, personal communication). A bag is the container used to transport harvested animals and has a volume of 15 L. Mean shell length for the main survey was 47.1 mm (+/- 9.5 SD) and ranged from 15.9 mm to 70.6 mm. Mean size for the systematic survey was 50.3mm (+/- 12.7SD) with a range from 10.17 to 77.8 mm. St. Croix area quahogs measured 48.3 mm (+/- 12.2 SD) and ranged from 11.06 to 75.26 mm. This size distribution was bimodal with a secondary peak at approximately 30 mm and main peak at 52 mm. The percentage of smaller quahogs encountered at this site indicates relatively recent recruitment. Since the mesh size of the dredge was 19 mm square, there are likely many more quahogs in the 10 – 20 mm range here than appeared in the catch. Mean size for Treat Island quahogs was the largest of all the areas at 55.8 mm (+/- 7.5SD) with a minimum size of 36.0 mm and maximum of 64.7 mm.

The length frequency distributions for individual permanent stations in selected currently and historically fished areas demonstrate the spatial variability of quahog size distribution (Figure 10). This was also reflected in the variability in the number of individual clams per unit volume or weight at neighboring sites.

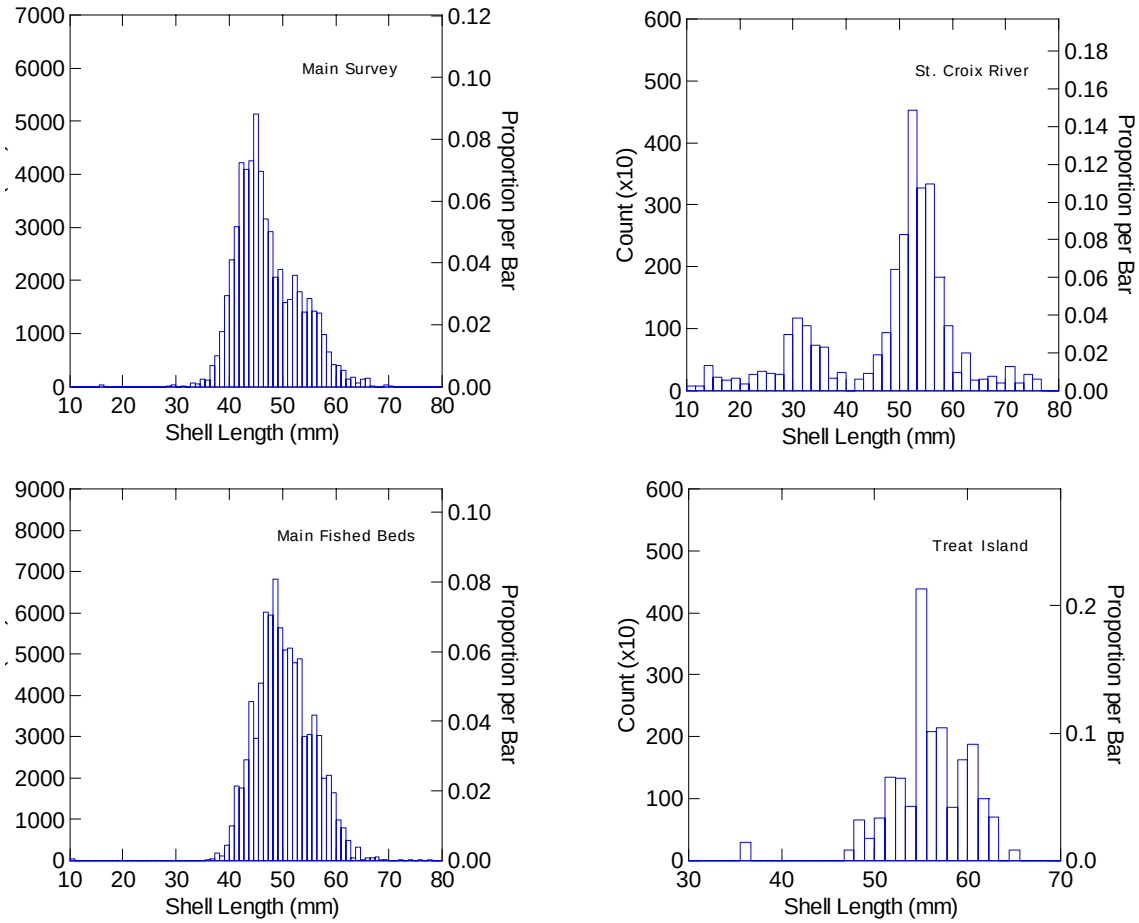

Figure 13. Length frequency histograms for the respective survey areas (expanded to standardized total catch).

Shell morphology

Shell height (SH) was related to shell length (SL) by the equation (SH = 0.9688SL – 1.8206; R^2 = 0.9838; Figure 14). More variability was apparent with the shell depth (SD) to length (SL) relationship (SL = 0.5811SD – 3.479; R^2 = 0.9096; Figure 15). The relationship held less for quahogs smaller than approximately 30 mm in shell height, although data in this size range was limited. From these data, quahogs appear to grow faster in length as compared to depth until a size of 30+ mm after which their shell depth increases at a proportionally faster, but variable, rate.

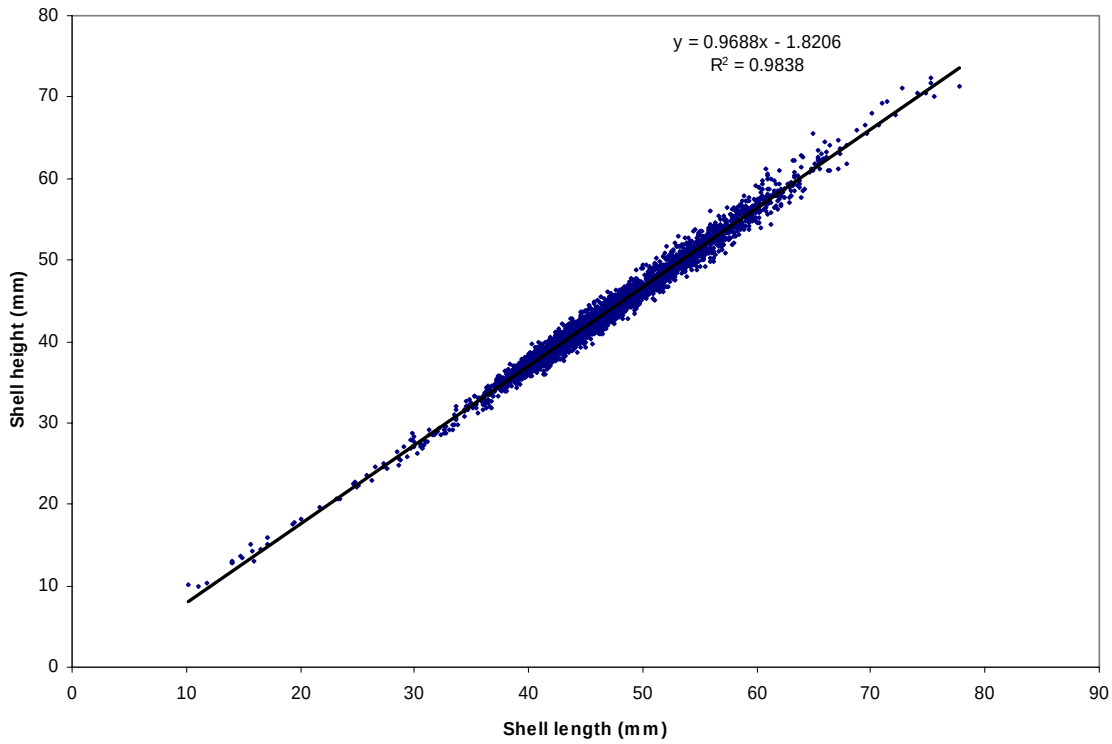

Figure 14. Shell height as a function of shell length (all data combined).

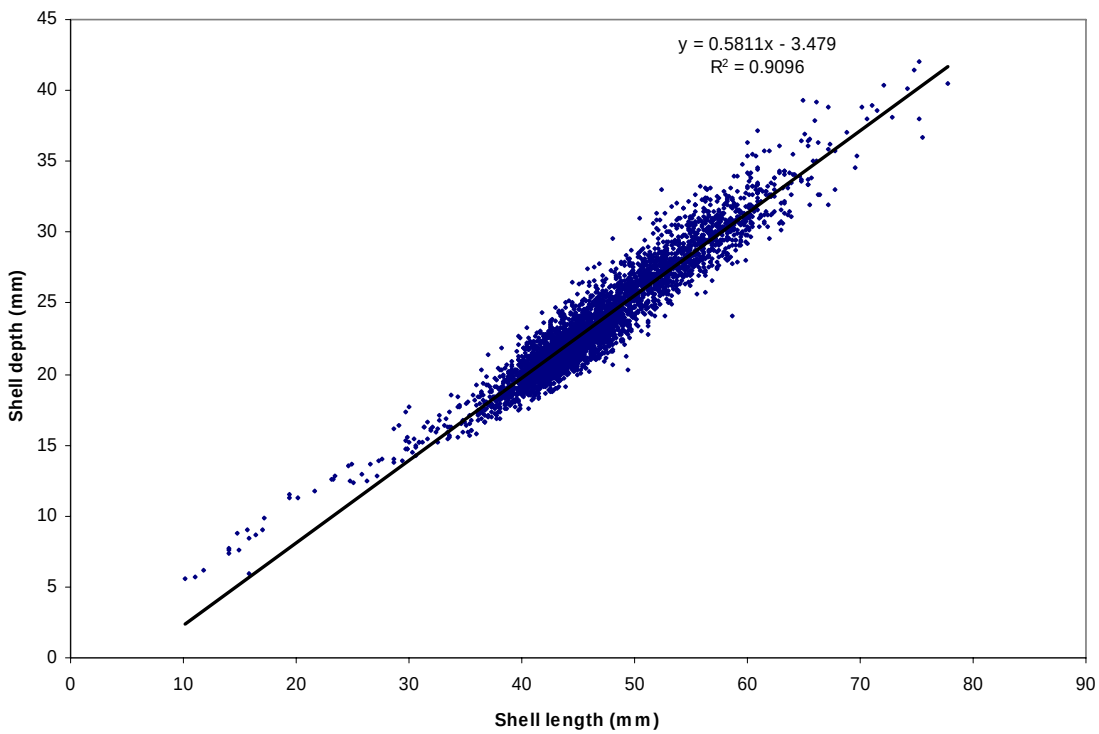

Figure 15. Shell depth as a function of shell length (all data combined).

Meat weight- yield and shell length meat weight relationship

The mean wet meat yield (for all samples) was 17.5% (+/-4.1%SD). This is comparable to Zettler et al.'s (2001) estimate of 18.3% for the Mecklenburg Bight, Baltic Sea and 18.4% for a population in St. Mary's Bay, Nova Scotia (Duggan et al., 1998) although slightly lower than that reported in other studies (23% for a Canadian population; Chiasson and Rowell, 1985 and 19.3 –22.2% for a population in Kiel Bay (Brey et al., 1990).

The relationship between shell length (SL) and individual meat wet weight (MW) was slightly higher than reported in some studies of different areas ($MW= 4.97x10^{-6} *SL^{3.5696}$) Figure 16). Compared to the Baltic Sea population (consisting of a similar size distribution of animals) reported on by Zettler et al. (2001), meat weights tended to be comparatively higher in the Gulf of Maine population measured in this survey for a similar sized animal. However, the number was comparable to a population in St. Mary's Bay, Nova Scotia ($y = 0.000008x^{3.409315}$).

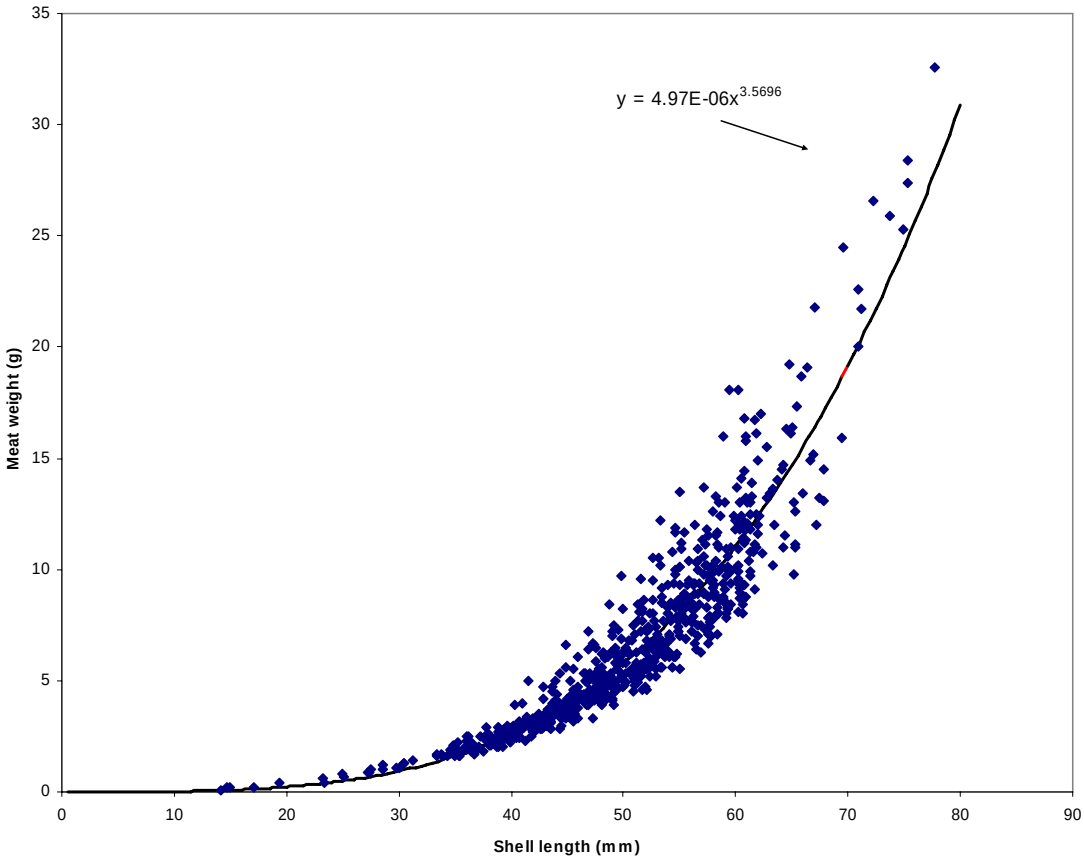

Figure 16. Meat weight as a function of shell length (all data combined).

Miscellaneous observations

Although no attempt was made to sex samples systematically, a few gonad smears did show active sperm when examined under the microscope in July (Figure 17). Also, one batch of animals appeared to spawn when brought back to the lab – probably due to the temperature difference in the water and from handling stress. The size range of examined animals was 49 -54 mm.

Figure 17. Active sperm obtained from a sample of quahogs on July 10, 2001. Sperm have conical heads measuring 4.8 microns in length.

Juveniles proved to be more susceptible to stress than larger (>30mm) animals as most of the juveniles brought back to the lab died within a week after being placed in a flow-through system – while larger animals from the same batch survived. Weigeit (1991) noted that although *A. islandica* is known to be highly tolerant of low oxygen conditions, this tolerance might be restricted to adults.

Equipment was purchased (vibratory lap machine, isomet saw accessories, epoxy) to process shell samples for aging. The method of Ropes (1983) with minor modifications proved successful for making acetate peels from sectioned shells. More time will be required to process the collected shells but early results are promising – with annual checks clearly seen in acetate peels (Figure 18).

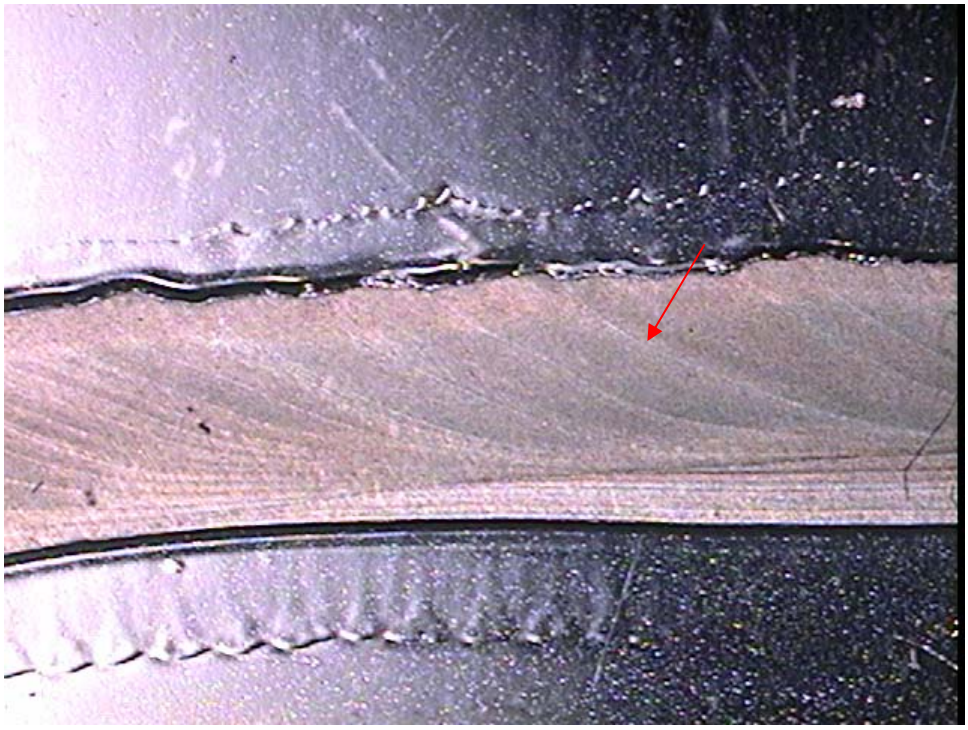

Figure 18. Close up of acetate peel (x40 power) of a sectioned quahog shell collected on the survey. Growth markings show as the light colored bands (arrow).

Discussion

Population structure and distribution

Past fishing activity has taken place primarily in locations off Jonesport, off Schoodic Peninsula and southeast of Isle au Haut (Chenoweth and Dennison, 1993, J. McGowan, personal communication). Reports of small quahog concentrations also included areas in Dyer Bay, as well as in regions west of zone 1 – off Spruce Head in Penobscot Bay and by Metinic and Monhegan Islands. It was thought that many more unknown locations also existed (Chenoweth and Dennison, 1993). Complicating, and contributing to, this biologically patchy distribution is a complex bathymetry and physiography - characteristic of the inner continental shelf of the western Gulf of Maine. The proportion of unfishable sites (39.7% over all 255 sites) in the random survey presented here corresponded well with the total rocky area estimated for the entire shelf (40.9%; Kelley et al., 1998). This current work taken together with past samples (NMFS survey data for 1992, 1994) represents the best depiction to date of this species' distribution within the PSP management zones (Figure 18). Areas of greatest abundance - off Jonesport between Cross Island and Petit Manan Island coincided roughly with current fishing activity. Based on this distribution, the majority of the resource appears to be in the federal EEZ. Lesser abundances appeared in the past-fished areas off Schoodic Peninsula and southeast of Isle au Haut. This is partly due to the patchy distribution in these areas but may also reflect local reductions in stock due to fishing. Although data

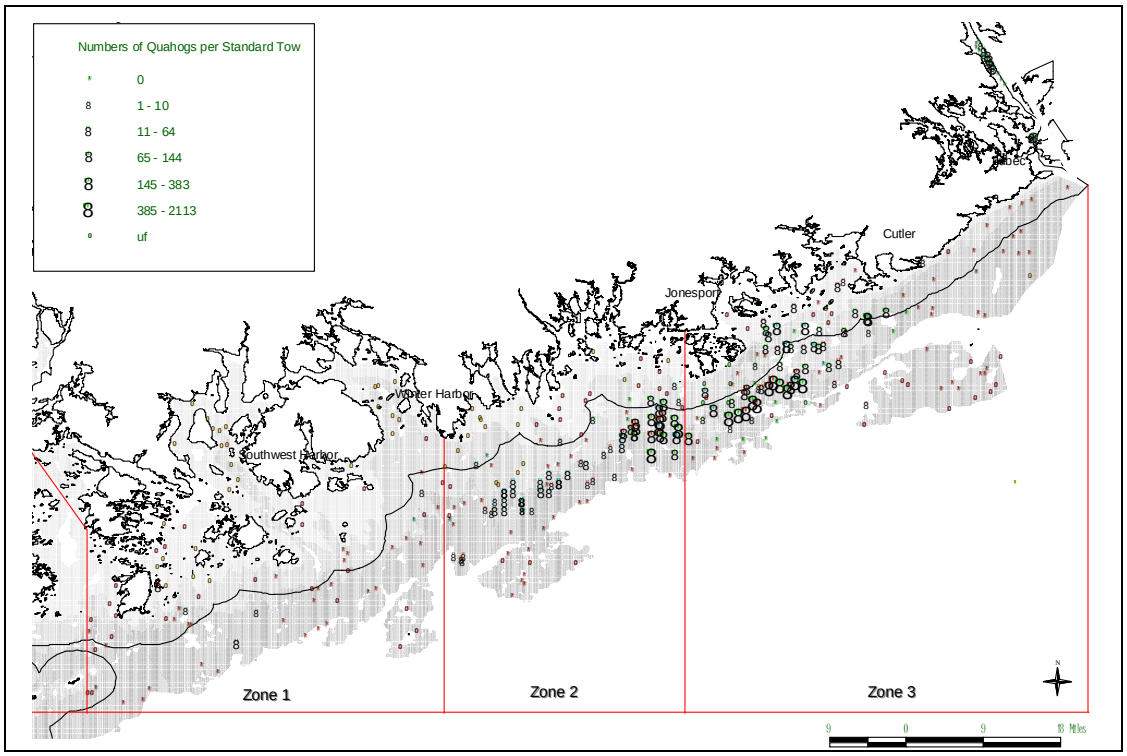

Figure 19. Distribution of quahogs in PSP management zones 1-3. Based on all survey data (this report and NMFS, 1994 survey data).

shows an increase in landings per unit effort (MAFMC, 2000), anecdotally there are reports of local depletions of past-fished sites (J. McGowan, personal communication, Chenoweth and Dennison, 1993). There are also a number of sites where catches consisted of significant amounts of quahog shell (judged to be relatively new because the periostracum was not excessively worn) but no live animals. This may indicate a mortality event due to unknown causes in some of these areas in the past. A hypoxic event off of NJ in 1976 caused a die off of clams in shoreward part of the population of up to 13% of ocean quahogs in this area (Kennish and Lutz, 1995). Other areas contained paleo-shell indicating a widespread distribution of these animals in times before recently fished beds were established.

Areas of quahogs nearer to shore were not well represented in this work because of unfishable bottom and, in stratum 1, interference with lobster gear. Live quahogs have been brought up in areas less than 20 meters in depth on SCUBA dives near Isle au Haut (S. Feindel, unpublished data). These animals tended to be older and larger than ones found in the main beds off Jonesport. Similarly, animals found near the shallowest site (11 Fathoms) by Treat Island were larger.

The area surveyed in Passamaquoddy showed a lower relative abundance than the main beds off Jonesport, but did show signs of recent recruitment. This area likely represents just the outer edge of a larger unfished bed on the Canadian side of Passamaquoddy Bay.

Beds occurring in Southern Maine from Cape Elizabeth to Ogunquit were surveyed by Card in 1976, but the small hydraulic dredge used in that study was limited to a depth of 120’ (20 FM) so the population in deeper waters there is still unknown.

Quahogs in Southern Maine were larger – averaging 3.5 inches in the Cape Elizabeth to Biddeford pool area, 3.75 inches in the Biddeford pool to Kennebunkport area, and 2 inches the Kennebunkport area, although some juveniles were found – including some 0.25 inch clams in grab samples. It may be desirable to further assess these populations outside of the PSP management zones in the future.

The overall population size structure of the surveyed portion of the Gulf of Maine stock that consist of animals measuring mostly between 30 and 70 mm shell length contrasts greatly with assessment areas in Southern New England and the Mid-Atlantic which typically contain quahogs from 60 – 120 mm in shell length (Kennish and Lutz, 1995). One implication of this may be that unlike the stable population size structure usual in this later region (NMFS, 2000), the Gulf of Maine stock may change more readily due to increased growth experienced by animals of this smaller size class, to the targeting of a specific size class of animals (1.5 to 2.5 inches) by the fishery, and possibly to increased recruitment in this area.

Relative biomass estimate

There was some discrepancy between the relative abundance estimates calculated for the stratified random survey of all three management zones compared to the systematic survey of the main fished beds between Petit Manan Island and Cross Island. Relative abundance for the overall survey comprising 1117 nm^2 (776,442 'Maine' bushels +/- 214,495 SE) was lower than the estimate derived from just the area of the systematic survey (comprising only 225 nm^2) with an estimate of 1.289 x 10^6 bushels (+/- 389,971 SE). Whether this was due to the large scope of the survey combined with a patchy resource distribution or due to biases in the systematic design of the smaller-scale survey, is unknown. Quahogs were present at only 30.5% of all stations in the survey of all three zones compared to 70% in the systematic survey. Large-scale surveys with patchy habitat will often contain a high proportion of stations with zero catches and produce skewed sample distributions. Fogerty (1981) in his calculation of relative abundance of *A. islandica* in Rhode Island Sound used a method that partitioned zero and non-zero catches (after Aitchison, 1995). Data presented in this report are preliminary and further work may be done with the data set. However, a second survey with more intensive sampling will likely be necessary to obtain more precise relative abundance estimates. Given the lack of 'new' large beds (or numerous small beds with a marketable size range of quahogs) discovered in areas outside of that covered by the systematic survey, it seems appropriate to concentrate future efforts on a better estimate of this smaller area since it contains the largest portion of the stock.

Despite relatively large standard errors associated with the relative biomass estimates, the mean and variance parameters obtained provide a basis to calculate the sampling effort needed to obtain a more precise abundance estimate. Table 3 shows the required number of sampling stations needed for 95% and 90% confidence intervals at precision levels of 10, 15, 20, and 25% of the population mean. Data from the systematic survey were used in these calculations since it was the area with the highest variance and highest population. An intensive survey of this area of about the same duration (12-15 days at sea assuming 40 stations per day or 400-500 stations) would be necessary to

achieve an estimate within 20% of the population mean with 95% confidence or within 15% of the mean with 90% certainty. Although the sampling intensity in the present survey was not as high as desired, it provides a basis with which to better define the overall sampling frame in future surveys and with which to refine strata designations based on relative abundance. It is important to sample beyond known fishing grounds early on in a survey series so as not to miss potentially important resource concentrations (Hilborn and Walters, 1992).

Table 3. Required number of sample stations needed for various levels of precision at 95% and 90% confidence intervals. Based on parameters estimated from the survey of the main fished beds.

Precision (% of mean)	95% C.I.	90% C.I.
10%	1739	1180
15%	775	524
20%	434	294
25%	278	188

Dredge efficiency

Converting relative abundance estimates to real abundances will require the further step of defining dredge efficiency. Numerous factors affect how the dredge fishes and its selectivity (length of the tow cable, dredge size and weight, angle and depth of dredge teeth with respect to the bottom, teeth spacing, dredge speed, and bottom substratum etc.). Some behavioral characteristics of *A. islandica* also affect its vulnerability to the survey gear. Although quahogs have short siphons and lie just below the surface when feeding, they can burrow into the sand and remain there for up to seven days (Taylor, 1976). *A. islandica* is known for its tolerance to low oxygen conditions and is unique among bivalves in the sense that this state is 'self induced' in the animals – unlike for intertidal organisms such as softshell clams. Divers in Maine have found quahogs to a depth of 12" in the sediment (Chenoweth and Dennison, 1993). Given these considerations in addition to the deep water and currents where the major beds occur, it was decided not to undertake a dredge efficiency (depletion) study here given the limited number of days at sea available. Because of all of the factors noted above, it may be difficult to obtain adequate dredge efficiency estimates with a dry dredge. Other surveys of *A. islandica* have used dry dredges only as an indicator of abundance rather than as quantitative sampling gear (Chandler, 1983). Biomass estimates in other assessment areas have been sensitive to dredge efficiency and recent efforts in federal surveys have focused on a better estimate of this for their hydraulic survey dredge – including the addition of a sensor package to measure pump voltage and water pressure and inclinometers to assess whether fishing occurs during haul-back etc. (Jim Weinberg, personal communication). While hydraulic dredges are more efficient (up to 95%; Medcof and Caddy, 1971) there are difficulties deploying a hydraulic dredge with enough power to work at the necessary depths and using the small vessels (35-55 feet) that characterize the Maine fleet. Small hydraulic dredges used in past studies have been

limited to an operating depth of 120 feet (Card's, 1976). A number of possible studies to address the dredge efficiency problem include: combination drag and diver sampling in shallower areas, a tag and release study, or paired towing from a vessel with a Maine dry dredge and a larger vessel using a hydraulic dredge in deep water. It will require more work to assess these approaches, but even a rough estimate of dredge efficiency will be helpful. We attempted to calculate a 'guesstimate' of the range of efficiencies likely for the dry dredge by comparing the highest relative densities we encountered in this work (16/ m^2) with other maximum and average real densities over beds with high abundances found in the literature for beds with the same size range of animals. Zettler et al.'s study of a Baltic Sea population showed a highest density of 571 clams/ m^2 and an average density of 91 clams/ m^2). Information from past Maine studies (Beal and Kraus, 1989) also indicate that between 300-400 clams/ m^2 is approximately the maximum density likely before intraspecific competition affects growth. Using these numbers a best guess of efficiency for the dry dredge used might be between 2-17%.

Fishing impact and other issues

It is clear given the abundances in the massive beds off Jonesport and the lack of bycatch in this area, that *A. islandica* makes up a significant proportion of the benthic community here and are likely a keystone species in the cycling of material into the benthic system (De-Wilde et al., 1986). The broader effects of fishing here are not well understood. Some questions are whether dredging creates a persistent sediment plume and, if so, what effect does it have on quahogs feeding there. There is also a build up of shell – especially in fished areas. Incidental mortality that may be caused by dredging should be assessed. Even if the incidence is low, due to a presumed low dredge efficiency the same area may be towed repeatedly for many years (Mike Danforth, personal communication). Shell damage may make clams vulnerable to predation. Brey et al. (1990) suggest that large sized clams (>30 mm) only become vulnerable to fish benthic predators when they are damaged by otter boards. Additionally it is unclear whether this build up of shell might have an effect on recruitment due to the changes in substratum.

Recruitment, size at maturity, and growth may be of increased importance in the population dynamics of the Gulf of Maine due to the smaller sized animals targeted in this fishery. These biological parameters are still not well understood for *A. islandica*. Thorarinsdottir and Einarsson (2000), in a study on gametogenesis, reported that the smallest mature male sampled was 36 mm in length and the youngest was 10 years old. The youngest mature female was 44 mm in length and 13 years old. This late reproductive maturity may serve as a 'bet hedging' strategy for animals that are susceptible to predation when young but relatively safe later in life. The market preference for small clams of 40-50 mm, if Maine stocks also reflect the above size at maturity rates, means that some harvested clams may not have yet spawned. However, ocean quahogs are also reproductively active throughout their long life span and clams that have grown beyond market size serve as a constant brood stock pool with de-facto protection.

Outreach

Results of the survey were presented at the Northeast Consortium symposium in 2002. A report on the survey was sent to the Mid-Atlantic Fisheries Management council for review. A brief summary of the survey was given at an industry meeting in Machias and we plan to mail survey reports to industry members this fall. Scott Feindel of Maine DMR also participated in the NMFS surfclam/ ocean quahog survey in order to become familiar with the survey methodology used by NMFS assessment biologists.

Future work

This survey work was a first stage effort to develop assessment methodologies for the ocean quahog resource in the Gulf of Maine, and it is clear that further research is needed. Archived shell samples from all sites will be aged as time allows and should provide more information on growth rates of this population. We also hope to conduct bed mapping work with Roxann – a sounder device coupled with a software package that enables fine scale resolution in substratum types. If shallow burrowing quahog concentrations produce a discernable acoustic signal using this system, bed distribution can be mapped more efficiently. The video ground truthing and collection of grab samples involved in this work should also produce a clearer understanding of the habitat associated with these beds. In combination with routine PSP sampling already in place, it should also be possible to collect monthly samples to assess size at maturity and seasonal gametogenesis.

In conclusion, a second optimized survey based on this work in combination with needed gear efficiency studies should produce a scientifically sound biomass estimate for the Gulf of Maine stock. However, additional work will be needed to more completely understand the population dynamics of this region.

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