Development of a survey method and associated resource estimation for the hard clam *Mercenaria mercenaria*

Prepared for

Town of Brunswick
Brunswick, ME 04011

207-846-9036 Office

Prepared by

MER Assessment Corporation
14 Industrial Parkway
Brunswick, Maine
207-798-7935 (Voice)/729-4706 (Fax)/751-3696 (Cell)
cheinig@merassessment.com

and

Resource Access International
710 River Road
Brunswick, Maine
207-406-4659

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Introduction

The intertidal mudflats in the Town of Brunswick have long been recognized for their productivity, especially for the soft-shell clam, *Mya arenaria*. In recent years, however, soft-shell clam populations in Casco Bay, including the intertidal flats of Brunswick, have declined precipitously. The decline has been attributed in large part to predation by the green crab, *Carcinus maenes*, populations which increased sharply in 2012-2013, possibly due to warmer than usual winters.

During this same time period the population of hard clams or quahogs, *Mercenaria mercenaria*, have been consistently increasing. An exceptionally dense population of quahogs was identified several years ago in the New Meadows Lakes, marine impoundments created by the Bath Road causeway at the boundary between Brunswick and West Bath. This exceptionally dense population led to the development of a whole new fishery specific to the area. However, expanding populations of quahogs were also identified in Maquoit Bay, Merepoint Bay and Middle Bay.

In view of the declining soft-shell clam resources and the growing interest of exploiting the expanding quahog resource, the Town of Brunswick wishes to better understand the extent of the resource and to properly manage it to avoid overfishing or underutilization.

Methods

Survey method and resource estimation

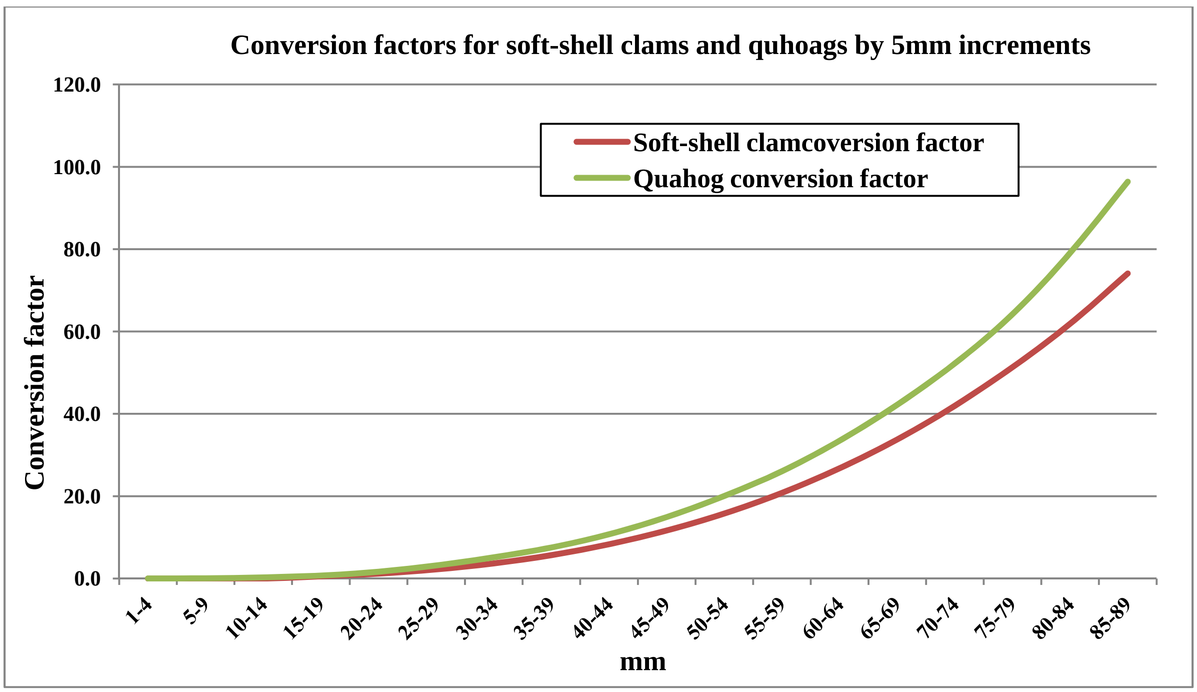
The Town of Brunswick already uses a well-established survey method for determining the stock of the soft-shell clam (Dow, 1952; Newell, 1983) within its jurisdictional area of intertidal flats. The goal of this effort was to use the same field data collection method as currently used for soft-shell clams and to modify the values used for calculating density and overall stock based on values specific to quahogs.

Belding (1912) did extensive work to determine the number of quahogs per quart using displacement for quahogs ranging in size from 1mm to 88mm. Assuming quahogs in Maine are morphometrically similar to Massachusetts quahogs these values can be used to calculate the number of clams in a bushel by multiplying the number per quart by 37.237, the number of liquid quarts per bushel. The survey method calls for the sampling of 2ft^2 plots using a duplicate 1ft^2 frame. Accordingly, each 2ft^2 plot represents 1/21,780th of a 43,560ft^2 survey acre. Dividing the number of quahogs per bushel by 21,780 gives the number of quahogs needed to be found per plot in order to result in one bushel per acre, for example there are 3,691 10mm quahogs per quart and 137,442 per bushel therefore approximately 6.31 (137,442/21,780) 10mm quahogs would need to be found in a 2ft^2 plot to yield one bushel per acre. Each 10mm quahog therefore represents approximately 1/6.31th of the number of quahogs need to be found in a 2ft^2 plot to yield a bushel per acre, thus the conversion value represented per 10mm quahog found per plot is 1/6.31th or 0.15847. Refer to Appendix I for the complete table of conversion calculations for quahogs 1mm to 88mm.

Although the table in Appendix I is for quahogs in increments of 1mm, field measurement of clams is usually within 5mm increments, for example 5mm to 9mm or 15mm to 19mm, etc. Taking this into consideration, conversion values were calculated for each 5mm increment for quahogs 1mm to 88mm by averaging the conversion values within each 5mm range. There are inherent inaccuracies, albeit small, that result from averaging measurements and the conversion values into 5mm intervals, but the practicality of measuring to 1mm increments in the field has been proven difficult.

Table 1 shows an example of the DMR standard survey summary table for soft-shell clams, *Mya arenaria*, used to calculate density in bushels per acre and total bushels for each 5mm increment based on the number of plots sampled and the acreage covered by a survey. This standard summary table has been modified for use with quahogs by replacing the soft-shell clam conversion factors to those for quahogs. Figure 1 shows a comparison between the soft-shell clam and quahog conversion factors.

Figure 1 Comparison of conversion factors for soft-shell clams and quahogs.



The number of quahogs in each 5mm increment can be entered into the No/size column either directly from a field sheet or by entering the field sheet data into the Excel® survey format that will automatically populate and update the summary table as data is entered. The percentage by size column for each 5mm increment is calculated by dividing the number of quahogs in each increment by the total number of quahogs collected. The B/A/SZ (bushels per acre per size) is calculated by multiplying the number of quahogs per size increment by the conversion factor for the size. Bu/ac (bushels per acre) is calculated by dividing the B/A/SZ by the number of sample plots taken. Bushels for each 5mm interval is calculated by multiplying the Bu/ac by the number of acres covered in the survey. Finally, Harvestable bushels is the sum of each interval's Bushels for all increments from 50-54mm and greater.

It is important to note that the calculation for bushels used here is based on volume (37.237 quarts/bushel) and not weight. Most sales of clams and quahogs today are based on weight which may not equate to a bushel volume; therefore the estimate of number of bushels by volume will likely be different from the bushels harvested by weight. Regardless, the estimation of harvestable bushels by volume should be fully useful for resource management purposes as long as the survey method and calculations remains the same over time. Furthermore, carefully tracking the number of bushels actually harvested from a surveyed area will allow comparison between the estimated and actual bushels; this comparison can be used for refinement of the calculation coefficients.

Quahogs are categorized by market size category as “little necks”, “cherrystones” and “chowders” based on size. An additional section can be added to the table that allows estimation of the total number of individuals in each 5mm increment. These values can be used to estimate the number of quahogs falling into each size category by segregating the quahogs by size ranges for each market category and summing the number of quahogs within the range.

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Table 1 Resource survey summary table for quahogs adapted from the standard table used for soft-shell clams

Middle Bay
Current year

Samples	28
Acres	4

Clam size in mm	Conv. Factor	No/Size	%/Size	B/A/SZ	Bu/ac	Bushels	Harvestable Bushels
0-4	0.02	**0**	0.0	0.0	0.0	0.0	0.0
5-9	0.07	**0**	0.0	0.0	0.0	0.0	0.0
10-14	0.27	**0**	0.0	0.0	0.0	0.0	0.0
15-19	0.73	**0**	0.0	0.0	0.0	0.0	0.0
20-24	1.65	**0**	0.0	0.0	0.0	0.0	0.0
25-29	3.18	**5**	1.4	15.9	0.6	2.3	0.0
30-34	5.15	**21**	5.7	108.1	3.9	15.4	0.0
35-39	7.55	**47**	12.8	354.9	12.7	50.7	0.0
40-44	10.75	**71**	19.4	763.4	27.3	109.1	0.0
45-49	14.92	**63**	17.2	939.7	33.6	134.2	0.0
50-54	20.08	**47**	12.8	943.6	33.7	134.8	134.8
55-59	26.05	**38**	10.4	989.9	35.4	141.4	141.4
60-64	33.47	**24**	6.6	803.2	28.7	114.7	114.7
65-69	42.21	**27**	7.4	1139.7	40.7	162.8	162.8
70-74	52.25	**12**	3.3	627.0	22.4	89.6	89.6
75-79	34.20	**7**	1.9	239.4	8.5	34.2	34.2
80-84	79.10	**4**	1.1	316.4	11.3	45.2	45.2
85-88	96.40	**0**	0.0	0.0	0.0	0.0	0.0
.>88		**0**	0.0	0.0	0.0	0.0	0.0
TOTALS		**366**	**100.0**		**258.6**	**1034**	**723**

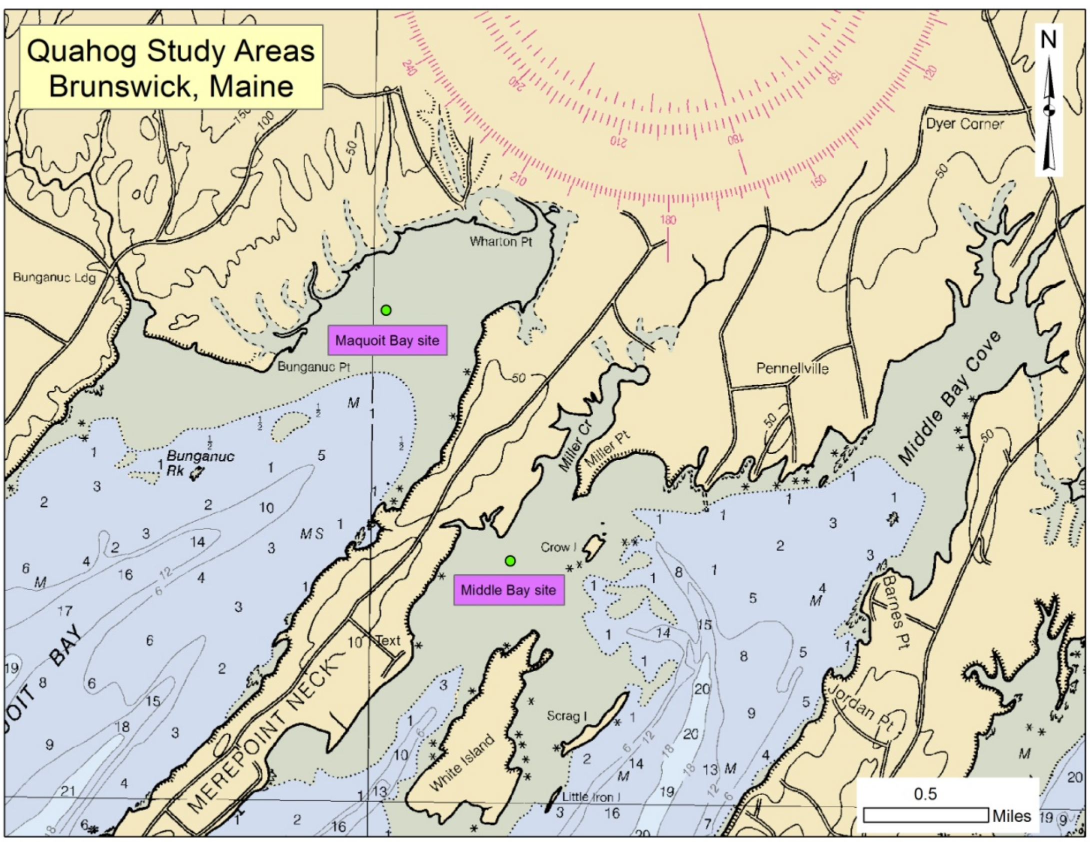
% BUSHELS HARVESTABLE 69.9

Quahog growth

The estimation of growth of the population over a growing season is based on the growth of each size category over the period. To get a better understanding of the rate of growth of individual sizes of quahogs in Maquoit and Merepoint Bays, a study was conducted to measure the incremental growth of quahogs between 20mm and 90mm in each of the bays.

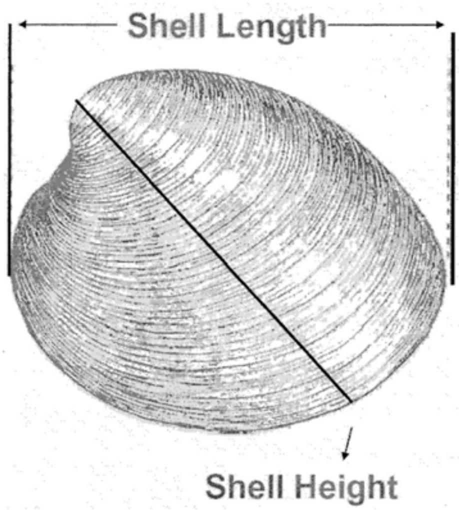
A 100 ft^2 (10ft by 10ft) plot was located and marked with orange and white spindles by Brunswick Marine Resources Warden Dan Devereaux and Darcie Couture of Resource Access International (RAI) in each of the bays at approximately the mid-tide level; in Maquoit Bay at 43° 51' 42.38"N/69° 59' 56.04"and in Merepoint Bay at 43° 50' 50.41"N/69° 59' 19.39"as shown in Figure 2. A crew representing Brunswick, RAI and MER were transported to the Maquoit Bay and Middle Bay sampling locations on May 19 and 20, respectively, by airboat just at the time the receding tide exposed the soft mud of the flat. Upon arrival at the marked plot, plastic fish totes were filled with seawater to be used in cleaning the sample quahogs. Harvesting of the quahogs was done by hand, two two-member teams each beginning at opposite ends from one another and working toward the center of the marked plot. Each handful of soft mud was gently squeezed between the fingers to allow for collection of smaller quahogs. As quahogs were collected they were handed off for washing and storage in fish totes. The entire 100ft^2 plot was harvested as fully as possible within a single tide. Small quahogs were likely undetected and no screening of sediment was done during this effort due to limited working time and lack of rinse water during ebb tide.

Figure 2 Location of sampling sites in Maquoit and Middle Bays



All quahogs were taken to the RAI lab facility, at 710 River Road, Brunswick for measurement and marking. Measurements were taken of each quahog for length (anterior to posterior), height (perpendicular to the umbo/hinge to the shell margin) and thickness (perpendicular to umbo) as shown in Figure 3 using electronic calipers (Mitutoyo 500-196-30 AOS Absolute Scale Digital Caliper.). Following measurement, three small "v" notches were made in the shell margin using a triangular file, one perpendicular to the umbo and one toward the anterior end and another toward the posterior end (see Figure 4); these marks are permanent and allow future measurements of new growth from the time of marking. Following marking, the quahogs were stored cool and dry until the next day when they were returned for replanting. Measurement data were input to an Excel® file for analysis and plotting.

Figure 3 Shell dimension measurements



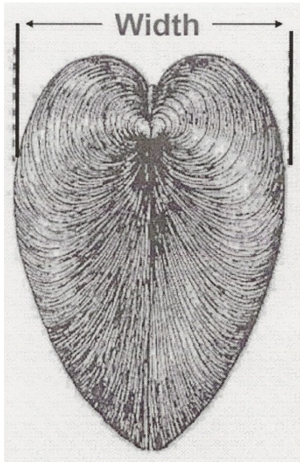


Figure 4 Filing a notch mark in shell margin

The quahogs harvested from Maquoit Bay on May 19, 2014 were replanted on May 20, 2014; quahogs harvested from Merepoint Bay on May 20, 2014 were replanted on May 21, 2014. The harvesting process resulted in substantial disturbance of the soft sediment within the original 100ft^2 plot creating a slurry of mud too soft for replanting the quahogs. A 10ft by 10ft plot is too large to avoid trampling the outer perimeter area when planting in the center of the plot. Consequently, a 10ft by 5ft area was marked with orange and white spindles a few feet to the side of the original harvest plot. The quahogs were planted siphon side up by pushing them into the sediment just slightly below the surface of the mud and were distributed as evenly as possible throughout the 50ft^2 plot while causing minor disturbance to the sediment. Once all of the quahogs were planted, the plot was covered with a Pentair brand black plastic mesh, UV-resistant 30% shade cloth fitted with several bullet buoys to raise the mesh netting from the sediment while water was over the plot at high tide. The mesh netting was anchored along each side with steel reinforcing rod rolled into the edge of the mesh and secured with wire-ties; the steel rods were pushed into sediments approximately 6 to 8 inches to securely anchor the mesh and to prevent predators, *e.g.* green crabs, from getting into the plot (see Figure 5). Once the mesh was securely in place a HOBO temperature logger was secured to the mesh to record temperature data during the growing season.

Figure 5 Replanted plot showing plastic mesh netting in place.

The quahogs were allowed to grow undisturbed throughout the growing season at the end of which they were recovered from both the Maquoit Bay and Merepoint Bay sites on November 13, 2014. The quahogs were again harvested by hand, placed in fish totes and returned to the RAI lab for measurement.

Several measurements were taken of each quahog, again using electronic calipers; measurements included those at initial time of marking (based on “v” notch) and at post-growing season recovery. First, the initial length was measured from the shell margin marked by the outer edge of the anterior and posterior notches; this was followed by measurement of the greatest full post-growing season length from the anterior and posterior shell margins. Similarly, the initial height was measured from the umbo to the shell margin marked by the outer edge of the notch followed by measurement of the full post-growing season height measured from the umbo perpendicularly to the shell margin. Post-growing season thickness was also measured; the initial thickness was the only measurement that could not be replicated. Additional information was collected for number of mortalities and quahogs displaying brown chevron referred to as “notada” markings.

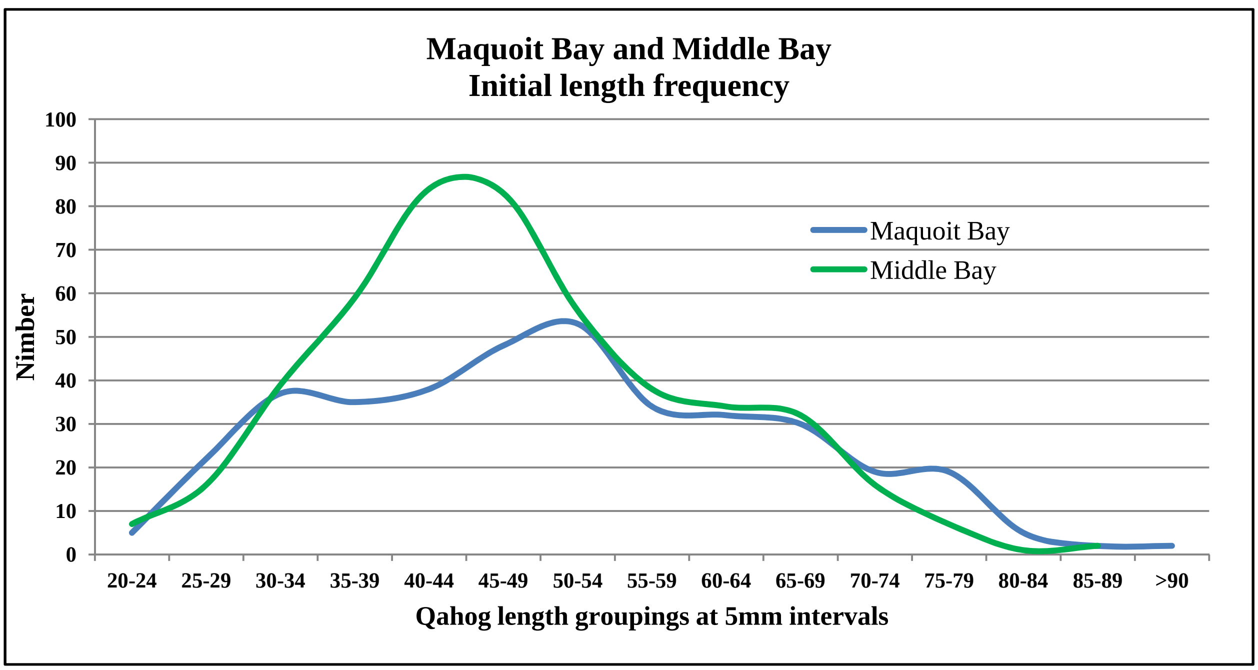
Because the marked quahogs were replanted in an undisturbed area adjacent to the initial harvest plot a number of unmarked clams were recovered from both Maquoit Bay and Middle Bay in the post-growing season collection. Some of these quahogs had distinct new growth beginning at a clearly visible annular ring; growth measurements of these clams were included in the analysis, although separately.

As in the initial harvest, measurement data were entered into an Excel® file to allow sorting, analysis and plotting.

Results

The initial quahog data was sorted by length to allow enumeration of quahogs within 5cm intervals between 20mm and 90mm and plotting as size frequency as shown below in Figure 6.

Figure 6 Initial size frequency of quahogs from Maquoit and Middle Bays.



The Middle Bay quahogs showed a relatively normal distribution with a peak between 40mm and 50mm then descending with a leveling between 60mm and 70mm. The Maquoit Bay quahogs showed a less distinct “bell” curve but rather one composed of several “bumps” suggesting the possibly of different year classes, although this is difficult to interpret given the mix of slow growers from one year class and the fast growers of a later year class.

Although the length frequency curves give a general idea of the demographics of the sampled population in each bay, the graphs provide little in the way of information of expected growth between length categories. In a first attempt to get some indication of anticipated growth over a growing season we used the equation for weight increase in fish (Ricker, 1975):

$$w_t = w_o e^{gt}$$

and adapted it for growth in length as:

$$l_t = l_o e^{gt}$$

where:

l_t = final length at time t;
l_0 = initial length;
e = 2.718 (base of the natural logarithm); and
g = growth coefficient.

First, to calculate the growth coefficient we used:

$$gt = ln\ l_t / l_0$$

or, when t =1 (one season)

$$g = ln\ l_t / l_0$$

The value of g was calculated from the initial (May 2014) and final (November 2014) lengths for the quahogs sampled in both Maquoit Bay and Middle Bay. We first concentrated on data from the marked quahogs, that is, those marked by filing in May in each bay. After sorting the data by ascending initial length, the growth coefficient (g) was calculated for each quahog. The average g for each 5mm length interval was then calculated, that is, for each 5mm interval *e.g.* 15mm-19mm, 20mm-24mm, etc. (similar to the survey intervals). In some cases the calculated average is based on only one or few quahogs leading to occasional aberrant results.

The predicted median length after one season of growth for each length interval was then calculated using the median length and the mean growth coefficient for each 5mm length interval and solving for l_t in the initial equation $l_t = l_o e^{gt}$.

Finally, the estimated number of seasons required for the median length quahogs in each length interval to reach a harvestable length of 50mm was calculated using the equation:

$$s = ln\,(50\,/l_m)/g_m$$

where s = number of seasons;
50 = harvest length;
l_m = median length for length interval; and
g_m = mean growth coefficient for length interval

The results of all above calculations for the marked quahogs from Maquoit and Middle Bays are summarized in tabular form in Tables 2 and 3, respectively, and graphically in Figure 7.

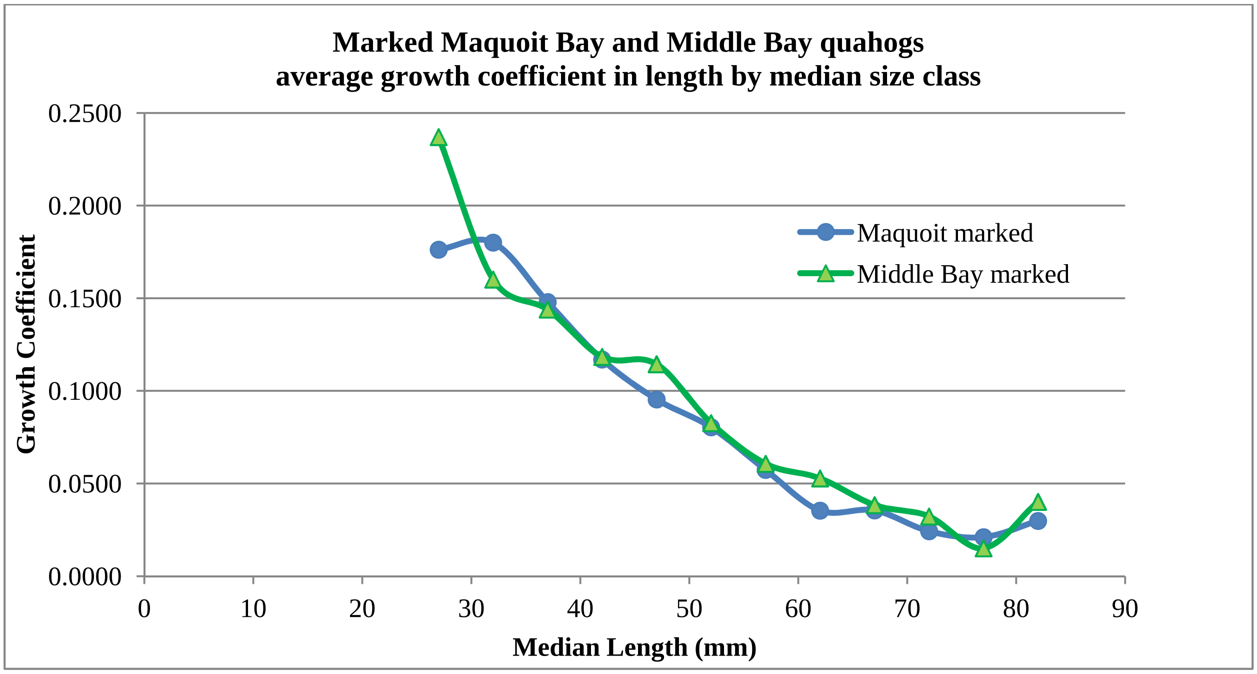
Table 2 Maquoit Bay marked quahog growth summary

Length interval	Median Length	Avg. growth coeff.	Median length after one season	seasons to 50 mm
25-29	27	0.1762	32.2026	3.50
30-34	32	0.1800	38.3120	2.48
35-39	37	0.1480	42.8998	2.04
40-44	42	0.1169	47.2099	1.49
45-49	47	0.0954	51.7040	0.65
50-54	52	0.0804	56.3522	n/a
55-59	57	0.0574	60.3657	n/a
60-64	62	0.0354	64.2343	n/a
65-69	67	0.0355	69.4230	n/a
70-74	72	0.0243	73.7703	n/a
75-79	77	0.0211	78.6399	n/a
80-84	82	0.0299	84.4843	n/a

Table 3 Middle Bay marked quahog growth summary

Length interval	Median Length	Avg. growth coeff.	Median length after one season	seasons to 50 mm
25-29	27	0.2370	32.4708	2.60
30-34	32	0.1601	36.2477	2.79
35-39	37	0.1439	41.3860	2.09
40-44	42	0.1184	46.0537	1.47
45-49	47	0.1144	51.3784	0.54
50-54	52	0.0827	55.4564	n/a
55-59	57	0.0607	59.7591	n/a
60-64	62	0.0528	64.6001	n/a
65-69	67	0.0384	69.0330	n/a
70-74	72	0.0322	73.8289	n/a
75-79	77	0.0151	77.9094	n/a
80-84	82	0.0401	84.6022	n/a

Figure 7 Maquoit Bay and Middle Bay marked quahog growth curves



The 15mm-19mm and 20mm-24mm intervals for both Maquoit and Middle Bays have only a single quahog with very fast growth that caused the curve to steepen initially making comparison with the other data difficult. By removing these single quahog categories the growth curve comparison is made easier.

The same calculations as described above were applied to the data collected from unmarked quahogs with a clear annual ring, thus allowing both initial and final length measurement. The results of these calculations for both Maquoit Bay and Middle Bay are summarized in Tables 4 and 5, respectively, and graphically in Figure 8. No unmarked quahogs greater than 69 were collected in either bay.

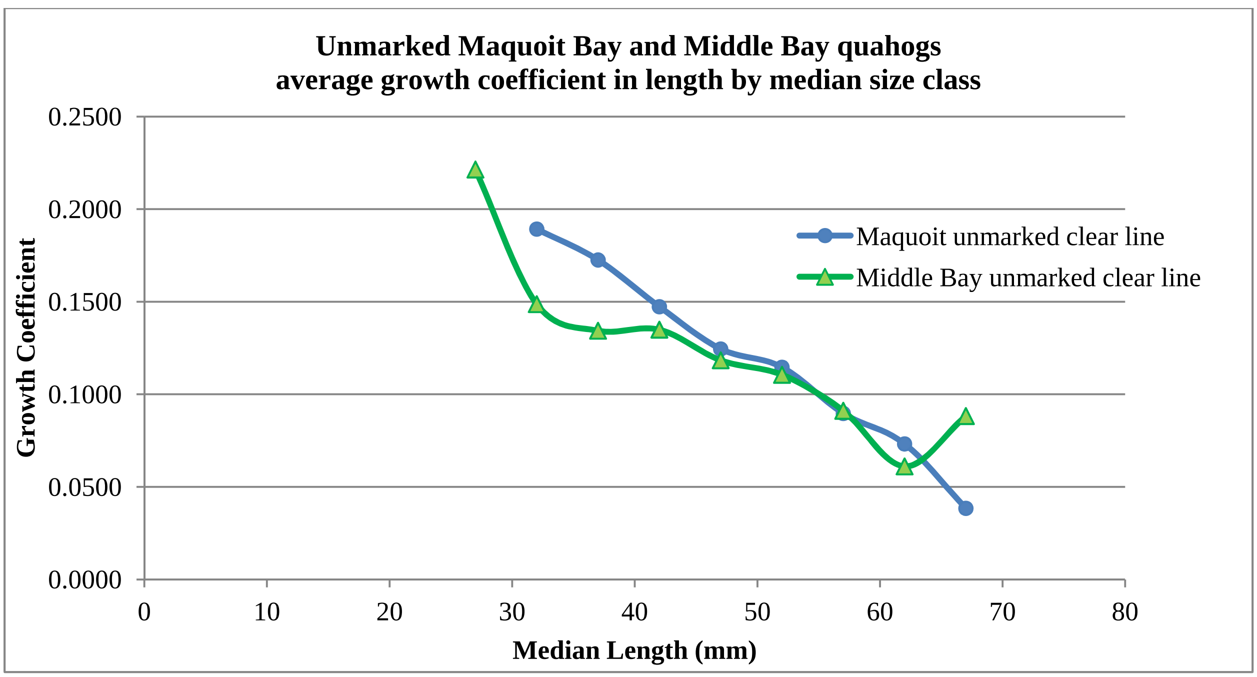
Table 4 Maquoit Bay unmarked quahog growth summary

Length interval	Median Length	Avg. growth coeff.	Median length after one season	seasons to 50 mm
25-29	27	0.0816	29.2941	7.56
30-34	32	0.1892	38.6658	2.36
35-39	37	0.1726	43.9679	1.74
40-44	42	0.1473	48.6654	1.18
45-49	47	0.1245	53.2300	0.50
50-54	52	0.1146	58.3154	n/a
55-59	57	0.0897	62.3468	n/a
60-64	62	0.0732	66.7102	n/a
65-69	67	0.0384	69.6249	n/a

Table 5 Middle Bay unmarked quahog data summary

Length interval	Median Length	Avg. growth coeff.	Median length after one season	seasons to 50 mm
25-29	27	0.2214	33.6911	2.78
30-34	32	0.1487	37.1300	3.00
35-39	37	0.1344	42.3203	2.24
40-44	42	0.1349	48.0660	1.29
45-49	47	0.1184	52.9057	0.52
50-54	52	0.1106	58.0797	n/a
55-59	57	0.0911	62.4389	n/a
60-64	62	0.0611	65.9067	n/a
65-69	67	0.0883	73.1839	n/a

Figure 8 Maquoit Bay and Middle Bay unmarked quahog growth curves



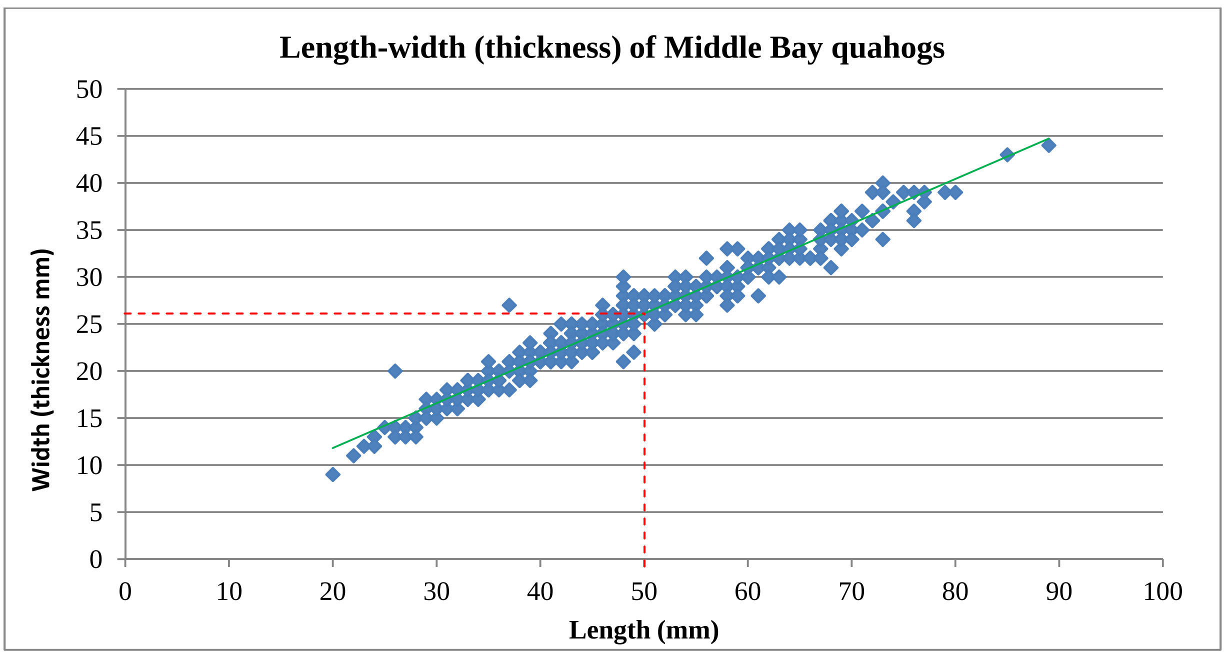
The curves are similar between the median lengths of 42mm and 62mm, the size range with the greatest number of measurements per 5mm interval; the apparent anomalies at either end are caused by the small number of quahogs sampled in first and final intervals.

Discussion

The survey sheet for quahogs was developed to remain similar to that used for soft-shell clams, *Mya arenaria* to allow data to be collected and treated using the same method that has been used for many years. As stated earlier, the conversion factor for each 5mm interval is based on the volumetric data developed by Belding (1912) for the number of quahogs in a quart for quahogs with lengths from 1mm to 88mm. An assumption is made that the volume by length relationship for Massachusetts quahogs is the same for Maine.

Estimation of harvestable bushels has been set to begin at the 50mm to 54mm interval based on the length and width (measurement across the hinge) relationship of Maquoit and Middle Bay quahogs (Middle Bay shown for initial measurements in May) and the need to ensure the harvestable size of 25mm (one inch) in width is met in most cases, as shown in the graph of Figure 9.

Figure 9 Length-width relationship of Middle Bay quahogs based on initial sampling.



As mentioned earlier, today, bushels of shellfish are based on weight rather than volume used here. Consequently, the calculated number of harvestable bushels is unlikely to closely match the actual number of bushels harvested by weight. To resolve this would require weights to be measured for each 1mm increment, a lengthy process at best.

An alternative approach would entail sectioning off an area of intertidal mudflat, *e.g.* one or half acre, in each bay and conducting an intense survey based on numerous sample plots to estimate the number of volumetric bushels within the area. The area would then need to be "harvested" either completely or within a known or closely estimated subarea(s) and the amount of resulting quahogs carefully monitored. The resulting harvest could then be compared to the estimated amount.

One possible confounding factor affecting the accuracy of a quahog survey may be the apparent gregarious behavior exhibited by quahogs. Quahogs have been reportedly found in relatively dense clusters rather than evenly distributed across an area (Dan Devereaux, Brunswick MPO) and similar observations were made during sampling for this project. Indeed, even in the replanted plots quahogs were found to be clustered despite an active effort to evenly distribute the experimental quahogs during replanting. This may have been the result of clustering within the replanting area prior to introduction of the replanted quahogs. In any event, this would suggest that more intensive sampling may be required to improve the accuracy of a survey.

In Maquoit Bay, of the 381 quahogs taken for measurement, marked and replanted, 314 or 82% were recovered at the end of the growing season; the number of mortalities within the recovered marked group was 13 or 4.1%. Additionally, 147 unmarked quahogs were taken during the recovery harvest, 91 of which had a clear annular ring, thus allowing measurement of growth over the season, and 56 without a clear annular ring thus not allowing for growth measurement. Quahogs with a brown chevron marking, referred to as “notada”, numbered 7 or 1.8%

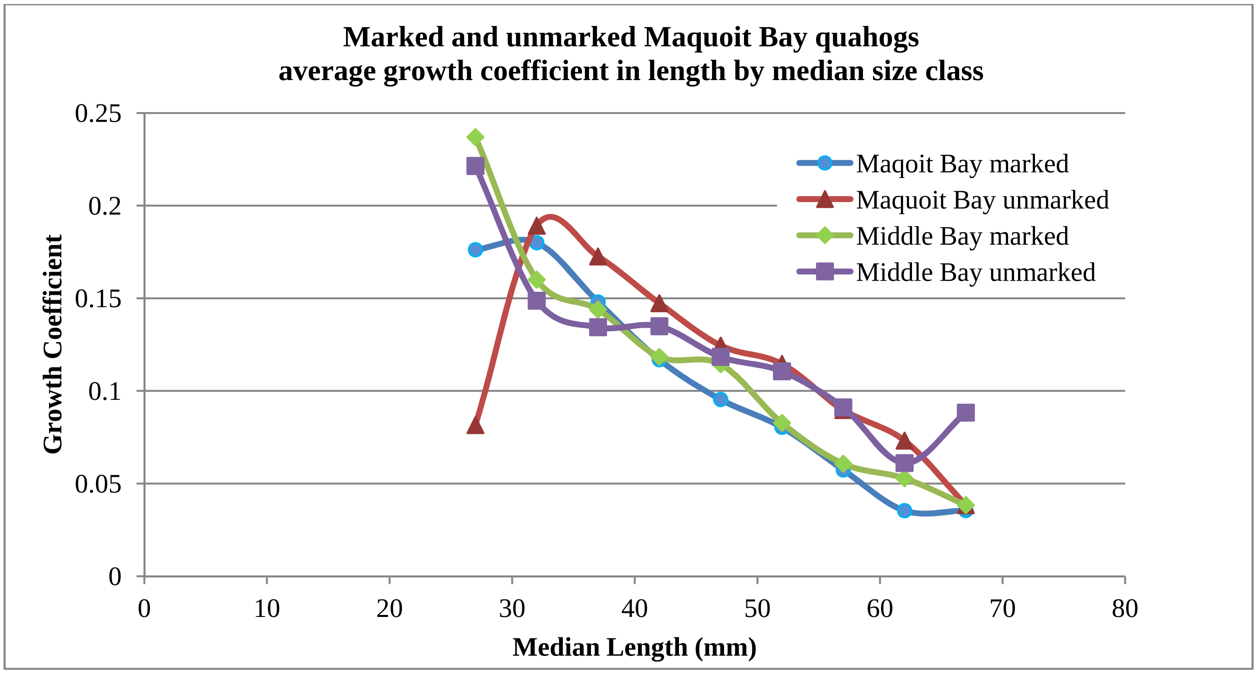
In Middle Bay, 474 quahogs were initially taken for measurement, marked and replanted; 366 or 77% were recovered at the end of the growing season; mortalities within the recovered marked group numbered 19 or 5.2%. An additional 171 unmarked quahogs were taken during the recovery harvest, 70 of which had a clear annular ring thus allowing measurement of growth over the season and 101 without a clear annular ring thus not allowing for growth measurement. Quahogs with a brown chevron marking, referred to as “notada”, numbered 5 or 1.5%

The low number of mortalities among the marked quahogs is very encouraging since there was concern at the start of the project that mortality might be high as a result of the marking process. There was also concern over the possibility of an initial lag in growth as the “v” marks were filled prior to adding new growth along the entire margin. As the growth coefficients for marked and unmarked quahogs (Table 6 and Figure 10) show, the growth coefficients of the unmarked quahogs is generally greater than the marked, particularly in Maquoit Bay, suggesting filing may resulted in slower growth.

Table 6. Marked and unmarked growth coefficients for Maquoit and Middle Bays.

	Maquoit Bay		**Middle Bay**	
Length interval	**Marked growth coefficient**	**Unmarked growth coefficient**	**Marked growth coefficient**	**Unmarked growth coefficient**
25-29	0.1762	0.0816	0.2370	0.2214
30-34	0.1800	0.1892	0.1601	0.1487
35-39	0.1480	0.1726	0.1439	0.1344
40-44	0.1169	0.1473	0.1184	0.1349
45-49	0.0954	0.1245	0.1144	0.1184
50-54	0.0804	0.1146	0.0827	0.1106
55-59	0.0574	0.0897	0.0607	0.0911
60-64	0.0354	0.0732	0.0528	0.0611
65-69	0.0355	0.0384	0.0384	0.0883

Figure 10 Comparison of marked and unmarked growth coefficients for Maquoit and Middle Bays.



Although the overall percent recovery from both sampling sites was good, the small number of quahogs falling into each 5mm interval at the ends of the population distribution resulted in what appear to be anomalous growth coefficient values.

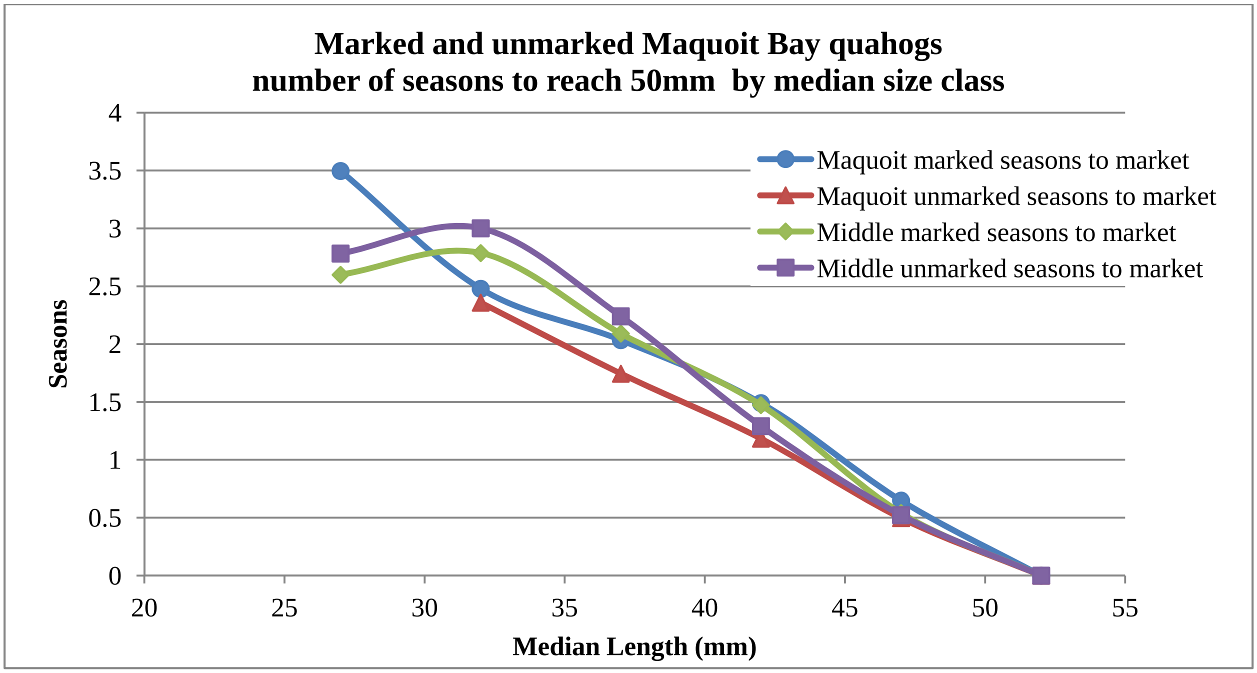
As expected, growth decreases with increase in size and age. The initial harvest of the quahogs was done by hand and few quahogs less than 30mm were taken with only one less than 25mm. Consequently, there is very limited data for the smaller sized quahogs and the rate of growth and number of seasons to market size could not be calculated. Nevertheless, the data for the 30mm to 49mm sizes does provide an estimate of time to reach the market size of approximately 50mm length.

Table 7 and Figure 11 shows the seasons to market size for both Maquoit and Middle Bays marked and unmarked quahogs.

Table 7. Seasons to market for marked and unmarked Maquoit Bay and Middle Bay quahogs.

	Maquoit Bay		**Middle Bay**	
Length interval	**Seasons to market marked**	**Seasons to market unmarked**	**Seasons to market marked**	**Seasons to market unmarked**
25-29	3.4965	7.5553	2.5996	2.7829
30-34	2.4787	2.3583	2.7871	3.0012
35-39	2.0350	1.7449	2.0922	2.2410
40-44	1.4909	1.1836	1.4730	1.2923
45-49	0.6486	0.4970	0.5407	0.5227
50-54	n/a	n/a	n/a	n/a

Figure 11 Seasons to market size by median length for marked and unmarked quahogs from Maquoit Bay and Middle Bay.



These results indicate that growth to market size from a 25mm-29mm quahog takes approximately 2.5 to 3.5 years. With little data for the under 25mm quahogs available it is not possible to establish the seasons required to reach 25mm; however, it is reasonable to assume that it would take 1 to 2 seasons from time of settlement. If so, the full growing period from set to market size would be approximately 4 to 5 years which is consistent with that reported by Beal et al. (2009) for quahogs in eastern Maine

The objective of the growth study was to develop a predictive model to allow projection of quahog resources into the following season from survey data. The model developed is based on empirical data rather than calculated values and is intended to work off of the standard survey Excel® format currently used for soft-shell clam survey work. For purposes of developing the preliminary model, data from the Middle Bay marked quahogs was used under the assumption that incremental growth in Middle Bay is generally representative of growth in most areas.

The Middle Bay data for marked quahogs was divided into 5mm increments, the same 5mm increments used for surveys. Each quahog within each 5mm increment (for example 15mm to 19mm or 25mm to 29mm, etc.) was then categorized by the number of 5mm increments it grew from the starting length to final length, that is, the growth in length over a season. Four categories were used, “0” for quahogs that remained within the initial growth increment, “1” for advancement into the next length increment, “2” for advancement by two increments and “3” for advancement by three increments. The number of quahogs falling into each category was then divided by the total number of quahogs within the 5mm increment to yield the proportion of quahogs falling into each of the four categories. This was repeated for all 5mm increments covering the increments from 25mm to 84mm, that is, from the smallest to largest quahog found during the study.

As shown earlier, each survey Excel® sheet has a summary table that calculates number of bushels for each 5mm increment based on the results of the current survey (Table 1). For purposes of projection, a second, similar table follows that preliminarily projects growth based on the incremental growth data derived from the previously described process. For example, if the current survey 40mm-44mm interval, comprised of 71 quahogs, has a proportional incremental advancement of 0.31 for "0" increments, 0.58 for the "1", 0.11 for the "2" and 0.00 for the "3", 0.31 of the number of quahogs in the current survey 40mm-44mm increment would be added to the second table's 40m-44mm increment; 0.58 of the number of quahogs in the current survey 40mm-44mm increment would be added to the 45mm-49mm increment and 0.11 of the number of quahogs in the current survey 40mm-44mm increment would be added to the 50mm-54mm increment, but none would be added into the 55mm-59mm increment. This process would be applied to the quahogs in each increment. Since some of the quahogs in each increment remain within the increment over a growing season, those advancing quahogs are added to those remaining within the increment. An example of the Current year and Following year projection of bushels is shown in Tables 8 and 9, respectively and graphically as a histogram in Figure 12.

The incremental growth data used for this initial step in developing a preliminary model is only from Middle Bay in 2014. The data set can be expanded by incorporation of additional data from other flats produced over subsequent years. Also, no mortality rates, either natural or from harvesting, are included since these are currently unknown; however these can be added once they are known.

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Table 8 Example of Current year survey data

Middle Bay
Current year

Samples	28
Acres	4

Clam size in mm	Conv. Factor	No/Size	%/Size	B/A/SZ	Bu/ac	Bushels	Harvestable Bushels
0-4	0.02	**0**	0.0	0.0	0.0	0.0	0.0
5-9	0.07	**0**	0.0	0.0	0.0	0.0	0.0
10-14	0.27	**0**	0.0	0.0	0.0	0.0	0.0
15-19	0.73	**0**	0.0	0.0	0.0	0.0	0.0
20-24	1.65	**0**	0.0	0.0	0.0	0.0	0.0
25-29	3.18	**5**	1.4	15.9	0.6	2.3	0.0
30-34	5.15	**21**	5.7	108.1	3.9	15.4	0.0
35-39	7.55	**47**	12.8	354.9	12.7	50.7	0.0
40-44	10.75	**71**	19.4	763.4	27.3	109.1	0.0
45-49	14.92	**63**	17.2	939.7	33.6	134.2	0.0
50-54	20.08	**47**	12.8	943.6	33.7	134.8	134.8
55-59	26.05	**38**	10.4	989.9	35.4	141.4	141.4
60-64	33.47	**24**	6.6	803.2	28.7	114.7	114.7
65-69	42.21	**27**	7.4	1139.7	40.7	162.8	162.8
70-74	52.25	**12**	3.3	627.0	22.4	89.6	89.6
75-79	34.20	**7**	1.9	239.4	8.5	34.2	34.2
80-84	79.10	**4**	1.1	316.4	11.3	45.2	45.2
85-88	96.40	**0**	0.0	0.0	0.0	0.0	0.0
.>88		**0**	0.0	0.0	0.0	0.0	0.0
TOTALS		**366**	**100.0**		**258.6**	**1034**	**723**
					% BUSHELS HARVESTABLE		**69.9**

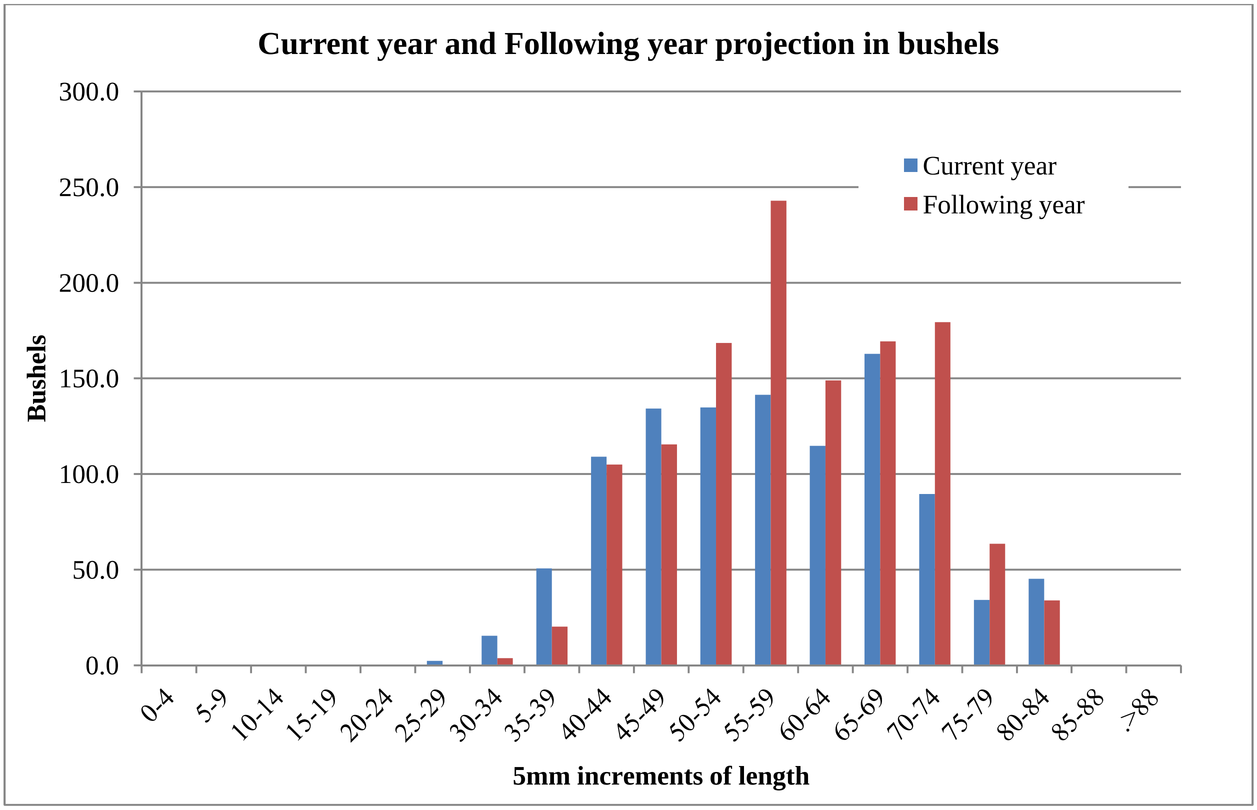
Table 9 Example of Following year projection

Middle Bay
Following year
Samples
Acres

Clam size in mm	**Conv. Factor**	**No/Size**	**%/Size**	**B/A/SZ**	**Bu/ac**	**Bushels**	**Harvestable Bushels**
0-4	0.02	**0**	0.0	0.0	0.0	0.0	0.0
5-9	0.07	**0**	0.0	0.0	0.0	0.0	0.0
10-14	0.27	**0**	0.0	0.0	0.0	0.0	0.0
15-19	0.73	**0**	0.0	0.0	0.0	0.0	0.0
20-24	1.65	**0**	0.0	0.0	0.0	0.0	0.0
25-29	3.18	**0**	0.0	0.0	0.0	0.0	0.0
30-34	5.15	**5**	1.4	26.2	0.9	3.7	0.0
35-39	7.55	**19**	5.1	141.4	5.1	20.2	0.0
40-44	10.75	**68**	18.5	734.7	26.2	105.0	0.0
45-49	14.92	**54**	14.7	808.7	28.9	115.5	0.0
50-54	20.08	**59**	15.9	1179.8	42.1	168.5	168.5
55-59	26.05	**65**	17.7	1700.0	60.7	242.9	242.9
60-64	33.47	**31**	8.4	1042.5	37.2	148.9	148.9
65-69	42.21	**28**	7.6	1185.8	42.3	169.4	169.4
70-74	52.25	**24**	6.5	1255.5	44.8	179.4	179.4
75-79	34.20	**13**	3.5	444.6	15.9	63.5	63.5
80-84	79.10	**3**	0.8	237.3	8.5	33.9	33.9
85-88	96.40		0.0	0.0	0.0	0.0	0.0
.>88			0.0	0.0	0.0	0.0	0.0
TOTALS		**370**	**100.0**		**312.7**	**1251**	**1006**
				% BUSHELS HARVESTABLE			**80.5**

The increase in No/Size between the Current and Following year surveys is due to rounding within each 5mm increment.

Figure 12 Current year bushels and Following year bushels projection for Middle Bay based on marked quahog advancement in 5mm increments



Conclusions and recommendations

The Survey Summary sheet developed here is essentially the same as that currently used by Brunswick for soft-shell clam resource assessments and field survey data can be entered into the Excel® file in the same manner.

The unmarked quahogs with clear growth demarcations did allow for measurements to be taken that generally resulted in higher growth coefficients than the marked quahogs. This is encouraging and suggests that additional measurement collection for the purpose of expanding the data base can be taken without the need for marking, thus avoiding any lag in growth associated with the marking process.

Quahog measurements for this preliminary study were taken from quahogs collected at a specific point within the mid-tide level of the flats. This level was chosen to represent the average time quahogs would be covered by water during an average tide, that is, average feeding time. While useful as a starting point, additional measurements for quahogs growing either higher or lower in the tide range would provide more information to better understand the rates of growth across an entire flat. Since shellfish surveys are conducted over a large portion of the flats in Brunswick quahogs collected from numerous locations and levels of the tide would provide additional information to better understand overall growth within flats; this may also provide data for different substrates, e.g. soft mud, sandy silt, and sand.

For the purposes of this study, quahogs native to the specific area of the flat and growing in undisturbed substrate (until the time of sampling) were intentionally selected to represent natural growing conditions. Measurements from these quahogs did allow growth to be measured over a single season; however, the age and growth rates of quahogs less than 25mm remain unknown. Transplanting seed of known size and age, whether collected from a natural site or purchased from a hatchery, into specific levels of the flat (perhaps three locations from the upper to lower extent of the natural population) would allow growth to be tracked over time. The seed would need to be confined in an easily removed structure, *e.g.* a moderately-sized tray with screened bottom, that would allow annual measurements to be taken late in the fall at the end of the growing season after which the quahogs would be returned to the flat.

Refinement of the growth projection table will require additional work. Data from specific flats, as described above, could be used to develop projections on a flat-by-flat basis, but this will require a substantial effort. Alternatively, the data could be pooled to yield a broader projection to be used for all flats.

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Appendix I

mm	From Belding #/qt	qt/bu	No./bu	5mm inc. mean	sq ft rep/plot	Num/plot =1bu/ac	Multiplier	5mm inc. mean
1	100714	37.237	3750287		21780	172.18950	0.00581	
2	54231	37.237	2019400		21780	92.71808	0.01079	
3	33572	37.237	1250121		21780	57.39764	0.01742	
4	22031	37.237	820368		21780	37.66613	0.02655	**0.01514**
5	16396	37.237	610538		21780	28.03204	0.03567	
6	12589	37.237	468777		21780	21.52326	0.04646	
7	9790	37.237	364550		21780	16.73784	0.05974	
8	7747	37.237	288475		21780	13.24495	0.07550	
9	5299	37.237	197319		21780	9.05964	0.11038	**0.06555**
10	**3691**	**37.237**	**137442**		**21780**	**6.31046**	**0.15847**	
11	2764	37.237	102923		21780	4.72558	0.21161	
12	2252	37.237	83858		21780	3.85022	0.25973	
13	1794	37.237	66803		21780	3.06718	0.32603	
14	1439	37.237	53584		21780	2.46024	0.40646	**0.27246**
15	1175	37.237	43753		21780	2.00888	0.49779	
16	982	37.237	36567		21780	1.67891	0.59562	
17	831	37.237	30944		21780	1.42075	0.70385	
18	706	37.237	26289		21780	1.20704	0.82847	
19	583	37.237	21709	31852.53	21780	0.99675	1.00326	**0.72580**
20	489	37.237	18209		21780	0.83604	1.19612	
21	420	37.237	15640		21780	0.71807	1.39262	
22	358	37.237	13331		21780	0.61207	1.63380	
23	310	37.237	11543		21780	0.53000	1.88678	
24	271	37.237	10091	13762.80	21780	0.46333	2.15831	**1.65353**
25	235	37.237	8751		**21780**	0.40178	2.48895	
26	207	37.237	7708		21780	0.35391	2.82561	
27	185	37.237	6889		21780	0.31629	3.16163	
28	166	37.237	6181		21780	0.28381	3.52351	
29	150	37.237	5586	7022.90	21780	0.25645	3.89935	**3.17981**
30	136	37.237	5064		21780	0.23252	4.30075	
31	124	37.237	4617		21780	0.21200	4.71695	
32	114	37.237	4245		21780	0.19490	5.13072	
33	105	37.237	3910		21780	0.17952	5.57050	
34	97.25	37.237	3621	4291.56	21780	0.16627	6.01442	**5.14667**

mm	From Belding #/qt	qt/bu	No./bu	5mm inc. mean	sq ft rep/plot	Num/plot =1bu/ac	Multiplier	5mm inc. mean
35	90.35	37.237	3364.36		21780	0.15447	6.47374	
36	83.92	37.237	3124.93		21780	0.14348	6.96976	
37	77.90	37.237	2900.76		21780	0.13318	7.50837	
38	72.31	37.237	2692.61		21780	0.12363	8.08881	
39	67.14	37.237	2500.09	2916.55	21780	0.11479	8.71168	**7.55047**
40	62.39	37.237	2323.22		21780	0.10667	9.37493	
41	58.75	37.237	2187.67		21780	0.10044	9.95578	
42	54.65	37.237	2035.00		21780	0.09343	10.70269	
43	51.09	37.237	1902.44		21780	0.08735	11.44847	
44	47.63	37.237	1773.60	2044.39	21780	0.08143	12.28012	**10.75240**
45	44.64	37.237	1662.26		21780	0.07632	13.10265	
46	41.72	37.237	1553.53		21780	0.07133	14.01971	
47	39.17	37.237	1458.57		21780	0.06697	14.93240	
48	37.11	37.237	1381.87		21780	0.06345	15.76131	
49	34.90	37.237	1299.57	1471.16	21780	0.05967	16.75937	**14.91509**
50	32.79	37.237	1221.00		21780	0.05606	17.83782	
51	30.92	37.237	1151.37		21780	0.05286	18.91663	
52	29.13	37.237	1084.71		21780	0.04980	20.07903	
53	27.54	37.237	1025.51		21780	0.04708	21.23828	
54	26.21	37.237	975.98	1091.71	21780	0.04481	22.31599	**20.07755**
55	24.91	37.237	927.57		21780	0.04259	23.48061	
56	23.66	37.237	881.03		21780	0.04045	24.72114	
57	22.53	37.237	838.95		21780	0.03852	25.96103	
58	21.36	37.237	795.38		21780	0.03652	27.38306	
59	20.38	37.237	758.89	840.36	21780	0.03484	28.69981	**26.04913**
60	19.42	37.237	723.14		21780	0.03320	30.11854	
61	18.46	37.237	687.40		21780	0.03156	31.68484	
62	17.49	37.237	651.28		21780	0.02990	33.44209	
63	16.63	37.237	619.25		21780	0.02843	35.17150	
64	15.84	37.237	589.83	654.18	21780	0.02708	36.92564	**33.46852**
65	15.13	37.237	563.40		21780	0.02587	38.65843	
66	14.48	37.237	539.19		21780	0.02476	40.39379	
67	13.85	37.237	515.73		21780	0.02368	42.23120	
68	13.30	37.237	495.25		21780	0.02274	43.97760	
69	12.77	37.237	475.52	517.82	21780	0.02183	45.80283	**42.21277**

mm	From Belding #/qt	qt/bu	No./bu	5mm inc. mean	sq ft rep/plot	Num/plot =1bu/ac	Multiplier	5mm inc. mean
70	12.22	37.237	455.04		21780	0.02089	47.86433	
71	11.73	37.237	436.79		21780	0.02005	49.86378	
72	11.19	37.237	416.68		21780	0.01913	52.27007	
73	10.73	37.237	399.55		21780	0.01834	54.51091	
74	10.31	37.237	383.91	418.39	21780	0.01763	56.73153	**52.24813**
75	9.92	37.237	369.39		21780	0.01696	58.96191	
76	9.50	37.237	353.75		21780	0.01624	61.56864	
77	9.12	37.237	339.60		21780	0.01559	64.13400	
78	8.77	37.237	326.57		21780	0.01499	66.69351	
79	8.40	37.237	312.79	340.42	21780	0.01436	69.63120	**64.19785**
80	8.08	37.237	300.87		21780	0.01381	72.38888	
81	7.76	37.237	288.96		21780	0.01327	75.37398	
82	7.42	37.237	276.30		21780	0.01269	78.82778	
83	7.09	37.237	264.01		21780	0.01212	82.49677	
84	6.77	37.237	252.09	276.45	21780	0.01157	86.39618	**79.09672**
85	6.47	37.237	240.92		21780	0.01106	90.40218	
86	6.18	37.237	230.12		21780	0.01057	94.64435	
87	5.94	37.237	221.19		21780	0.01016	98.46837	
88	5.73	37.237	213.37	226.40	21780	0.00980	102.07716	**96.39802**