

Recruitment of the ocean quahog (*Arctica islandica*): size and age structure in collections with the Dameron-Kubiak dredge in summer 2014.

A final report to Industry Advisory Board (IAB) of the  
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## **Summary**

In sister reports we describe the design and testing of a new dredge, the Dameron-Kubiak (DK) dredge, constructed to capture pre-recruit-to-the-fishery-sized individual ocean quahogs (*Arctica islandica*) and surfclams (*Spisula solidissima*) when operated as part of the annual NEFSC-NMFS survey from an industry vessel, the F/V ESS Pursuit. The dredge was deployed as part of the 2014 survey effort south of Long Island and collected a substantial number of pre-recruit-sized ocean quahogs. A subsample from this collection was aged, and the resultant age versus length relationship employed to recast the field length demographic as an age demographic, and thus illustrate recent recruitment in the target species. This report describes collection of the individuals, age determination method, verification of the age determinations, recasting of the length demographic from field collections as an age demographic, and implications of the data for fishery management.

## **Collection of the pre-recruit-size ocean quahogs in the field**

Ocean quahogs were collected as part of the 2014 NEFSC stock assessment survey (NOAA Cruise EP201401) using a DK hydraulic dredge (150 in = 3.85 m dredge knife) deployed from the F/V ESS Pursuit (164 ft LOA, commercial vessel). Specimens came from a single dredge tow (NMFS-NEFSC cruise reference station number 713) on

8/9/14 (Lat 40 48 431, Long 072 11 236) in 125 ft (39 m) depth of water. The dredge was towed for two minutes at 3 knots with 2:1 scope, a 3.5 in (9 cm) blade depth, and a 20 mm (0.75 in) bar space setting. Catch for the single tow was 95 bushels (1 bushel = 50 L) in volume and included an estimated 39,330 clams with a live weight of 3082 kg. Mean clam density for the tow (all sizes included) was estimated at 55.4 m<sup>-2</sup>. The dredge was still clean and operating well at the end of the tow without accumulation of sediment, indicating no loss of dredge performance throughout the tow length. A random subsample of 5 bushels of clams was separated from the total catch and a length distribution was recorded (NEFSC data archive). Animals <65 mm shell length (SL) were separated from the total catch as the focus of the current study because annual growth increment sizes are larger during the early part of the age versus length relationship (Harding et al 2008, Figure 3). 121 individuals between 17.4 and 70.2 mm SL<sup>1</sup> (maximum dimension parallel to the hinge), covering the majority of mm size class intervals were selected, frozen and transported to laboratory.

### Age determination

A subset of the collected clams were allowed to thaw at room temperature until the soft tissue could be removed without damaging the valves. Valves were cleaned, labeled and measured with respect to both length and height (SH, maximum distance from the hinge to the growing edge). Clams with minimal damage to the valve were then selected for sectioning<sup>2</sup>. Prior to sectioning, individual valves were filled with temperature sensitive modeling clay (craft smart® plastalina modeling clay) to fill the

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<sup>1</sup> Individual SL (mm) values are as follows:

17.4,19.3,20.4,20.8,22.8,24.4,24.5,26.1,26.1,26.5,28.0,28.8,30.3,31.4,33.1,33.5,33.8,34.1,34.2,34.4,34.6,34.8,35.1,35.5,35.8,36.5,37.0,37.1,37.2,37.3,37.6,37.8,38.0,38.0,38.4,38.7,38.7,38.8,39.0,39.6,39.8,40.7,40.9,41.1,41.5,41.6,42.5,42.9,43.2,43.2,43.3,43.3,44.1,44.7,44.9,45.0,45.1,45.8,46.1,46.1,46.3,46.3,46.4,47.1,47.4,47.8,48.0,48.2,48.2,48.3,49.1,49.5,49.5,49.8,49.8,49.8,49.9,50.7,50.7,51.0,51.2,51.4,51.9,52.2,52.4,52.4,53.0,53.5,53.6,54.4,54.4,54.5,54.6,54.6,54.7,54.8,54.8,55.1,55.2,55.2,55.4,55.5,55.9,55.9,56.1,57.8,58.2,58.4,58.6,58.7,59.7,60.0,60.1,62.1,62.7,63.3,63.4,65.3,65.5,65.5,70.2.

<sup>2</sup>Individual SL (mm) values selected for age determination are as follows:

17.4,19.3,20.4,20.8,24.5,26.1,27.8,28.8,31.4,33.3,33.9,34.1,34.2,34.4,34.6,34.8,35.6,36.8,37.2,37.8,38.0,38.3,38.7,38.8,39.1,39.8,40.7,41.3,42.9,44.1,44.7,44.9,45.5,46.1,46.4,46.7,47.8,48.2,49.3,49.9,50.6,50.7,51.4,53.9,54.4,54.8,55.0,55.1,55.4,55.7,58.2.

valve cavity and stabilize the valve against breakage during sectioning, then sectioned along the height measurement with a Buehler slow speed saw. The modeling clay was removed after sectioning. The sectioned valve was cleaned again and the exposed cross-section sanded through a series of fine wet grits on a Buehler grinder and polisher, with a final two-stage polish employing diamond suspension. The polished product was cleaned as necessary with sonication. Sections were observed at both this state of preparation and with the edge stained with Mutvei solution as described by Schone et al (2005)<sup>3</sup>.

The polished and/or polished + stained edge was observed under both axial and oblique light on an Olympus model SZH dissecting scope and an image of the stained edge acquired (Olympus MagnaFire SP). A series of overlapping images were tiled to create a combined hinge to growing edge image using Image J software (free from US NIH at <http://imagej.nih.gov/ij/>).

Two options are available to provide an age at length plot. The first employs a single measure of height and a single corresponding measure of age. Given that the signatures in the valve may suffer from abrasive loss near the hinge in continuing growth, the conservative option here is to count growth lines in the hinge structure. The alternative is to count the growth signatures as they emerge at the growing edge along the sectioned axis of the valve – these are illustrated in the tiled image (examples are discussed in detail later in this text). The latter generates an age versus length plot for an individual animal. The intersections of the annual growth increments with the outer valve surface are marked, numbered sequentially beginning at 1 closest to the hinge, and year specific height values measured using the tool in Image J from the hinge to the intersection to create an individual age versus height plot. The earlier-described individual specific shell length (SL) and height (SH) measures provide a transformation of the above plot to an age versus shell length plot. A suite of plots can thus be collected for the individuals and size range of clams within the collection. Either approach requires a large, high-resolution screen given the typical size of a tiled image (approximately 4

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<sup>3</sup> Mutvei is an equal volume of 25% glutaraldehyde and 1% acetic acid with addition of Alcian Blue (500 mls of each solvent + 5-10 g dye, reduce proportionately for smaller volumes). Staining is accomplished by immersion of the valve in Mutvei at 37°C for 25-30 minutes with gentle mixing, followed by gentle rinsing in deionized water (DI) and air drying. The temperature of immersion is critical, below 37°C the stain will not penetrate the specimen and “peels” on rinsing. This staining mixture is very toxic and appropriate caution is required in use.

GB) – the current effort used a MacBook Pro or a 27” (diagonal measure) iMac with Retina 5K display. Annual growth lines were determined by independent reading of tiled images by a minimum of two readers.

### **Verification of the age determinations using hinge and valve signatures.**

The previous text addresses counting of annual growth lines. There are other, sub-annual lines in both the hinge and valve structure. So care is required to insure that annual lines are clearly discriminated from other lines. In its simplest form the bivalve shell is calcium carbonate crystalline structure deposited over a protein matrix (analogous to fibre glass resin over structural mat). The shell grows by coordinated production of matrix with carbonate deposition. Carbonate can be used as a buffer to maintain pH of the mantle cavity and is subject to dissolution in this process. So there is non-uniformity in the shell structure observed in polished sections driven by the continuous versus the periodic components of shell production and loss. The observations are complicated by the fact that non-uniformity can be produced by growth cessation for varying reasons (tidal, seasonal, spawning, feeding, starvation, physical trauma (exposure and/or burial = hypoxia), annual and probably more) and with obvious varying periodicity. So the signature series in the exposed and polished edge can be very complex. It is appropriate to review the project history in reading ages in polished sections. This is complex but worthy of inclusion given the technical challenges that have been overcome in this project, and the importance of age structure in management of the target species.

### **Age determination methods developed for prior studies in 2005-2008.**

Hinge sections preparation and examination is described in Harding et al (2008). Images were collected with an Olympus Magnafire SP digital camera mounted on an Olympus SZH dissecting microscope. Images were acquired on an IBM PC clone as single images including the entire span of the hinge section. ImagePro software was employed to discriminate annual lines from sub annual lines using a scanning densitometry tool – a digital trace was drawn across the section image, the tool plotted a black to white densitometry scale along the trace giving light versus dark “peaks and valleys”, and these were quantified to discriminate the “darkest” peaks that were defined

as annual lines or signatures. Even though background illumination with this system was not uniform (big image area, incident light) the baseline or background illumination intensity was easily distinguished from that of the image so impact on the discrimination of the light versus dark “peaks and valleys” was not compromised. Additionally, the output data was suitable for quantitative discrimination of “peaks and valleys” thus limiting observer related variation in discrimination. The limitation of the system as described is that the entire image must fit in a maximum size of 1280x1024 pixels. This is acceptable where specimens are relatively young: 50 years on a 800 pixel span is 16 pixels per year, As the specimens get older the number of pixels per year decreases to a point that a single image has limitations in age discrimination, but this was not a problem in the 2005-2008 studies that focused on smaller clams.

**Application of 2008 methods to 2014 (this study) and 2015 (other objectives) collections.**

Consider the challenge of describing age structure of an entire population demographic, or an image employing tiled images (where there are not enough pixels to employ the single image approach as for the 2005-2008 study). The downside of tiling is that it is tedious and time consuming, the background illumination varies across the tiled image thus compromising the use of scanning densitometry to discriminate annual lines, and the tiled images trace the arcs of the valve growth trajectory thus foiling the line densitometry approach, even if the illumination problem could be adequately addressed. Tiled images are large - up to about 5000 x 8000 pixels. These can challenge memory in many desktop computer view and require scrolling on a typical screen (see earlier comment on project hardware). A large, high definition screen and lots of memory allow view of the entire tiled image at once and magnification of sections of that image as required to identify and discriminate lines. Both annual and sub-annual lines can be viewed. The approach to line counting in this situation is to use two or three independent observers to discriminate and count lines based on guidance in the literature and prior experience. Consistent outcomes between readers was obtained, and was pursued to develop age versus length data sets for material collected on both 2014 assessment and early 2015 cruises for other objectives. Note here the use of the term “consistent

outcomes between readers”. This does not mean that all are correct, it could also mean that all were consistently incorrect!

### **Evaluating improved images obtained with improved hardware.**

Frustration with both the tedium of the tiling procedure and the fragility of a decade old image acquisition system prompted the purchase of a new and improved camera system in mid 2015 (Olympus DP73 17MP camera, Cellsens 1.13 software) with funds from the Virginia Higher Education Equipment Trust Fund. With this camera came a vastly improved image quality and a much-improved software for tiled images. The first step in its employment in this and other on-going projects was comparison of images and data for the old camera/software combination with the new camera/software combination. A new challenge arose – yet more lines were visible in the new images! These lines were not as distinct as the presumed annual lines on images acquired by the older camera system, but they were nonetheless present. Which lines are the annual lines and which are the sub annual lines in the new images? The task remained to develop a guideline for discriminating them in this and future studies.

There are two inherent assumptions underpinning the above described age estimation procedures. Assumption #1 is that ocean quahogs grows symmetrically throughout their life span. While growth may not be isodiametric, that is growing equally in posterior and anterior directions, the growth is in constant proportion in anterior and posterior directions. Simply stated, the shape of the clam is constant as size increases. Additionally, the hinge components grow in proportion to the valve – this is very important to what we are about to do. Assumption #2 is that carbonate deposition and dissolution occurs symmetrically across the entire exposed inner valve face as the clam grows and responds to physiological challenges. Again, simply stated, a signature of growth, spawning or any other event is present throughout both the valves and hinge structure. Additionally, the intensity of that signature with respect to adjacent signatures is a constant or near so. A dark/intense growth signature in the valve relative to adjacent signatures remains as a dark signature in the hinge relative to adjacent signatures. Do we have evidence to support these assumptions?

*Assumption #1 evidence.* The study of hinge measurements as proxies for clam height and length measurements have been extensively examined over the past two years as part of the shell breakage and assessment project supported by SCeMFiS. There is a strong relationship between hinge measures and valve dimensions that can be described quantitatively by simple linear regression. Thus in the current application we can assume that the maximum dimension of the hinge remains in proportion to the height and length of the valve.

*Assumption #2 evidence.* We can find no focused examination of this assumption, although mixing in the mantle cavity suggests that a marked deviation from this assumption would be very difficult to effect mechanistically. So let us make the bold step and grant the assumption acceptance.

### **A comparison of age and growth using hinge and growing edge data.**

We presume that signature(s) at the valve growing edge mark growth variations and growth cessation events. Recall that valves are like laminates with most recent layers deposited internally and protruding at the growing edge in a shingle-like fashion beneath older deposited layers. These are permanent signatures extending into the laminate-like body of the valve. The surface component will only be obliterated by valve surface erosion, as can occur near the umbo in older animals where surface structure produced in early life can be eroded away, or by physical damage such as a predator attack.

A valve is sectioned and polished along both the hinge and the entire exposed cut from hinge to growing edge at the maximum dimension from the hinge to the growing edge (height measure). The origin point of growth is identified. The number of annual growth signatures along the axis of the hinge structure is counted. This requires discrimination of annual versus sub-annual lines in first examination. This action may be a source of error through either omission of annual lines or inclusion of sub-annual lines. We will return to this point of concern as we progress. Starting at the same origin point and working along the valve towards the growing edge, external growth signatures are identified and recorded. Again, this requires discrimination of annual versus sub-annual signatures, but the former should be quite distinct. Thus we have two values for age, one

each from internal to the hinge lines and external to the valve surface lines, and we consider them in the following manner.

Are these age estimates the same? If so then the discrimination of lines is consistent in both hinge and valve, and we presume consistent between annual and sub annual lines (but we may be under or over counting both). If the values differ then we are including lines in one but not the other. If this is a reader problem then we collectively revisit how we examine and categorize lines; however, the difference may also be ascribed to valve signatures that have been eroded resulting in their absence in the valve line count.

What is the shape of the growth curve? Measure from the point of origin to each of the lines identified in the first task above. The image software allows this measurement in pixels that can be converted to mm. Now plot these independently as a cumulative distance from the origin (lines 1 through n versus a distance). If clams grow in a typical manner we should observe a typical growth curve emerge in both data sets with a decreasing growth increment with each growth interval (year). If we have too many or too few lines identified throughout the preparation we can still, by rare chance, produce a typical growth curve but this is unlikely. If we have too many lines included at the beginning of the plot, a possibility with the inclusion of sub annual lines early in growth, then the plot will have an s-shaped inflexion. Such a plot provides guidance on which lines are sub annual and should be excluded in final analysis. An additional plot is that of the cumulative measurements (distance to line n in hinge section versus distance to line n in valve section) against each other. If Assumption #1 is correct, as the previously collected hinge breakage data set concludes, then the additional plot will be a straight line passing through the origin.

Again, what if the number of presumed annual lines in the hinge and valve differ? How will this affect the additional plot suggested above, how do we identify corresponding lines on the hinge and valve, and how do we identify extra lines (the latter most probably being in the hinge measurements). If the number of lines differs then arrange the measurements for both hinge and growing edge as two columns in a spread sheet with a plotting tool (Microsoft EXCEL works, choose your own if you want). Plot these as an x versus y scatter plot, and then sequentially add cells as appropriate in the

Table 1. Line number corresponds to the annual lines selected for measurement in the specimen. Lower numbers represent annual lines earlier in the lifespan. Hinge and growing edge measurements are measured from the origin of growth to the selected line. Growing edge adjusted measurements have been manipulated using the above-described iterative approach to produce the plot shown in Figure 1.

line number	hinge measure	growing edge measure	adjusted growing edge
1	0.02	1.21	
2	0.05	1.45	
3	0.08	1.65	
4	0.11	1.93	1.21
5	0.15	2.15	1.45
6	0.19	2.29	1.65
7	0.22	4.19	1.93
8	0.24	6.06	2.15
9	0.27	7.91	2.29
10	0.31	8.34	
11	0.33	9.3	
12	0.39	10.04	4.19
13	0.46	10.5	
14	0.53	10.81	6.06
15	0.59	11.96	
16	0.66	15.86	7.91
17	0.69	16.85	8.34
18	0.73	17.03	
19	0.77	17.95	9.3
20	0.82	18.35	10.04
21	0.91	21.47	10.5
22	0.97	27.02	10.81
23	1.05	29.65	11.96
24	1.12	35.06	
25	1.15	35.78	
26	1.27	37.2	
27	1.35	39.19	15.86
28	1.46		16.85
29	1.58		17.03
30	1.73		17.95
31	1.85		18.35
32	1.95		
33	2.05		
34	2.15		21.47
35	2.22		
36	2.31		
37	2.41		
38	2.51		27.02
39	2.7		
40	2.78		29.65
41	2.97		
42	3.08		
43	3.26		35.06
44	3.38		35.78
45	3.57		37.2

column with the lesser number of values to produce a scatter plot with a linear relationship (see Table 1 and Figure 1). In essence the plot is used to identify lines on the hinge for which there is no corresponding line on the growing edge. This is an iteration process in that the lines in both instances are date marked using the tree ring dating application available in Image J. Use these dates as reference points to find corresponding lines on the hinge and at the growth edge, then look for the “missing” line at the growth edge after the matching process to produce the linear fit.

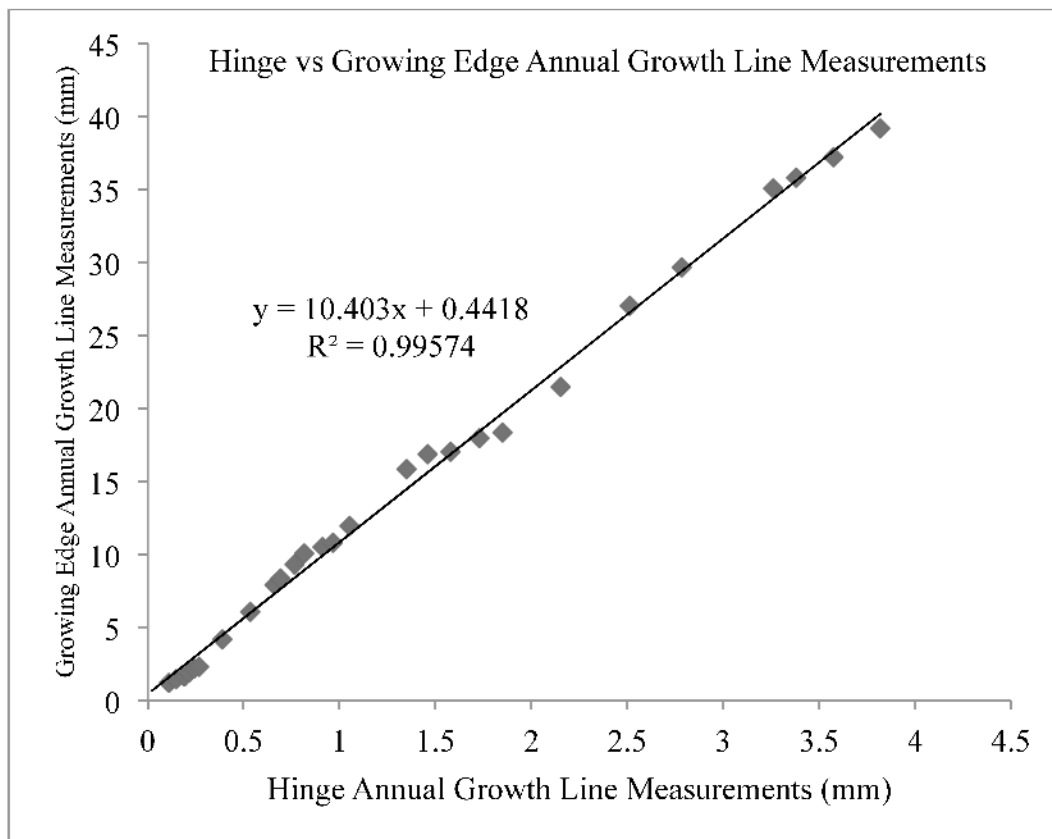


Figure 1. Plot of data from Table 1. The linear relationship portrayed in this plot was achieved by manipulating the alignment of growing edge measurements to corresponding hinge measurements (see text)

Observations on a small specimen ~12 mm SL and ~ 3 years old are given with Figure 2. This hinge section has 2 bold lines that are evident on both the polished specimen and the same specimen after Mutvei staining. The stain both etches the surface

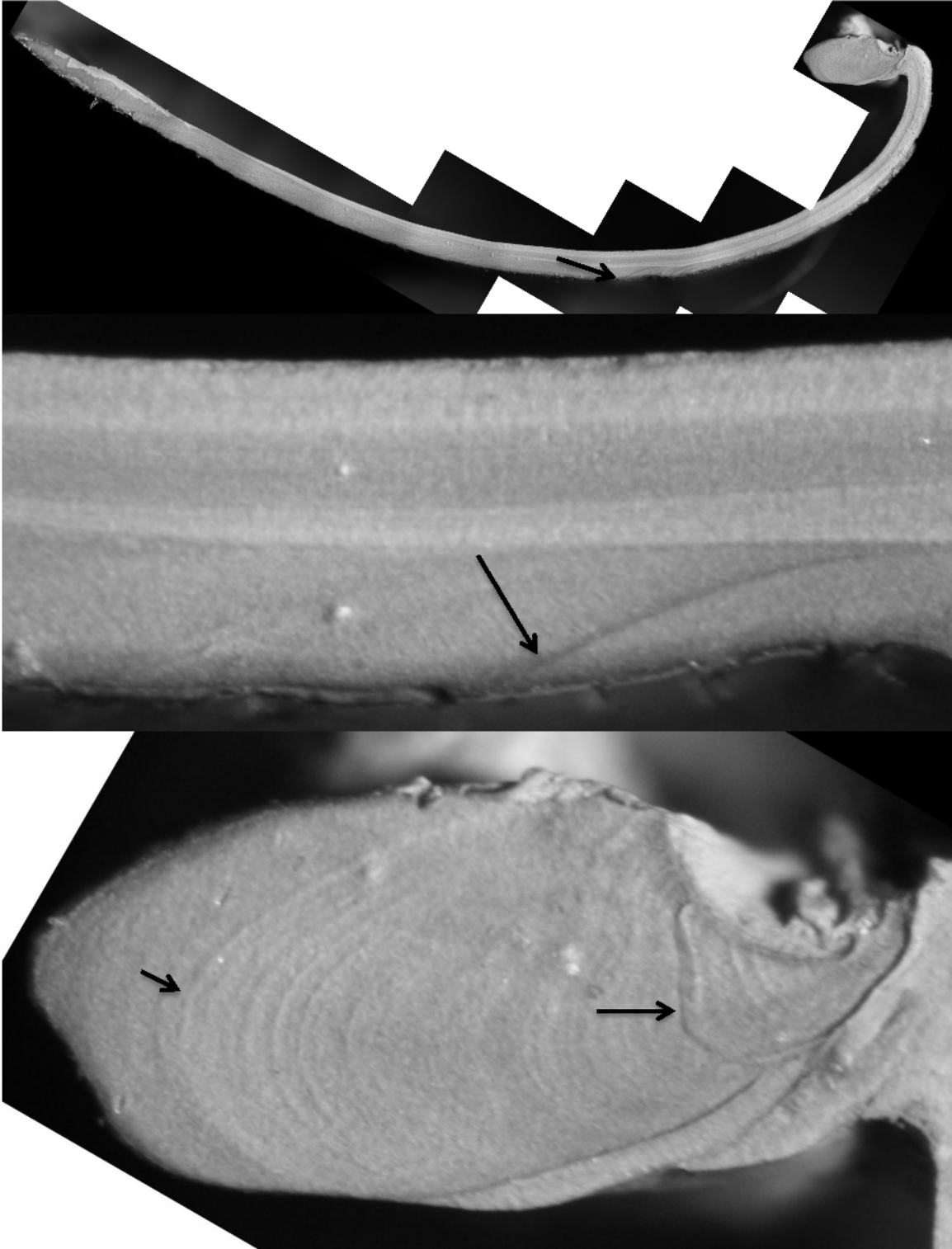


Figure 2. The top image shows a complete cross-section of a 3-year-old ocean quahog after staining and etching with Mutvei solution. The middle image shows an annual growth line as it emerges along the growing edge of the valve. The bottom image shows a close-up view of the hinge region of the cross-section, including the two annual lines noted by the black arrows in the image.

and stains to enhance the view of the micro-topography under oblique incident light that remains after the differential etching of the carbonate rich versus matrix rich components of the shell. Between the bold, presumed annual lines are a series of lines of lesser intensity. If these are viewed towards the valve growing edge they, like the annual lines, “curl” from being members of the laminate like appearance of layers in the shell towards the shell external surface, eventually intersecting with that surface. The aggregation of the lesser lines immediately prior to the annual line, especially the second annual line, rather than an even distribution between annual lines, is informative. Recall that this specimen was collected south of Long Island on the NEFSC survey in August 2014. It has a distribution of annual growth rings wherein the measure between the growth origin and the first line was less than that between the first and second lines, and the period after the second to the growing edge was also less than the distance between the first and second lines. Why? Consider that adult clams spawn in mid summer to early fall (Mann 1982) and that larvae are in the water column for in excess of 35 days (Lutz et al (1982). Metamorphosis to the benthos occurs in early fall as the thermocline decays and water column mixing occurs. With vertical mixing nutrients are injected from the benthos to the water column, and a fall phytoplankton bloom results. A growth event at this time is expected for filter feeding clams as that productivity is mixed back to the bottom. A series of blooms coincident with wind events and fall mixing leaves a series of sub annual growth lines until falling water temperature eventually results in overwinter cessation of growth and an annual growth line. The young of the year (YOY) individuals do not experience a complete growing season prior to the first annual growth line. They also do not complete a full growing season during the year of collection - hence the observed pattern. So, we can relate the sub annual patterns to the ecology at the individual level. On-going studies in our lab from field collections in 2014 and 2015 suggest that ocean quahogs do not exhibit first maturation at this early age, so a spawning line or lines would not be expected in this specimen. Also, the sequence of sub annual lines immediately prior to the annual growth line suggest that closely paired growth lines in an otherwise regular sequence may just as easily represent a single year rather than a poor growth year inserted in a sequence of comparable years. Close examination of these

“doublets” is strongly suggested with a caution that they are probably better counted as single year records rather than two sequential years.

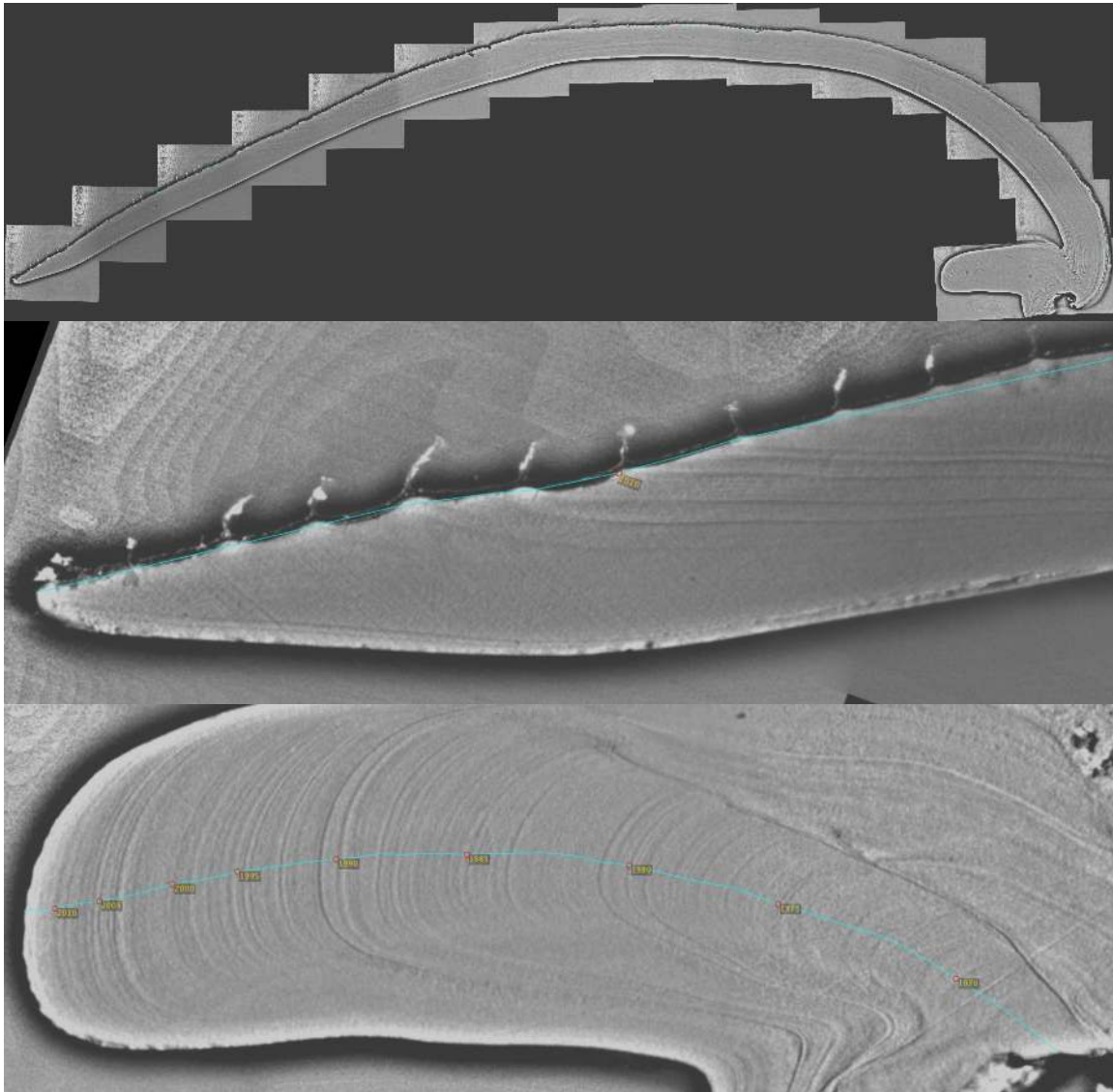


Figure 3. The top image shows the complete cross-section of specimen ~ 45 years old. The middle image shows a close-up view of the extreme growing edge of the valve. In this view can be seen several growth lines emerging on the surface of the valve. The bottom image shows a close-up view of the hinge region of the cross-section. At least 40 years worth of growth lines can be seen here, as well as many more sub-annual lines.

Observations on a specimen ~ 45 years old are given with Figure 3. Counting of both hinge and growing edge lines produced a scenario as described earlier wherein the

number of hinge lines exceeded that counted in growing edge lines, and the matching/plotting procedure using EXCEL was employed to identify appropriate data point pairs on a straight line plot. Modest manipulation resulted in a very good ( $r^2 > 0.99$ ) fit of line. The data plot suggests too many lines included at the early growth section of the hinge, and a very small number of omissions in the growing edge record. Working backwards from the data plot to the hinge image with the dated record the suggestion is that some of the early hinge lines are of lesser intensity and easily re-categorized as sub annual rather than annual, but several annual lines may remain unidentified at the growing edge.

### **Recasting of the length demographic from field collections as an age demographic and implications of the data for fishery management.**

The current study, like that of Harding et al (2008), developed an age versus shell length plot for small ocean quahogs (Figure 4); several important points emerge. The data of Harding et al. (2008, grey diamonds, broken line fit) overlap with that developed by Long (2014 collection, open squares, solid line fit) for this study. The lines are power fits simply to illustrate trends. Within both data sets there is both considerable variation in shell length at age (in Harding et al 40y includes 50 to 80 mm, Long at 20y includes 35 to 55mm), and variation in age at shell length (Harding et al 50mm includes 10 to 40y, Long at 50mm includes 18 to 32y). Thus while fitted age at length estimators can be generated for discussion purposes, the variation around such a fit must be considered of importance as well. None the less the slow growth is notable – using a 65 mm shell length cut off as approximate selectivity for a commercial dredge indicates that recruits to the fishery can easily exceed 40y in age, thus information on these four decades of immediate past recruitment are not fully represented in current assessments and cause for discussion at the management council level. The DK dredge alleviates that problem in that it provides for collection of pre-recruit to the fishery sizes as illustrated by the data summarized in the footnote on page 2 of this report and in the Long 2014 data in Figure 4 (Data in Appendix 1).

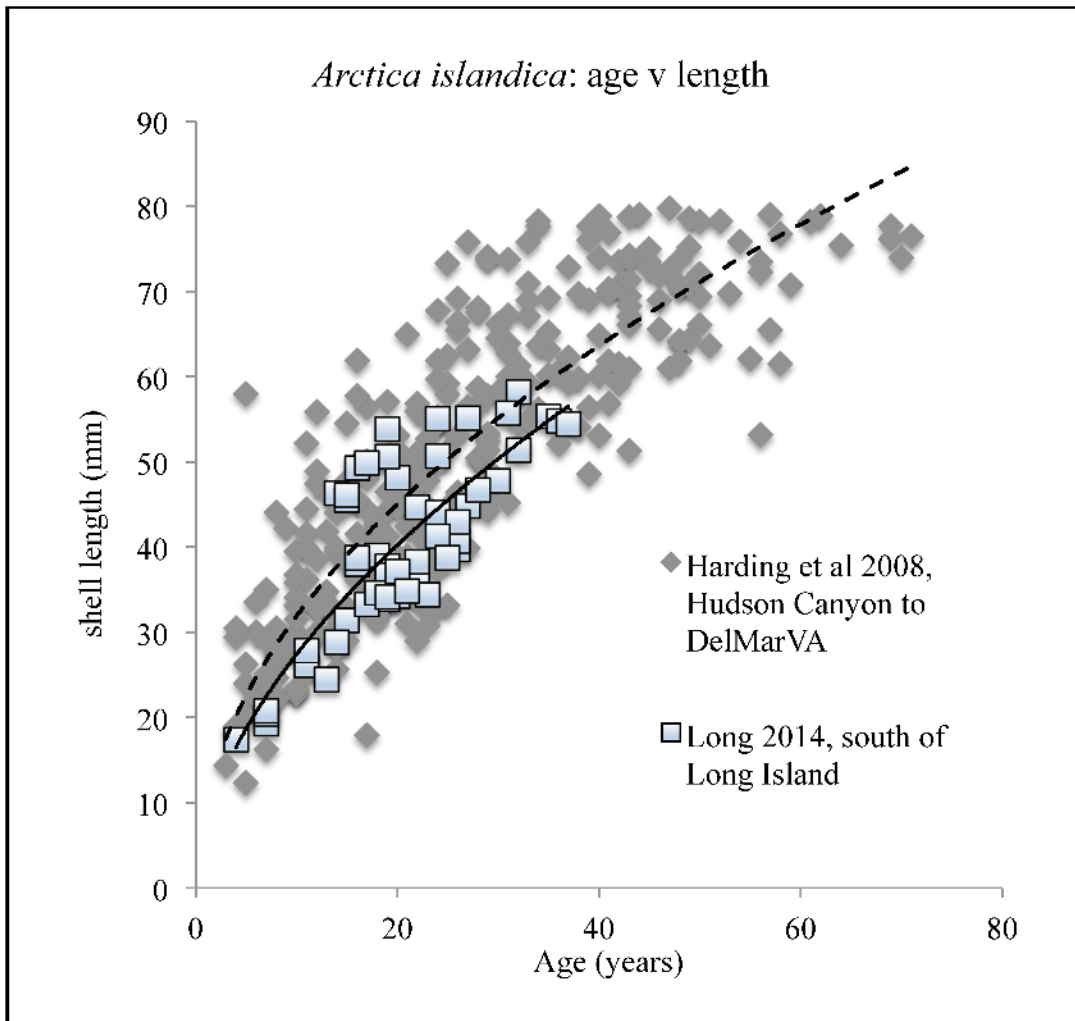


Figure 4. Age versus shell length (mm) for ocean quahogs (*Arctica islandica*) as reported by Harding et al (2008) and for the current study by Long on 2014 collections.

To further illustrate the demographics of pre-recruit to fishery size clams a length demographic is taken from the 2014 lined dredge versus DK dredge study, as described in the sister report of Hennen, and plotted as both abundance (number in size class) versus shell length (Figure 5), and number in age class versus age (Figure 6). Immediately evident in both Figures 5 and 6 is the consistent representation of pre recruit to the fishery size and age classes from approximately 38 mm in shell length and 15 y of age and upwards. Recall that the DK dredge has a minimum bar spacing of 20 mm, thus retention is based not on shell length but the smaller of length, width and height of the live quahog. In a sister report on dredge design considerations a plot is presented of shell

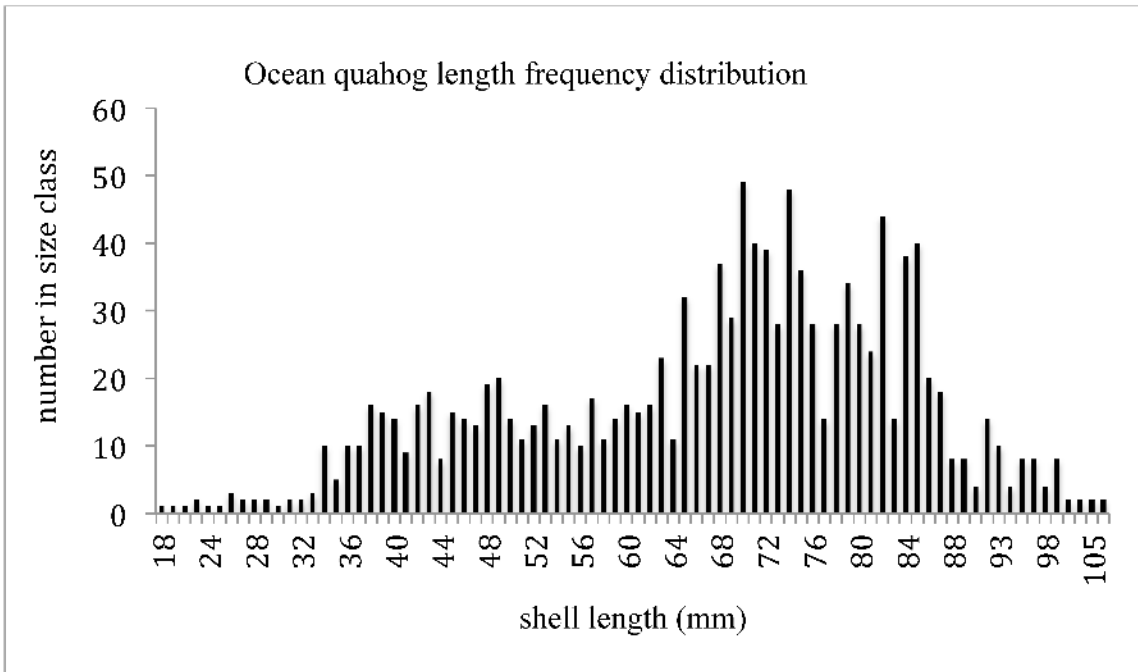


Figure 5. Length frequency distribution of ocean quahogs in lined dredge and DK dredge studies, south of Long Island NY, 2014

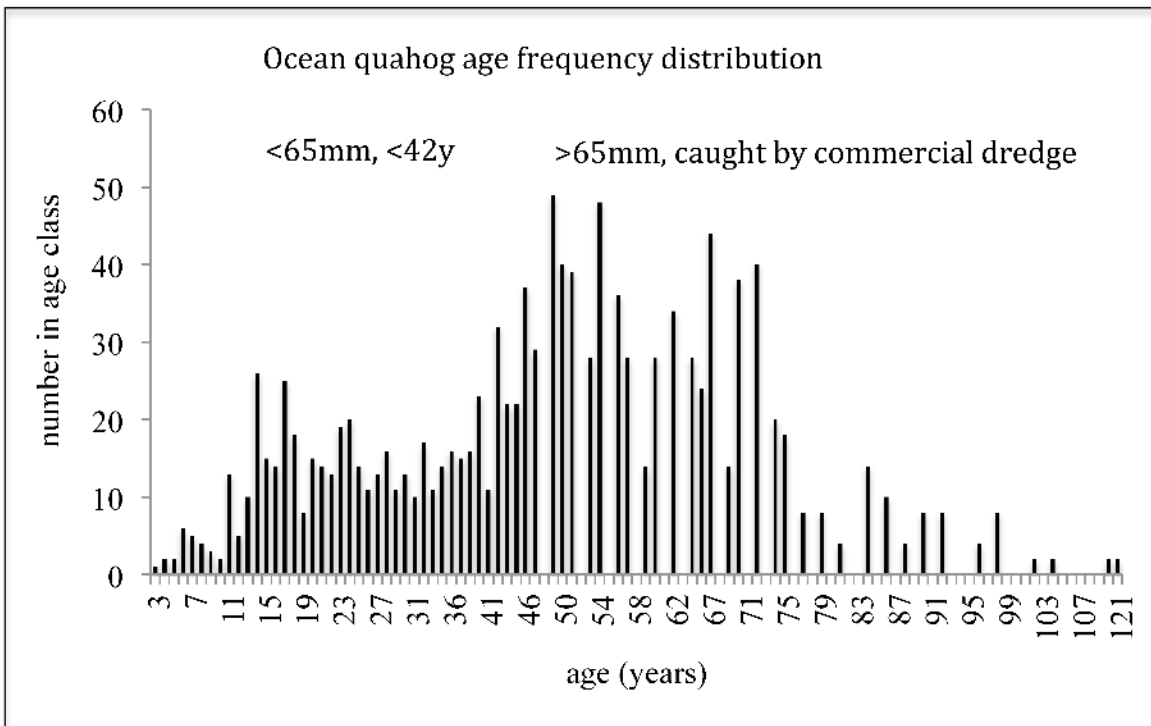


Figure 6. Age frequency distribution of ocean quahogs in lined dredge and DK dredge studies, south of Long Island NY, 2014

length versus shell height and shell width of ocean quahog shells – that plot illustrates a shell width (smallest dimension) of 20 mm approximating to a shell length of 40 mm. Thus shell lengths below 40mm are retained with lower efficiency than larger clams, especially so when the dredge is operated to be clean of sand and sediment (its major design consideration). None the less clams with shell lengths as small as 14 mm with an approximate age of 3y were still retained. The data illustrated in Figures 5 and 6 do much to allay fears of recent recruit failures in ocean quahogs; indeed they do much the opposite.

The DK dredge has proven its worth in demonstrating recruitment in situations where such data is not available through the survey dredge. Time at sea in survey mode is limited given the expense of ship time. The desire to maximize the number of stations occupied to increase statistical confidence in general stratified random survey data is important; however, the demonstrated performance of the DK dredge in providing a valuable juvenile abundance index for ocean quahogs also warrant serious discussion of its general use in surf clam and ocean quahogs stock assessment in years to come.

### **Literature cited**

- Harding, J. M., S. E. King, E. N. Powell, and R. Mann. (2008). Decadal trends in age structure and recruitment patterns of ocean quahogs *Arctica islandica* from the Mid-Atlantic Bight in relation to water temperature. *J. Shellfish Research* 27(4): 667-690).
- Lutz, R. A., R. Mann, J. G. Goodsell, and M. Castagna. 1982. Larval and Early Post-larval Development of the Ocean Quahog *Arctica islandica*. *Journal Marine Biological Association United Kingdom*, 62: 745-769.
- Mann, R. 1982. The Seasonal Cycle of Gonadal Development in *Arctica islandica* on the Southern New England Shelf. *Fishery Bulletin*. 80(2): 315-326.
- Schone, B.R., E. Dunca, J. Fiebig and M. Pfeiffer (2005). Mutvei's solution: An ideal agent for resolving microgrowth structures of biogenic carbonate. *Palaeogeography, Palaeoclimatology, Palaeoecology* 228: 149-166.

Appendix 1: SL (mm) and associated age estimates (yr) from Harding et al (2008) and and Long (2014, this study)

SL	age	SL	age	SL	age	SL	age	SL	age	SL	age
12.4	5	33.0	15	44.1	8	53.3	29	64.5	30	75.8	33
14.4	3	33.1	10	44.2	26	54.1	38	64.8	40	75.9	54
16.3	7	33.2	25	44.2	29	54.4	32	65.0	21	76.0	39
17.9	17	33.3	12	44.3	19	54.5	15	65.2	35	76.2	69
18.5	4	33.5	13	44.4	17	54.5	24	65.4	26	76.5	71
19.0	4	33.6	6	44.5	11	54.6	24	65.5	57	76.8	58
20.1	5	33.6	12	44.6	20	55.0	23	65.6	46	76.9	41
22.2	8	33.9	22	44.7	25	55.0	33	66.1	43	77.7	34
22.4	6	34.1	10	44.8	23	55.3	24	66.1	50	77.7	39
22.5	8	34.6	19	45.0	21	55.9	12	66.2	30	77.7	69
22.7	6	34.8	13	45.2	22	56.0	22	66.4	26	78.2	50
22.8	10	35.0	7	45.2	31	56.2	34	67.1	33	78.2	61
23.0	7	35.0	19	45.6	16	56.4	17	67.1	43	78.3	34
23.3	10	35.0	22	45.7	29	56.4	39	67.2	31	78.3	52
23.3	10	35.6	18	46.0	20	56.5	27	67.6	28	78.6	49
23.4	10	35.8	10	46.0	29	56.6	28	67.8	24	78.7	43
23.8	7	36.1	16	46.1	21	56.9	22	68.1	28	78.9	40
24.0	5	36.1	19	46.4	14	56.9	41	68.3	43	78.9	62
24.7	8	36.2	11	46.4	26	57.1	19	69.0	33	79.0	44
25.1	7	36.5	18	46.5	13	57.8	16	69.0	39	79.0	57
25.2	11	36.8	10	46.5	19	57.8	29	69.0	46	79.8	47
25.3	18	36.8	17	46.5	27	57.9	25	69.2	26		
25.7	14	37.2	18	47.3	22	58.0	5	69.3	35		
26.3	5	37.3	24	47.5	12	58.1	32	69.4	50		
26.7	8	37.6	17	47.8	15	58.2	30	69.5	43		
26.8	11	38.1	20	47.8	23	58.7	28	69.7	38		
27.0	11	38.2	15	48.1	17	59.2	25	69.8	53		
27.1	8	38.2	20	48.5	22	59.2	37	69.9	41		
27.2	11	38.5	12	48.6	21	59.2	42	70.3	41		
27.7	8	38.5	16	48.6	39	59.3	33	70.4	48		
28.0	9	38.6	24	48.9	12	59.4	32	70.7	42		
28.2	14	39.0	16	48.9	22	59.7	24	70.7	48		
28.3	9	39.0	20	49.2	29	59.8	38	70.8	49		
28.3	10	39.0	21	49.6	23	60.0	31	70.8	59		
28.5	9	39.5	10	49.8	24	60.1	40	71.0	33		
29.0	7	39.5	14	49.9	16	60.2	35	71.4	43		
29.0	15	39.8	24	50.1	17	60.6	36	71.8	46		
29.0	22	39.9	11	50.2	21	60.9	43	72.1	50		
29.4	4	39.9	14	50.3	20	61.0	47	72.3	56		
29.7	12	39.9	27	50.4	22	61.3	32	72.6	47		
29.9	10	40.7	23	50.5	28	61.5	42	72.9	37		
30.0	6	41.1	18	50.5	28	61.5	58	72.9	45		
30.0	12	41.3	19	50.6	19	61.8	41	73.3	25		
30.5	4	41.5	16	51.1	22	61.8	48	73.5	42		
30.5	8	41.6	11	51.3	25	61.9	16	73.5	45		
30.6	14	41.6	22	51.3	43	61.9	24	73.5	56		
30.8	23	41.7	18	51.4	20	62.1	55	73.8	29		
31.0	21	41.8	13	51.4	29	62.3	37	73.8	31		
31.4	18	42.1	18	51.7	32	62.4	25	73.8	43		
31.5	10	42.2	9	52.1	36	62.7	31	73.8	48		
31.6	15	42.4	21	52.2	11	63.2	27	74.0	40		
32.0	14	42.5	18	52.4	29	63.2	35	74.0	70		
32.0	18	42.6	18	52.7	23	63.6	51	74.1	29		
32.4	23	43.2	18	53.0	26	63.7	34	74.2	43		
32.6	18	43.2	23	53.0	29	63.9	31	75.0	45		
32.7	24	43.3	22	53.1	20	64.1	48	75.2	49		
32.8	12	44.0	14	53.1	40	64.2	48	75.4	64		
32.8	18	44.0	22	53.2	56	64.4	49	75.8	27		