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Archaeology, taphonomy, and historical ecology of Chesapeake Bay blue crabs (*Callinectes sapidus*)

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ABSTRACT

Blue crabs (*Callinectes sapidus*), an important commercial and ecological species in the eastern United States, are a key part of Chesapeake Bay culture, tourism, and fisheries. Blue crab remains are rare in Middle Atlantic North American archaeological sites, however, leading to speculation that Native Americans did not eat crabs, that taphonomic processes and/or excavation strategies are not suitable to crab preservation or recovery, or that seasonal use of estuarine foods limited blue crab exploitation. We explore these hypotheses through examination of archaeological blue crab remains, analysis of allometric relationships to investigate changes in crab size, and experiments (soil pH, animal scavenging, etc.) focused on the preservation and recovery of blue crab remains. These data demonstrate that blue crab remains are fragile and that their preservation and recovery is strongly influenced by taphonomic processes, excavation strategies, and perhaps seasonal exploitation. Despite these potential biases, blue crabs have been identified in 93 Chesapeake Bay archaeological sites from at least 3200 years ago through the 20th century. Blue crabs were an important food source for Native Americans, EuroAmerican colonists, and African Americans, with size estimates demonstrating that a range of crab sizes were harvested in the past, including a higher proportion of large crabs than those found in the Bay today under the intense modern fishery. Our experimental and archaeological analyses provide an approach that can be used generally by archaeologists working in marine environments and on other species around the world.

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1. Introduction

Crabs, lobsters, and other crustaceans have been important food sources for humans for millennia. Freshwater crab (*Potamon* sp.) remains from Israel date to nearly 800,000 years ago, for instance, and are one of the early aquatic species known to have been harvested by hominins (Ashkenazi et al., 2005). From dungeness crab (*Metacarcinus magister*) in the Pacific Northwest (Losey et al., 2004) to land crabs (Gecarcinidae) in the Caribbean (Newsom and Wing, 2004), brown or white shrimp (*Farfantepenaeus/Litopenaeus*) in Georgia (Quitmyer and Reitz, 2006), and cape rock lobster (*Jasus lalandi*) in South Africa (Jerardino and Navarro, 2002), archaeological data demonstrate that humans often relied on these organisms as sources of protein and other nutrients. Despite their widespread distribution, the remains of crabs, lobsters, and crustaceans sometimes preserve poorly in archaeological sites or are only recovered using flotation or other specialized sampling techniques, including fine screen (1/16-inch) recovery (see Jerardino and Navarro, 2002; Voorhies et al., 1991).

Callinectes sapidus, the blue crab, is an emblematic species of the Chesapeake Bay and is part of a large-scale commercial and recreational fishery along the Atlantic and Gulf coasts of the United States (Fig. 1). Despite their modern abundance and popularity, blue crab remains generally appear to be rare in prehistoric and historical sites of Chesapeake Bay and the North American Middle Atlantic region. This has led to debate among researchers about

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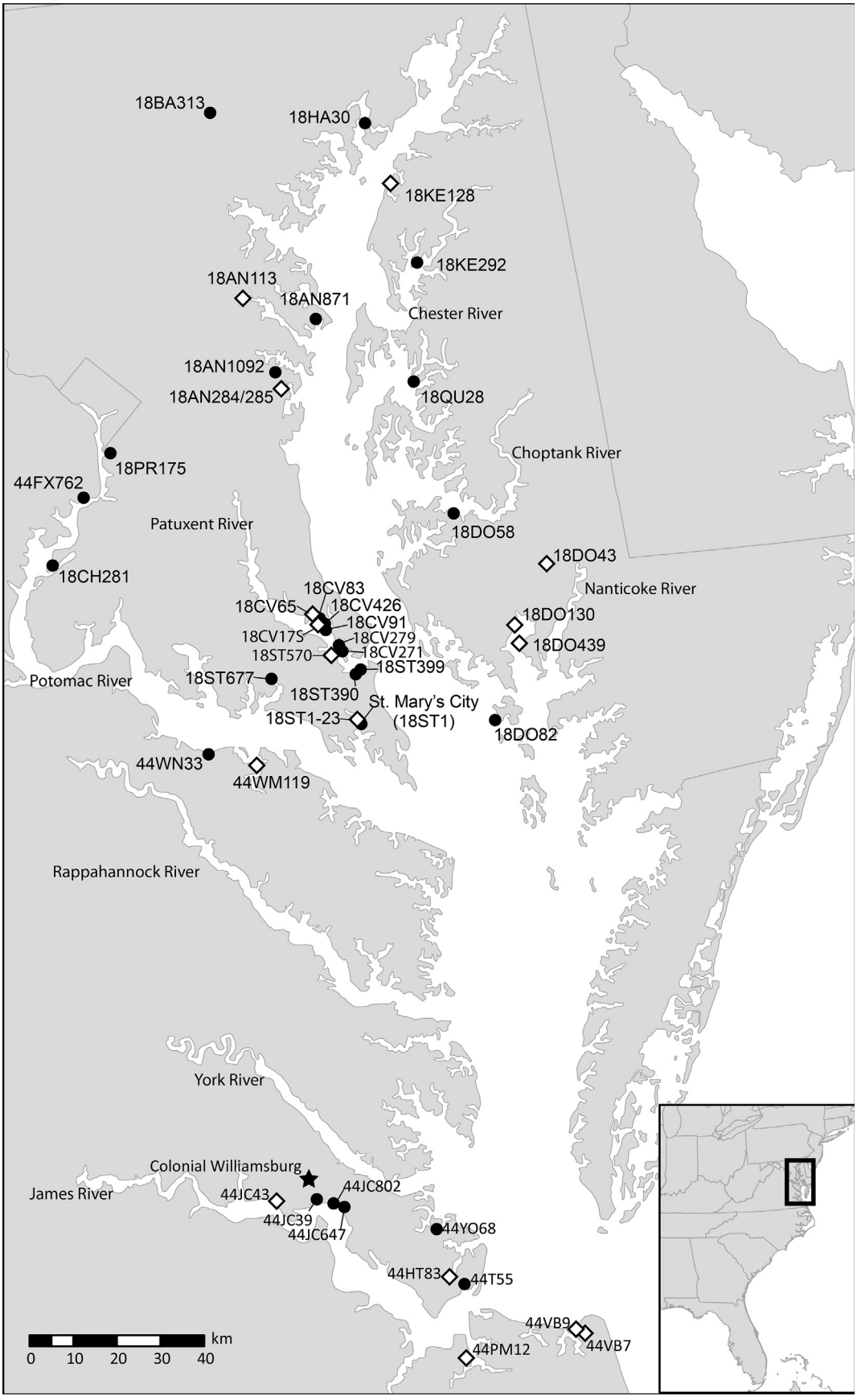

Fig. 1. Archaeological sites with blue crab remains. Diamonds are for Native American sites and dark circles indicate Colonial/Historic sites. The star at Colonial Williamsburg indicates multiple Colonial/Historic sites.

whether blue crab remains are scarce or absent because of preservation issues (Whyte, 1991), food preferences that precluded eating crabs (Mounier, 2003), or seasonal exploitation of estuaries with people focusing on oysters (*Crassostrea virginica*) in colder fall and winter months when crabs were not available (McNett and Gardner, 1971:28; see also Whyte, 1988). Consumption and disposal of crabs at separate sites from oysters, which reduce soil acidity and enhance drainage, or consumption of crabs during the soft shell phase that follows molting, might also prohibit the preservation of crab remains. Mounier (2003:142) argued that for coastal New Jersey: "*Crustaceans—even easily captured species such as the common blue crab* (*C. sapidus*)*—are almost never recovered from archaeological sites. This situation suggests the possibility of a culturally prescribed food prohibition rather than a lack of organic preservation.*" Although the Number of Identified Specimens (NISP) are often small, *C. sapidus* remains, especially chelipeds (claws), have been reported in prehistoric archaeological sites throughout the eastern US, including New York (Claassen and Whyte, 1995), Massachusetts (Little, 1984), Georgia (Quitmyer and Reitz, 2006), and Virginia (Waselkov, 1982).

In this paper, we explore the Native American and Colonial blue crab fisheries on the Chesapeake Bay through experiments on modern crab remains, synthesis of archaeological crab remains from throughout the region, and an allometric analysis of crabs from zooarchaeological collections. We test three hypotheses related to crab exploitation: 1) People, especially Native Americans, did not eat crabs; 2) Preservation, deposition, and or excavation techniques are not suitable for preservation and or/recovery of blue crab remains; and 3) People harvested crabs but they were at seasonally focused spring/summer camps not readily identified archaeologically and/or with poor preservation due to the absence of oyster shells. To evaluate these hypotheses, we develop test expectations about ancient harvest of crabs based on modern crab biology. We then assess taphonomic and preservation issues through a series of experiments that investigate the effects of soil pH and animal scavenging. Finally, we explore the historical ecology of Chesapeake Bay blue crabs by analyzing and synthesizing all known prehistoric and historic archaeological crab remains. As a first step toward incorporating blue crabs into standard zooarchaeological research in eastern North America, we present regression methods to estimate blue crab size from cheliped fragments.

2. Blue crab biology and ecology

C. sapidus has a large biogeographic range extending along the western Atlantic Coast from Nova Scotia to Argentina and into the Gulf of Mexico (Williams, 2007). The fossil record of *Callinectes* suggests that the genus has persisted since the Pleistocene, Miocene, or perhaps earlier, though distinguishing between *C. sapidus* and other species is difficult (Williams, 2007:15). According to Williams (2007:16), specimens identified to *C. sapidus* from Maryland to Florida are likely confined to the Pleistocene.

Blue crabs mate from May to October in the Chesapeake Bay primarily in low-salinity waters (Hill et al., 1989). After mating, females migrate to high-salinity waters in lower estuaries, sounds, and nearshore spawning areas (Aguilar et al., 2005). During winter, crabs burrow in the mud and then spawn the following summer some 2–9 months after mating. After a series of larval stages, first crab instars emerge and are typically about 2.5 mm in carapace width (CW). The growth of juvenile crabs occurs during a series of molt and intermolt phases largely in lower saline waters of rivers and upper estuaries. After about 0.5–1.5 years, crabs reach sexual maturity at about 110–180 mm CW, after which males continue to grow but females do not (Hines, 2007:565). The average crab lives about three years in the Chesapeake Bay, but a small proportion lives 4–5 years and less than 1% live 6–8 years (Hines, 2007). Each molt results in a size increase, but rates of growth vary with age and sex and are influenced by temperature and access to food. Mature males in Chesapeake Bay commonly reach sizes of 180–200 mm CW, with a few growing to >250 mm CW (Hines, 2007).

Blue crabs provide important ecological services as both predator and prey. Juvenile and adult crabs are generally opportunistic scavengers or carnivores focused on bottom-dwelling invertebrates, especially bivalve molluscs. Blue crabs can tolerate salinities ranging from ocean conditions (34 ppt) to freshwater in rivers, but salinities of at least 22–28 ppt are needed for normal hatching and development of larvae. Crabs are active at temperatures of 12–28 °C and can tolerate low temperatures to 3 °C and high temperatures to 30 °C, depending on duration. *C. sapidus* are known to inhabit all areas of estuaries, with shallow sea grass and near-shore habitats serving as important nurseries for juveniles, with mature males preferring channels of rivers and upper estuaries from depths of 0.5–20 m.

The blue crab fishery is the largest crab fishery in the United States. However, the amount of crabs harvested by the fishery fluctuates wildly per year and is affected by recruitment, habitat quality, cold winter temperatures, salinity, parasites, water quality, and other variables. The fishery is highly seasonal and yields have generally declined since the mid-1980s, with Chesapeake Bay having the highest yield of crabs in North America in most years (Hines, 2007:572). Although crabs were eaten by colonists in the 1600–1700s, transportation of crabs was difficult without refrigeration and early on they were eaten only near where they were caught (Kennedy et al., 2007:655). Little is known about the technologies used to harvest crabs by Native Americans and colonists, though it is likely people used baited string lines and long handled dip nets ("scapping") much like people do today. Blue crabs were highly abundant in the Chesapeake Bay in the late 1800s, but they had a limited market with a casual fishery until the 20th century. Today blue crabs are intensively fished and regulations require at least 25% of Chesapeake's spawning stock be preserved (Miller et al., 2011), leading to contention between watermen and regulators (Paolisso, 2002). The decline in *C. sapidus* has prompted increased import of crabs from southeast Asia and South America, ultimately having important ramifications for cultural traditions in the Chesapeake region (Paolisso, 2007).

Blue crab anatomy provides important indications of which crab parts are most likely to preserve and be recovered archaeologically. The skeleton and appendages are largely composed of chitin and lightly mineralized layers (especially calcium carbonate [$CaCO_3$]) and are considerably thinner and more friable in blue crabs than some other harvested crab species (e.g. dungeness crab). The more robust chelipeds (claws) are the most likely to preserve archaeologically, followed by anterolateral spines, legs, body fragments, and possibly other calcified body parts, including mandibles (Fig. 2). The vast majority of crab parts recovered and reported in eastern US archaeological sites are chelipeds. Paleontologists have also noted the limited preservation of crab parts, with experimental studies in marine sediments showing preservation of chelipeds, mandibles, and the last anterolateral spine over all other body parts (Krause et al., 2011; Mutel et al., 2008). We did not observe mandibles in the samples we analyzed, possibly because they may not have been identified as crab parts by the original researchers, suggesting that future research may also identify these parts in Chesapeake Bay area sites.

Blue crab chelipeds are also easily distinguished from those of other potential estuarine crab species in Chesapeake Bay. There are a few species with somewhat similar cheliped morphology (*Callinectes similis*, *Ovalipes* spp., *Portunus* spp., and *Arenaeus cribrarius*), but these are generally smaller, much less abundant, rarely

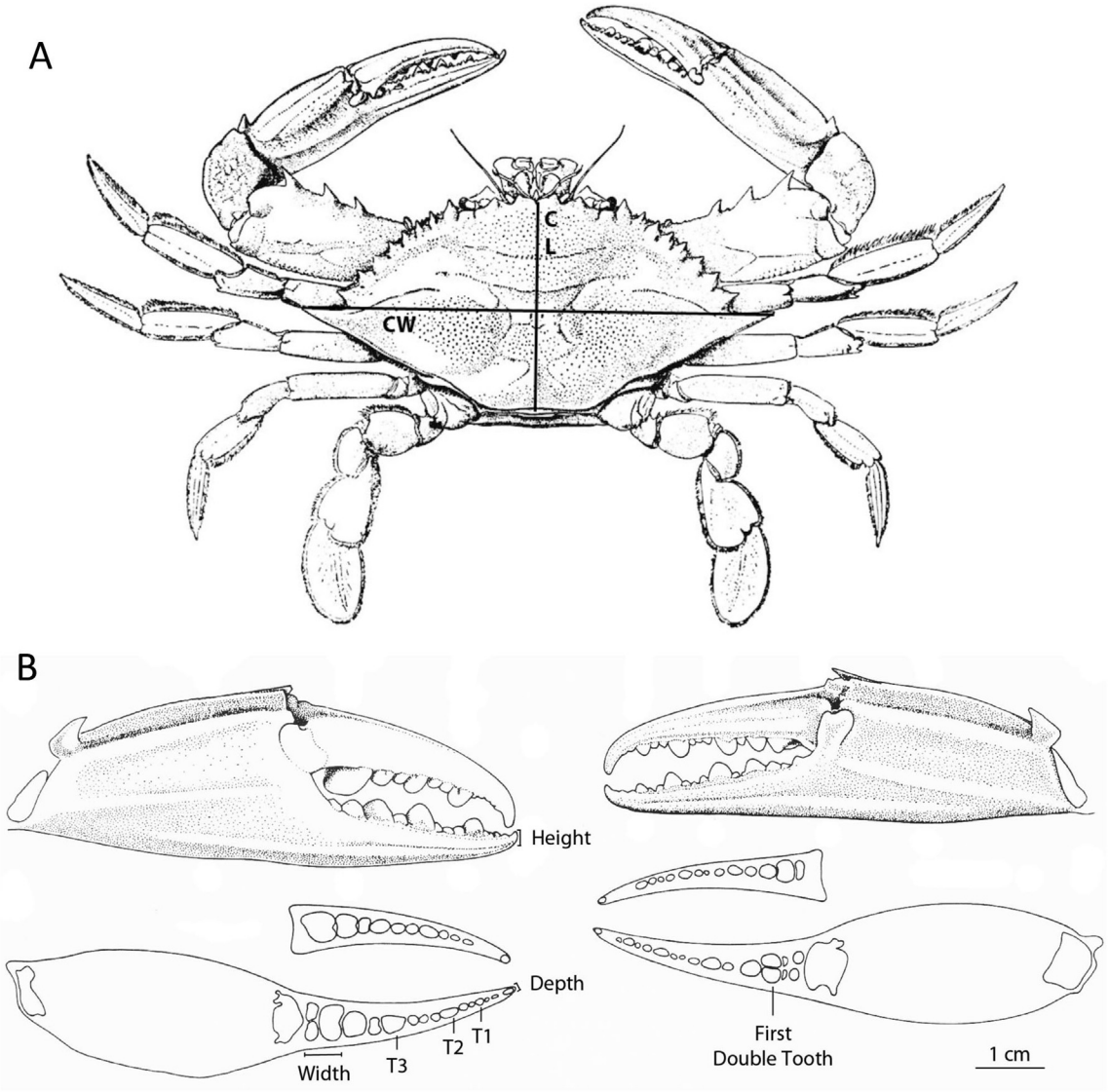

Fig. 2. A. Top view illustration of blue crab noting the carapace length (CL) and carapace width (CW) measurements discussed in the text. B. Illustration of chelipeds (crusher [left], cutter [right]) showing measured landmarks used for allometirc analysis. Images adapted from Kennedy and Cronin (2007).

harvested, and are restricted to high salinity areas near the bay mouth. Within Chesapeake Bay, there is no similar crab species that could have been harvested in abundance in recent millennia. Because chelipeds are the most likely remains to preserve and be identified archaeologically, they are the focus of much of our analysis. Blue crab chelipeds consist of a cutter and a crusher with a series of "teeth" (Fig. 2) that are easily identified archaeologically; and we used these to build a regression formula for estimating crab body size from fragmentary claws.

3. Experiments in crab preservation and taphonomy

We performed three experiments to test the effects of soil characteristics and animal scavenging on the preservation of blue crab remains: 1) burial experiments to determine the impact of soil pH and aeration, 2) exposed plots to determine the impact of scavenging, and 3) laboratory experiments in acid etching to determine the impact of soil acidity on crab preservation. For our burial plots, we hypothesized that both elevated pH and anaerobic conditions would result in greater preservation of crab shell. For the scavenging experiment, we hypothesized that dispersal of crab shells would be greater than that of oyster shell due to a higher content of edible tissues remaining on the shell and lighter weight of discarded fragments. Finally, in our acid etching experiments, we hypothesized that the higher surface area to volume ratio in crab shells would result in the loss of more relative weight in acid washes compared to oyster shell. We begin by outlining the methods we employed in these three experiments and then summarize the results.

3.1. Burial

The burial experiment was conducted in an open patch of eastern deciduous forest at the Smithsonian Environmental Research Center (SERC) in Edgewater, MD. Crab parts (carapace and chelipeds) were buried in 32 L storage containers filled with soil that were themselves buried to a depth of 30 cm. Soil that was removed to bury each container was separated out into the O, A, and B horizons (Fig. 3). Horizon separation was based on visual identification of soil descriptions from local soil surveys for the

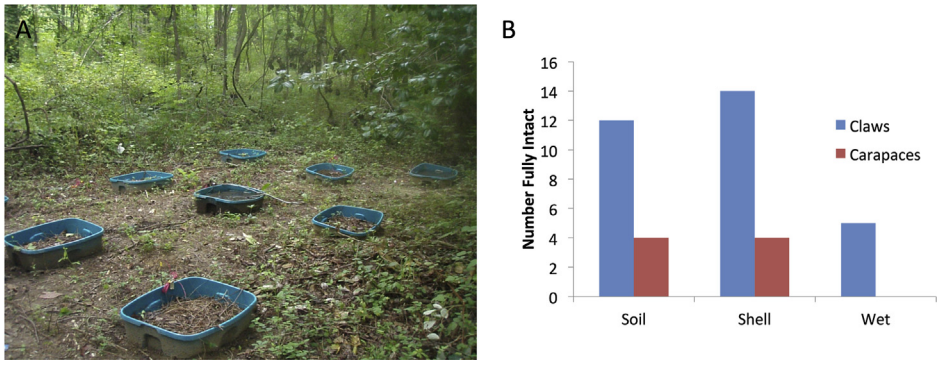

Fig. 3. Photographs of the burial experiment. A. The location and configuration of some of the burial plots; B. The number of intact remains recovered from each plot type.

Annapolis series (Hapuldult) soil. Soil was added to the containers so that the position of soil horizons matched that of the surrounding area. Crab carapaces and claws were steamed, cleaned of their meat and tissues, and air dried for 24 h. They were measured for length, width, thickness, and weight and given a unique identification number. The 36 crab shells were then randomly assigned to the containers, with two crabs buried at 10 and 20 cm depth in each, for a total of four crabs per container.

The experiment consisted of three treatments: ambient soil conditions (controls), elevated pH, and anaerobic conditions. For the elevated pH treatments, whole oyster shells were scattered throughout the treatment and the top 10 cm of the soil layer was mixed with 250 g of ground oyster shell. For the anaerobic treatments, water was collected from a rain water retention pond and the soil was flooded such that 2 cm of water was present above the soil at all times. For control and elevated pH units, holes were drilled in the bottom of the containers to allow water to drain naturally. Three replicates were conducted for each treatment, for a total of nine experimental containers.

The experimental containers were undisturbed for six weeks, with periodic monitoring of pH and redox potential. The redox potential was monitored through the use of platinum tipped redox probes and a calibrated reference probe attached to a voltimeter. The pH was measured using a pH probe (Milwaukee Instruments pH600AQ) in a slurry of water and soil in a 1:1 ratio. Both of these measurements were collected from the top 10 cm of soil.

After a six week burial period, crabs were excavated by carefully digging down to the burial depth and retrieving the claws and carapace. A 3 mm sieve was used to collect any remaining crab shell fragments. In the anaerobic plots, crab shells had shifted in position, likely due to the saturated soil conditions. These units were excavated by washing all soil through the sieve under a gentle spray of water. The effect of burial treatments was evaluated by comparing fragmentation, weight loss, and hardness of crab parts. Shell fragments were graded for fragmentation using a relative, six point scale dependent on the amount of fragmentation (1 = fully destroyed/not recovered, 2 = less than 25% intact, 3 = less than 50% intact, 4 = greater than 50% intact, 5 = 75% intact, 6 = fully intact). Claws rated fully intact, were carefully cleaned of dirt, dried, and reweighed. The percent loss from the initial weight was recorded.

Carapaces were then tested for relative puncture strength as a measure of hardness. This was done by suspending the largest carapace fragment across two wooden blocks, with the centroid of the fragment spanning a 1.7 cm gap. A conical 15 mL centrifuge tube was then placed on top of the centroid and weighted by pennies. The number of pennies required to pierce the shell was then recorded as a proxy for puncture force. Kruskal–Wallis one-way Analysis of Variance (ANOVA) on ranks was used to compare results among treatments in SigmaPlot 12.0.

3.2. Animal scavenging

To test for the influence of scavengers, crab and oyster shells were placed in an open forested area at SERC (Fig. 4). Crab fragments were collected from the remains of 12 crabs that had been steamed and eaten. The remains included shell, connective tissue, organs, and small amounts of meat. Oysters were obtained from a separate research experiment at SERC, euthanized via freezing, thawed, and shucked to simulate raw consumption. Approximately the same volume (2–3 L) of oyster shells was used as crab remains.

Four scavenging trials were conducted, one each of oyster or crab remains alone and two with crab and oyster. For each trial, remains were placed within a 50 cm diameter ring and left undisturbed for five days. Potential scavengers were monitored with an infrared game camera. Although infrared cameras are ideal for capturing terrestrial mammals and other species, it is possible that they missed raptors or birds that could have scavenged some of the remains. Photos from game cameras were analyzed to identify scavengers. The effect of scavenging on remains was assessed by counting the number of individual remains moved outside the 50 cm ring, as well as by measuring the distance and direction (relative to magnetic north) of movement.

3.3. Acid etching

An acid etching experiment was conducted to determine whether there were differences in dissolution rate between crab and oyster shells. For this experiment, 32 small oyster shells were obtained from another study at SERC and 32 pieces of crab carapace consisting of 16 2 × 2 cm squares and 16 2 × 1 cm strips, were cut from the back of frozen adult crabs using a Dremel tool. Unlike the other two experiments, the crab remains in this experiment were not steamed or cooked, which would have further weakened their shells. All shells were thoroughly washed, dried, and weighed, and estimates of surface area were taken. The surface areas of oyster shells were estimated assuming they could be represented as a two dimensional ellipse while crab surface areas were estimated as two dimensional rectangles. Dissolution was tested at four different pH levels (2, 4, 6, and 7), with acid solutions generated from concentrated hydrochloric acid and distilled water. Experimental treatments included crab carapace only (2 × 2 cm squares), oyster shell only, and mixed crab and oyster (2 × 1 cm strips to maintain a roughly equivalent amount of material in all treatments). Four replicates of each treatment were conducted in 300 mL of each pH solution. After 24 h, the carapace sections and oyster shells were

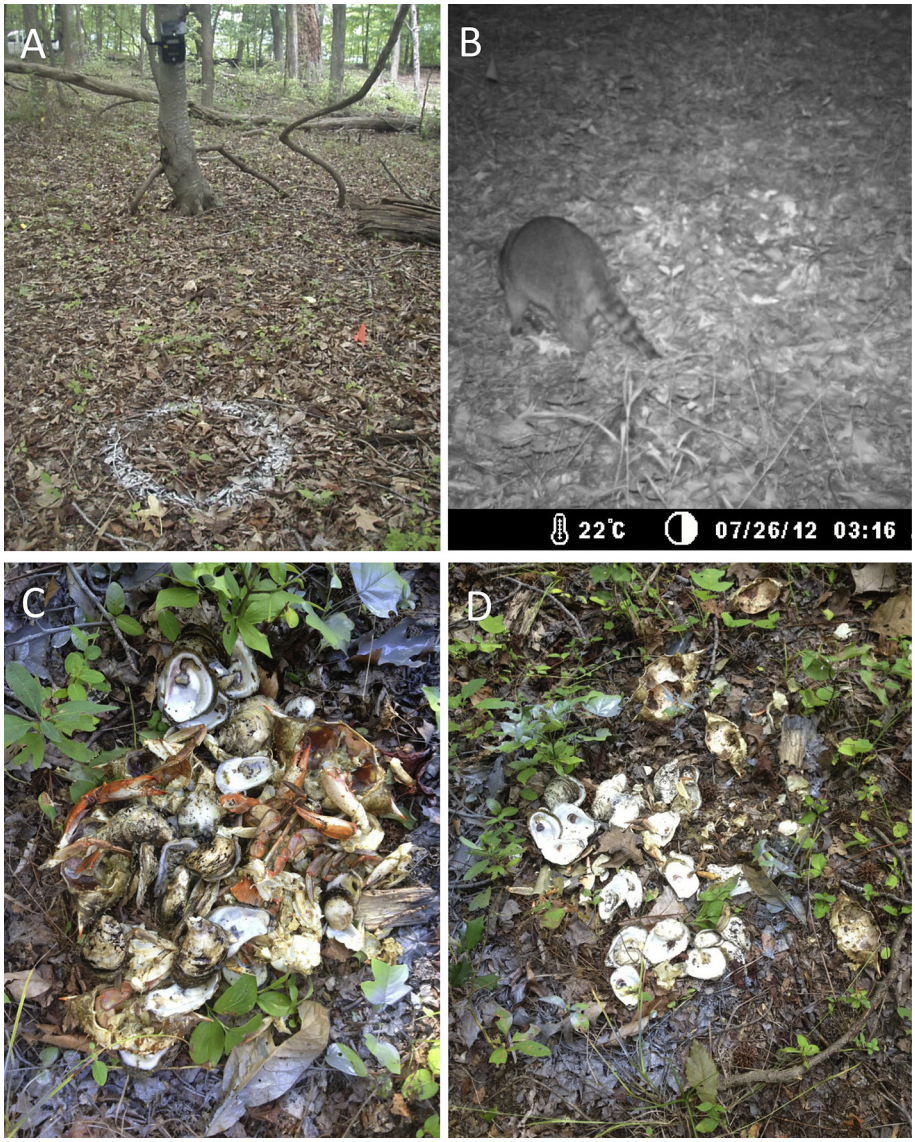

Fig. 4. Images of the scavenging experiment: A. Photo of the camera trap mounted on the tree showing the area circled where the crab remains were deposited; B. A raccoon caught on the camera trap scavenging in the midden; C. A crab and oyster deposit after consumption and immediate deposition; D. Crab and oyster deposit after it had been scavenged.

removed and dried before being reweighed. The absolute and percent loss of mass were then compared among treatments and pH levels using two-way ANOVA with posthoc pairwise comparisons using the Holm–Sidak method in SigmaPlot 12.0.

3.4. Results of the experiments

Crab claws and carapaces subjected to burial experiments showed considerable decay, but there were no significant differences among the ambient, elevated pH, and anaerobic treatments. Although fewer intact parts were recovered from the anaerobic treatment, the number of fully intact parts was not significantly different among treatments (Carapaces: $H = 2.713$, d.f. $= 2$, $p = 0.258$, Claws: $H = 2.682$, d.f. $= 2$, $p = 0.262$). Similarly, there were no significant differences in carapace hardness ($H = 0.287$, d.f. $= 2$, $p = 0.866$) or percent weight loss of intact claws ($H = 1.003$, d.f. $= 2$, $p = 0.606$). We measured elevated pH in treatments with oyster shell and anaerobic conditions in the saturated soil, indicating that we were successful in creating the expected treatment conditions. Although the differences were not statistically significant, the largest number of intact claws was recovered from the elevated pH treatment. This result suggests that differences might eventually emerge as burial time increases, with crab parts in elevated pH treatments potentially remaining intact the longest. In addition to soil pH, the wetting and drying of soils following storm events would also have a significant effect on preservation.

In the scavenging experiments, crab remains were moved outside the 50 cm diameter perimeter more often and greater distances than oyster shells (Fig. 5). Twenty-one crab remains were moved outside the perimeter in the control sample, six fragments were moved outside of Plot 1, and 22 crab fragments were moved outside of Plot 2. In contrast, a single oyster shell was moved outside the perimeter. This result supports the hypothesis that scavengers may have had a differential impact on the burial and preservation of crab and oyster remains. The infrared camera captured images of raccoon scavenging taking place (Fig. 4). Other potential scavengers that may also cause differential movement of crab and oyster remains include dogs, opossums, or birds, among others. Birds could have scavenged from the experiment, but might not have triggered the infrared camera. The crab remains were

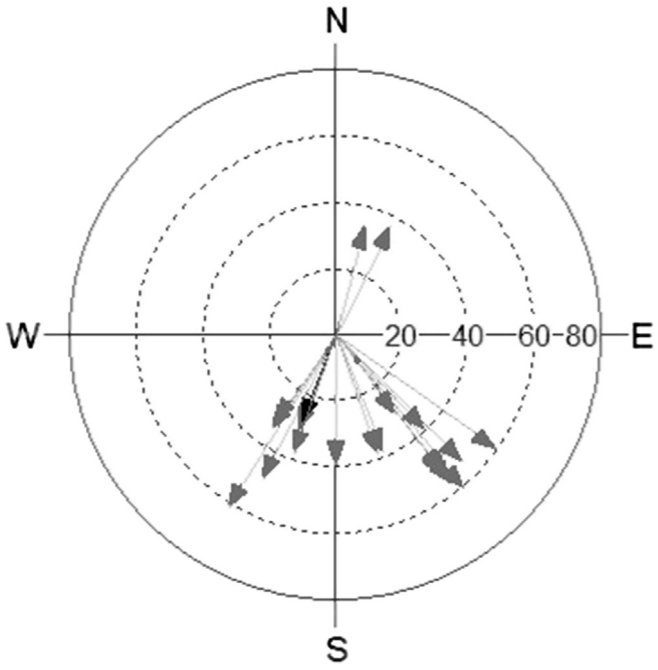

Fig. 5. Plot showing the movement of crab (gray arrows) and oyster (black arrow) remains outside of the original circle during the scavenging experiment. X-axis is in cm. Note that only one oyster moved beyond the original circle (see black arrow in bottom left quadrant).

disarticulated when buried and this may have made it easier for these specimens to be moved by scavengers.

Under the most acidic conditions (pH 2), crab and oyster shells dissolved at the same rate per unit surface area, but crab shell lost a greater percentage of mass (Crab 22.4–17.5%, Oyster 3.3–2.5%). The acid etching experiment demonstrated a significant difference in percent weight loss by both shell type (crab or oyster), pH, and their interaction (pH: $F = 34.618$ $p = <0.001$ Type: $F = 17.035$ $p = <0.001$ pH x Type: $F = 6.891$ $p = <0.001$) (Fig. 6). When adjusted for surface area, however, only pH treatment was significant ($F = 54.662$ $p = <0.001$).

4. Blue crab archaeology

To document the distribution, abundance, and significance of blue crabs in Chesapeake Bay archaeological sites, we conducted a literature and database search and an analysis of crab remains from Chesapeake Bay area sites housed in museums and repositories. We also contacted colleagues for potential archaeological crab remains not reported in the literature, searched the Maryland Historical Trust's digital database of Cultural Resource Management reports, and performed a similar literature search of files at the Virginia Department of Historic Resources. Tables 1 and 2 contain the results of this survey for prehistoric and historic collections with crab remains. We re-analyzed the collections for 13 of the sites discussed here, confirming the identification as *C. sapidus* and measuring claws for a size analysis reported below. While our synthesis was as thorough as possible, there may be additional archaeological crab remains from the region.

We are confident in the identification of archaeological chelipeds as blue crabs based on morphological observations. As noted earlier, other species of *Callinectes* are either smaller than the size range indicated by many of the chelipeds we studied and restricted to high salinity habitats (*C. similis*) or subtropical or tropical regions. The range of *C. sapidus* extends much further than any of the other species in the genus both north and south of the equator. Given the warming climatic trend in the Chesapeake region, there is no reason to suspect that other species in the genus would have been present in high numbers and disappeared during the course of the last several thousand years. If anything, *C. similis*, which is near the northern extent of its range at the mouth of Chesapeake Bay, may have been less common in recent millennia with colder temperatures.

Despite reports that crabs are rarely identified in Middle Atlantic sites, our analysis documented 14 prehistoric Native American sites with crab remains, including 10 in Maryland and four in Virginia. These sites span 200 km distance and a wide range of present-day salinities from 30 ppt near the mouth of the Chesapeake Bay at Virginia Beach to 3 ppt in Baltimore, Maryland and on both the western and eastern shores of the Bay (Fig. 1). Blue crab remains date from as early as 1200 cal BC (Early Woodland) to the late 19th or early 20th century. A minimum of 1412 crab remains were identified at those sites for which the number of identified specimens was reported, the vast majority of which were claw fragments. The majority of claws came from 44VB9, a large site complex near Virginia Beach, which produced 1176 blue crab remains primarily from Middle Woodland deposits (Whyte, 1988).

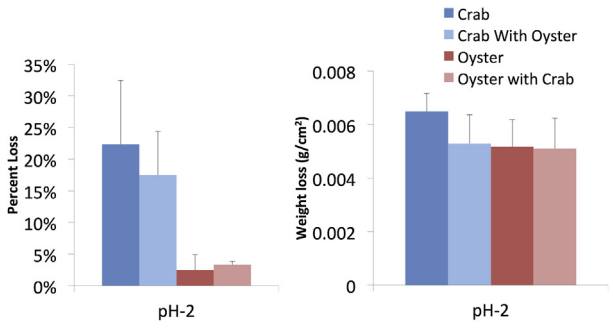

Fig. 6. The results of our pH acid bath studies, showing percent lost at a pH of 2 (left) and the weight lost at a pH of 2 (right). There is a significant difference in the percent lost but not the weight lost. In the "crab with oyster" category crabs were the specimens that were measured, while in the "oyster with crab" category oysters were what was measured.

Table 1
Native American archaeological sites with blue crab remains on the Chesapeake Bay.

Site number	Age	NISP[a]	References
Maryland			
18AN113 (Obrecht)	Early-Late Woodland	1	Peck, 1976.
18AN284/285 (Smithsonian Pier)	AD 220–570	P	Gibb and Hines, 1997:73.
18CV17S (Sterns)	AD 1270–1660	57	Whyte, 1991.
18CV65 (Patterson 1)	AD 100–800	22	Whyte, 1991.
18DO43 (Lankford)	Late Woodland/Contact	1	Flegel, 1975a, 1975b, 1976.
18DO130 (Snake Island)	AD490–670	15	This paper.
18DO439 (Elliotts Island)	AD 950–1060	1	This paper.
18KE128 (KCARP PL-22)	700–400 BC	P	Custer et al., 1997:55.
18ST1-23 (St. John's)	Archaic and Woodland	P	Chaney and Miller, 1990.
18ST570 (Thomas Point)	AD700–1070	12	Herbert, 1995:170, 196, 204, 207.
Virginia			
44HT83	AD 1035–1285	P	Stuck et al., 1997.
44VB7 (Great Neck)	Middle Woodland	P	Hodges, 1998:91.
44VB9 (Addington)	Middle Woodland	1176	Whyte, 1988.
44WM119 (White Oak Point)	1200 BC to 19th century	127	Waselkov, 1982.

[a] P = present.

Table 2
Colonial and historical archaeological sites with blue crab remains on the Chesapeake Bay.

Site number	Age	NISP[b]	References[c]
Maryland			
18AN871 (Homewood's Lot)	1650–1740s	274	Luckenbach, 1995.
18AN1092 (Site 2)	Late 18th-Mid 19th Century	36	Saint Onge and Fehr, 1999.
18BA313	Mid- 1800s	2	Payne and Baumgardt, 1994.
18CH281 (Posey)	1650–1680	8	Landon and Shapiro, 1998.
18CV83 (Kings Reach)	1690–1711	65	Pogue, 1990.
18CV91 (Smith's St. Leonard)	1711–1784	181	Chaney, 2003.
18CV271 (Patuxent Point)	1658–1690s	22	Gardner et al., 1989.
18CV279 (Compton)	1651–1685	28	Louis Berger and Associates, 1989.
18CV426 (Sukeek's Cabin)	Late 19th early 20th century	3	Uunila, 2002.
18DO58 (Horn Point)	Late 17th to 18th century	2	Jull, 1980.
18DO82 (Wilke III)	Late 19/20th century	1	Davidson, 1982.
18HA30 (Old Baltimore)	Late 17th to 18th century	P	Davis et al., 1999.
18KE292 (Buck)	1660–1700	P	Alexander, 1984.
18PR175 (Oxon Hill Manor)	1687–1895	P	Dent et al., 1983.
18QU28 (Bennett's Point)	1675–1749	41	Wesler, 1984.
18ST1-13-1221/1222P (Pope's Fort Moat)	1645–1655	47	Miller, 1984.
18ST1-19 (Van Sweringen)	1735–1750	587	Miller, 1984.
18ST1-23 (St. Johns Cellar)	Late 1600s	1	Miller, 1984.
18ST1-23-77C (St. John's Site)	~1700	2	Miller, 1984.
18ST390 (Mattapany)	1666–1740	7	Pogue, 1987.
18ST399 (Susquehanna)	Mid18/19th century	1	King, 1989.
18ST1-925F (Country's House)	1685–1695	12	Miller, 1984.
18ST677 (Tudor Hall)	Late 17th century	1	Child et al., 1998.
Virginia			
44FX762/40-47 (Mt Vernon, House for Families)	1759–1779	P	Pogue and White, 1991.
44HT55 (Hampton University)	17th century	22	Edwards et al., 1989.
44JC39 (Kingsmill Tenement)	1625–1650	22	Miller, 1984; Kelso, 1984.
44JC43 (Drummond Site)	1680–1710	186	Miller, 1984.
44JC647 (Carter's Grove 8)	1625–1650	3	Edwards, 2004.
44JC802 (Sandys Site)	1630–1650	1	Mallios, 2000.
44PM12	Mid-18th century	3	Cultural Resources, Inc., 2006.
44YO68 (Bennett Farm)	1648–1665	5	Miller, 1984; Luccketti, 1983.
44WM33 (Clifts Plantation)	1670–1730	37	Miller, 1984; Neiman, 1980.
Colonial Williamsburg[a]	1600–1850	1240	Stephen Atkins, Personal Communication, 2014.

[a] 1240 claws are distributed across some 47 sites in Colonial Williamsburg. Given that they come from a confined range within the bay we have given them a single entry here.
[b] P = present.
[c] Many of the crab remains from these sites were identified in Maryland Historical Trust database of Maryland Cultural Resource Management projects or from similar files at the Virginia Department of Historic Resources. Some of the citations listed provide site context or chronology, but do not present the raw blue crab data.

The White Oak Point site (44WM119) in Virginia along the lower Potomac River produced 127 crab remains, including a continuous sequence from 1200 cal BC to the early 19th century. This site has some problems with stratigraphic mixing (see Rick and Waselkov, 2015), but 69% (n = 88) of the remains come from Late Woodland or Historic deposits, with the other 31% coming from Early and Middle Woodland deposits. Faunal remains from the substantial flotation samples at this site were reported separately, allowing us to compare the recovery of crab remains in screened versus floated samples. All of the Early Woodland remains, 94% of the Middle Woodland, and 90% of the Late Woodland remains came from flotation samples, while 67% of the Historic crab remains were from standard excavation units screened over 1/4-inch mesh. These data suggest that preservation and sampling played a role in the recovery of crab remains at White Oak Point. Blue crab remains from 18AN284/285, 18KE128, and 18DO130 also were only recovered in flotation or fine mesh screen samples, including both 1/8 and 1/16-inch mesh.

Seventy-nine colonial and historical archaeological sites contained the remains of blue crabs (n = 2840). About 1240 cheliped fragments (44% of all colonial/historic crab remains) from 47 archaeological sites dated to the Colonial and Historic periods (~AD 1600–1850) have been identified at the Colonial Williamsburg Foundation alone (Stephen Atkins, personal communication 2014). These have been given a single entry in our table because these sites all correspond to a relatively confined area. Thirty-two additional sites, including 23 from Maryland and nine from Virginia, also produced blue crab remains. They are found at a wide variety of site types, including George Washington's Mount Vernon Estate, a series of plantations and manors in Maryland, a 17th century Native American site (the Posey Site), and a 19th-20th century African American domestic site (Sukeek's Cabin) (see Table 2). These crab remains range in age from the early 17th century to the 20th century, suggesting continuous consumption of crabs from prehistoric to modern times and across all major cultural or ethnic groups (Native American, EuroAmerican, African American).

Although considerably more colonial and historic sites (n = 79) have been identified with crab remains compared to prehistoric Native American sites (n = 14), the number of crab parts is closer with 2840 from Historic compared to 1412 from Native American sites. We caution that 1176 (83%) of the Native American crab remains come from a single site (44VB9). The higher number of colonial and historic sites likely reflects preservation bias with better preservation found in more recent sites, and possibly a research bias, with excavation of comparatively few Native American shell middens.

5. Estimating the size of ancient blue crabs

Because of the relative scarcity of blue crab remains in archaeological sites, they have generally been excluded from detailed

faunal analyses beyond mentioning their presence. This study has the advantage of looking at a larger sample across many archaeological sites, and thus provides an opportunity to develop methods for assessing historical ecological changes in crab populations. We developed a method for estimating the total size of fragmentary crab remains using principles of allometry based on modern crab specimens. Allometry is the study of the relationships of overall body size to shape and physiology (Peters, 1983). Archaeologists and other researchers often use allometric relationships to predict animal size dimensions (total length, width, etc.) from measurements of archaeological specimens (Reitz and Wing, 2008; Reitz et al., 1987). Our analysis provides the results of size estimates for prehistoric and historic crabs based on measurements of archaeological cheliped and cheliped fragments using landmarks depicted in Fig. 2. These methods and data provide a biologically based framework for evaluating changes in blue crab size from prehistoric to modern times and can be applied broadly to blue crab remains throughout their range.

5.1. Allometry

The size distribution of crabs present in archaeological samples was estimated using allometric relationships derived from modern blue crabs. Relationships were derived from 28 modern crabs (13 female, 15 male) ranging from 78.0 to 200.0 mm CW and 37.0–87.5 mm carapace length (CL) (Fig. 7). Although CW is the standard measure of blue crab size, estimated CL is also reported here because it is more closely correlated with crab weight (Gelpi et al., 2009). Because most crab fragments were partial segments of chelipeds, a set of 15 independent measurements was developed for landmark locations identifiable on cheliped fragments by the pattern of large and small teeth, which was consistent for nearly all modern crabs examined (see Fig. 2). Blue crabs have distinct crusher (major) and cutter (minor) chelipeds which are usually found on the right and left sides, respectively. Each cheliped has a moveable upper dactyl finger and fixed lower propal finger. Cheliped fragments, with the exception of very small fragments, were easily identifiable as crusher or cutter and dactyl or propal finger based on the tooth morphology and curvature of the finger. This allowed us to develop a specific set of allometric relationships for each finger of each type of claw, which provided more accurate estimates of crab size than when all chelipeds were considered together (a total of 56 relationships). Measurements at landmark teeth were the first (depth, height, height without tooth), second (depth, height, height of tooth, height without tooth, tooth width), and third (depth, height, height of tooth, height without tooth, width of tooth) large tooth from the cheliped tip and the first double tooth (two distinct teeth in line with an anterior to posterior section; depth of cheliped at double tooth and depth of double tooth only; double teeth on propal fingers only). Depth was measured in an anterior to posterior direction when chelipeds were folded against the body, height was measured from bottom to top, and tooth width was measured from distal to proximal ends of cheliped fingers. These measurements were chosen because they provided the best allometric relationships (see Appendices 1–4 for regression equations and coefficients of determination [R^2]) out of a larger suite of measurements initially tested.

The allometric relationships presented here were derived from a mixed sample of male and female crabs, which exhibit some differences in carapace and cheliped morphology. Standard allometric power functions provide a poor fit to the data due to these differences in male and female allometry (Fig. 7 A, B). Specifically, power functions led to overestimates of carapace width for the largest crabs, an issue that was corrected using exponential growth functions for most relationships (Fig. 7C, D) and linear functions for others. Variability in these relationships could be reduced if males and females were treated separately; however, we were unable to distinguish crab sex from archaeological samples.

The crabs used to develop the allometric relationships had claws that appeared normal, with no obvious deformities, abnormalities, or signs of regrowth. For archaeological samples, it was not possible to determine whether a claw was regrown, leading to the

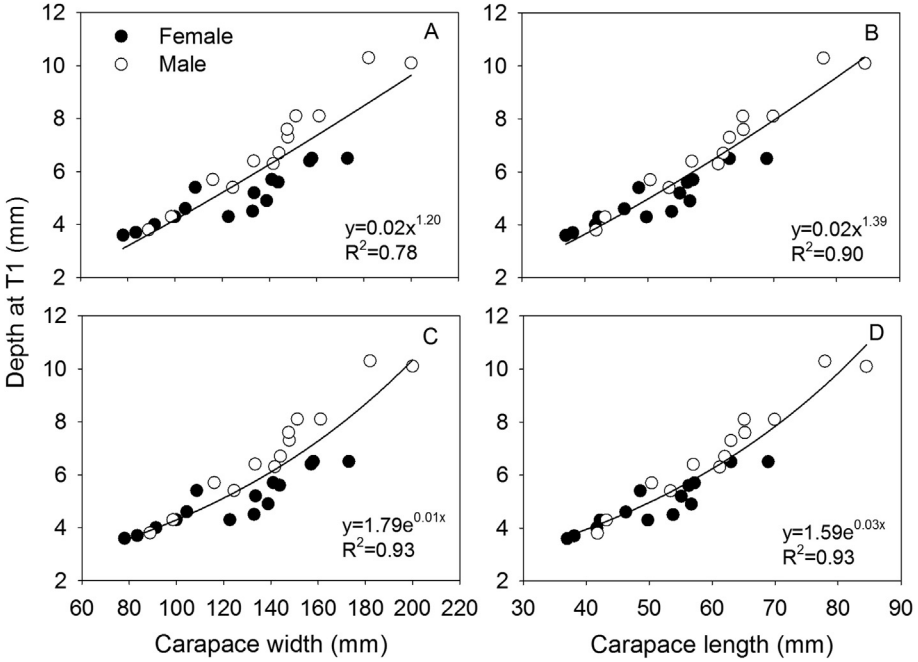

Fig. 7. Allometric relationships for carapace width and carapace length and cheliped depth at the first double tooth from the distal end of the crusher propal finger. Relationships (black lines) are power functions (A and B) and exponential growth functions (C and D) and include both male and female data. All relationships were statistically significant ($p < 0.05$).

possibility that the size of some crabs was underestimated. Observed cheliped loss ranges from 4 to 17% of individuals (Hines, 2007), although the relative contribution of interspecies aggression vs. fishery interactions to cheliped loss is unclear. As noted above, it is possible to distinguish "crusher" from "cutter claws" by their tooth morphology. All blue crabs start with a right crusher and left cutter claw. If a claw is lost (automized), the regenerated claw becomes a cutter upon molting. If the right is lost then the crab has two cutters. On the second molt after loss, the left claw becomes a crusher. We noted cutter and crusher morphology when possible and we did not record any instances of either right cutters or left crushers.

For each fragment, an estimate of crab size was calculated for each measurement that could be made. The mean of these measurements was used as the estimate of crab size for that fragment. Fragment length and color (tan, white, black) were also recorded. Black (or dark gray) fragments appeared to have been burned, tan fragments retained the smooth, waxy epicuticle, and white (or very light gray) fragments lacked the epicuticle and were rougher and brittle. The distribution of carapace widths derived from archaeological samples was compared to a five-year dataset (2007–2011) of crabs (N = 8062) caught in a trawl survey conducted monthly from March to November in the Rhode River. The trawl net is constructed of 38.1 mm stretch mesh and has a cod-end of 6.4 mm stretch mesh. Carapace length was not measured in the trawl survey.

5.2. Ancient size distributions

A total of 971 crab fragments from 13 archaeological sites were evaluated (Table 3). The majority of fragments (92.5%) were sections of chelipeds, but lateral spines (2.1%) and various other fragments (5.5%) were also present. Crab fragments varied in length from 3.2 to 42.4 mm (Fig. 8) and in color and texture from black (9.4%) to tan and smooth (39.5%) or white (or very light gray) and rough (50.6%). Of the 898 cheliped fragments, 638 had identifiable landmarks to allow for estimation of crab size. The number of measurements that could be made from each fragment varied from 1 to 15. There was no trend in the mean or range of crab size estimates with number of measurements taken, suggesting that the size estimates were not biased by the number of measurements taken.

The estimated CW of blue crabs in archaeological samples varied from 50.5 to 233.6 mm and had a higher mean (139.9 ± 29.7) than that of modern crabs from the Rhode River (90.8 ± 44.1), primarily because small crabs were rare in archaeological samples (Fig. 9). This is most likely due to size-selective harvest, but could also be related to better preservation of larger chelipeds. In contrast, large crabs, those >170 mm CW, comprised 30% of archaeological samples that would be harvestable under current Maryland regulations (crabs >127 mm CW), but only comprised 7% of harvestable crabs in trawl samples from the Rhode River (Fig. 9). There is also differentiation in the size distribution of crabs by site (Fig. 10). This was particularly evident for the two St. Mary's sites for which the mean lengths were 173.6 ± 20 mm (18ST1-13) and 134.8 ± 27.8 mm (18ST1-19). Carapace length varied from 26.0 to 95.7 mm with a mean of 57.8 ± 10.8.

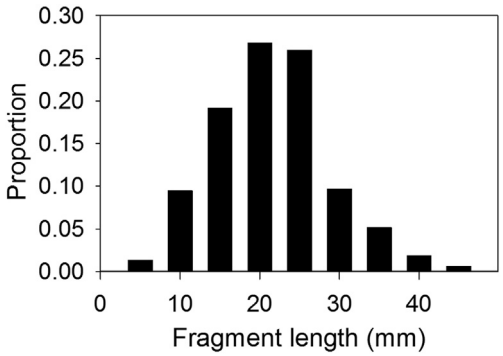

Fig. 8. Histogram of crab fragments by fragment length (N = 971).

6. Discussion and conclusions

The experimental, archaeological, and allometric analyses of blue crabs presented here provide a means to evaluate the importance of blue crabs to prehistoric, colonial, and historic peoples in the Chesapeake and re-evaluate previous assertions that blue crab remains are rare to absent in Middle Atlantic and Chesapeake sites. Our research was designed to test three hypotheses that had previously been used to explain a dearth of blue crab remains in Chesapeake sites: 1) people, especially Native Americans, did not eat crabs, 2) crab remains do not preserve in Chesapeake sites or are recovered only in fine-mesh or flotation samples, and 3) crabs were rare in many sites because they were occupied seasonally during colder months when oysters were abundant, but crabs were absent. Our data allow us to address each of these below.

Because we identified over 4250 blue crab remains from 93 archaeological sites spanning from at least the Early Woodland (1200 cal BC) to the 20th century, we reject the hypothesis that people in the past did not eat crabs. These 93 sites come from

Table 3
Summary of number of samples used in allometric analyses, percent of fragments that were chelipeds, number of size estimates, mean estimated carapace width (CW), and mean estimated carapace length (CL) by site.

Site	Samples (N)	% Cheliped	Size est (N)	CW (mm)	CL (mm)
18CH281	5	80	4	122.4 ± 20.3	51.5 ± 7.0
18CV426	3	100	0	N/A	N/A
18CV83	55	93	27	159.1 ± 23.0	64.7 ± 8.6
18CV91	181	89	94	141.5 ± 32.2	58.5 ± 11.9
18QU28	6	100	1	179.3	71.9
18ST390	7	100	1	174.1	70.8
18CV271	7	100	3	159.3 ± 31.7	64.3 ± 11.3
18CV279	8	88	5	152.6 ± 16.4	62.2 ± 5.6
18ST1-13	47	96	37	173.6 ± 20	69.9 ± 7.1
18ST1-19	587	94	435	134.8 ± 27.8	55.9 ± 10.1
18ST1-23	2	100	2	147.9 ± 31.5	60.5 ± 11.3
18DO130	9	56	5	120.0 ± 31.6	49.6 ± 10.5
44WM119	54	87	24	149.4 ± 29.9	61.2 ± 11.4

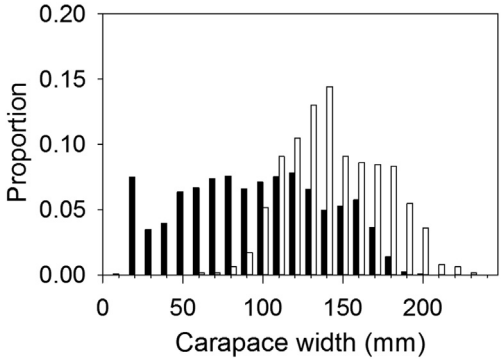

Fig. 9. Size frequency distribution (carapace width) of all crabs caught in trawls (Black) in the Rhode River during 2007–2011 and size estimates for crabs from archaeological samples (White). Bin labels on the x-axis indicate the largest size present in a given bin (e.g. 10 indicates carapace widths of 1–10 mm).

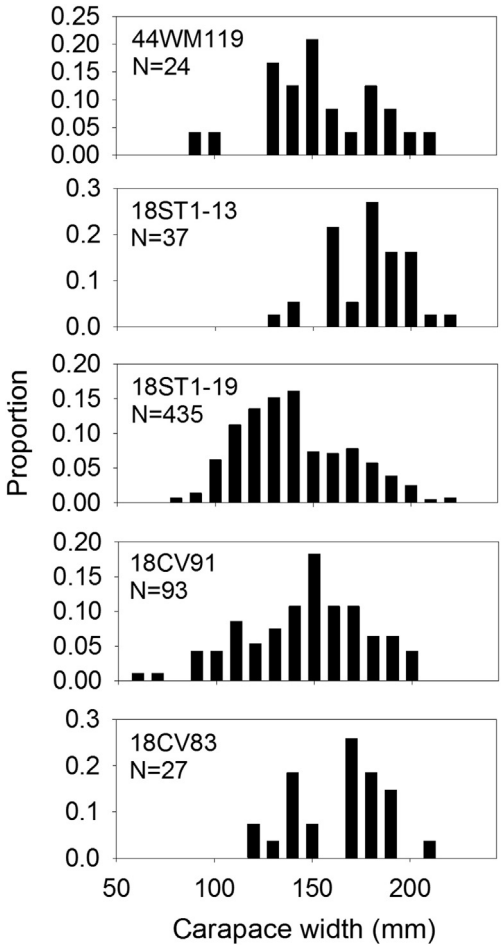

Fig. 10. Distribution of carapace width by site for sites with >20 size estimates available.

Native American, EuroAmerican, and African American contexts, suggesting that a wide range of different ethnic and cultural groups consumed crabs in the past. The importance of crabs to Chesapeake Bay Native Americans is also supported by a request made in 1666. On April 12 that year at St. Mary's City, treaty negotiations were conducted with the leaders of multiple Maryland Indian groups dwelling along the Potomac and Patuxent rivers. The head of the "Choaticks" asked Governor Charles Calvert and his Council to "… let their Priviledge of hunting be preserved as also fishing & crabbing" (Archives of Maryland (1884):15). Eight days later the treaty was signed with the fourth provision reading "The priviledge of hunting Crabbing fishing and foweling shall be preserved to the Indians inviolably" (Archives of Maryland (1884):25). This same wording was used in later treaties such as one with the Nanticoake in 1668 (Archives of Maryland, 1887:15). Moreover, Chief Powhatan in Virginia included crabs as part of a morning meal given to European colonists in the early 1600s (Hamor, 1615; Kennedy et al., 2007:655). Clearly, crabbing was a significant aspect of the subsistence regime of Native peoples into the late 17th century.

The burial, scavenging, and pH experiments were performed to help evaluate hypothesis 2 that focused on the potential for taphonomic processes to significantly effect the preservation of crabs. These experiments suggest that, when compared to oysters and probably other Chesapeake shellfish (barnacles, clams, etc.), crabs are extremely fragile and more susceptible to post-depositional processes, including dissolution from soil acidity, fragmentation during deposition and burial, and the effects of scavenging. Although our burial study was constrained by the short duration the materials were buried, our pH study presents evidence that crab remains are susceptible to dissolution from soil pH. Another variable is the effect of continued wetting and drying on archaeological faunal remains from rain, runoff, tidal surges, and other processes, with less compact and better drained deposits likely enhancing preservation. Finally, the use of camera traps to monitor multiple deposits of recently processed crab and oyster remains evaluated the impact of scavenging animals. A raccoon that disturbed and altered the experimental deposits almost exclusively affected the crab remains rather than oysters, implicating scavenging as a possible factor that limits crab remains in some archaeological deposits. This is especially true given that the camera traps we used would likely not have recorded evidence of birds rapidly scavenging in the refuse piles. None of our experiments specifically investigated recovery techniques (i.e., screen size, etc.), but we note that many of the archaeological crab remains (especially prehistoric) noted in our literature review or collections analysis were recovered primarily from flotation samples or using 1/8-inch or smaller screen sizes. There were also more crabs recovered from the Late Woodland, Colonial, and Historic periods than earlier time periods. This could be because of better preservation in more recent samples and a focus on Colonial and Historic sites over prehistoric sites, but it is also possible that the consumption of crabs increased through time.

The third hypothesis suggested that the consumption of crabs would have occurred seasonally during warmer months when crabs were more accessible (see McNett and Gardner, 1971; Whyte, 1988). If shell middens dominated by oysters were occupied primarily during fall and winter, when oysters are at their peak, crabs may not have been harvested. Alternatively, if crabs were harvested seasonally and then deposited in an area without oysters or other shells that could help neutralize soil acidity, their preservation and recovery would also be affected. Similarly, if soft shell crabs were harvested when available during the spring and summer, there would be no hard parts available for recovery. The seasonality hypothesis remains valid and future isotopic seasonality studies may help evaluate it further, but previous seasonality estimates for Chesapeake sites suggest that oysters were harvested at multiple seasons of the year.

Collectively, the data generated here suggest that blue crabs were an important component of Native American and later diets in the region. Though not as conspicuous as oysters and other resources (e.g., deer and raccoons), they were still a component of the diet at many sites. Given the preservation and recovery issues we noted here, we suspect that crab remains are under-represented in most archaeological studies. We also caution, however, that many sites with archaeofaunal remains have not produced crab remains and did not necessarily contain their remains. For instance, our work at Fishing Bay, Maryland on six Middle to Late Woodland shell middens using fine mesh recovery techniques produced only two sites (18DO130 and 18DO439) with modest amounts of crab remains. We cannot assume that the absence of crab remains is from preservation conditions alone, as many sites simply may not have contained crabs. Future work in Chesapeake shell middens using fine-mesh (1/8-inch and less) recovery and searching for other crab parts (e.g., mandibles) will likely produce more crab remains, but evaluating soil acidity and depositional characteristics at archaeological sites can help develop expectations about whether preservation conditions are suitable for crab recovery or not.

The inclusion of allometric methods presented here in future research should expand our understanding of the historical ecology of blue crabs throughout their large range, as well as the intensity of their use by prehistoric and historic people. The recovery of crab remains at 93 sites and our allometric data indicate that a wide

range of crab sizes were fished in archaeological assemblages, with more large size crabs than we see in today's catches and smaller crabs than are legally fished under today's regulations of a 127 mm minimum CW. This higher proportion of large crabs in archaeological assemblages is consistent with current intense fishing removing many crabs before they reach the largest sizes and the absence of fishery regulations of the past.

Our study provides implications for researchers working in other areas of the Atlantic and Gulf coasts that may contain blue crab remains. They also further illustrate the importance of crustaceans to Native Americans and people around the world, as the general ease of harvest and nutrition they supplied made them attractive for at least 800,000 years and especially during the Holocene (Ashkenazi et al., 2005; Jerardino and Navarro, 2002; Losey et al., 2004). Our work also underscores the importance of archaeological studies designed to use modern experiments to help understand ancient data. This research and other recent experimental or taphonomic studies on invertebrate species illustrate that this is well worth the effort, and can help inform issues of preservation, transport and procurement costs, and other variables (Jerardino, 2014; Thomas, 2014; Wolverton et al., 2009). When put in the context of other zooarchaeological and paleoenvironmental data, these studies can greatly improve our understanding of ancient and modern human environmental interactions.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.12.016.

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