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*Essay*

# Integrating Paleobiology, Archeology, and History to Inform Biological Conservation

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**Abstract:** *The search for novel approaches to establishing ecological baselines (reference conditions) is constrained by the fact that most ecological studies span the past few decades, at most, and investigate ecosystems that have been substantially altered by human activities for decades, centuries, or more. Paleobiology, archeology, and history provide historical ecological context for biological conservation, remediation, and restoration. We argue that linking historical ecology explicitly with conservation can help unify related disciplines of conservation paleobiology, conservation archeobiology, and environmental history. Differences in the spatial and temporal resolution and extent (scale) of prehistoric, historic, and modern ecological data remain obstacles to integrating historical ecology and conservation biology, but the prolonged temporal extents of historical ecological data can help establish more complete baselines for restoration, document a historical range of ecological variability, and assist in determining desired future conditions. We used the eastern oyster (*Crassostrea virginica*) fishery of the Chesapeake Bay (U.S.A.) to demonstrate the utility of historical ecological data for elucidating oyster conservation and the need for an approach to conservation that transcends disciplinary boundaries. Historical ecological studies from the Chesapeake have documented dramatic declines (as much as 99%) in oyster abundance since the early to mid-1800s, changes in oyster size in response to different nutrient levels from the sixteenth to nineteenth centuries, and substantial reductions in oyster accretion rates (from 10 mm/year to effectively 0 mm/year) from the Late Holocene to modern times. Better integration of different historical ecological data sets and increased collaboration between paleobiologists, geologists, archeologists, environmental historians, and ecologists to create standardized research designs and methodologies will help unify prehistoric, historic, and modern time perspectives on biological conservation.*

**Keywords:** applied paleozoology, Chesapeake Bay, conservation paleobiology, environmental history, historical ecology, restoration, shifting baselines

Integración de Paleobiología, Arqueología e Historia para Informar a la Biología de la Conservación

**Resumen:** *La búsqueda de métodos nuevos para establecer líneas de base ecológicas (condiciones de referencia) está limitada por el hecho de que la mayoría de los estudios ecológicos abarcan las últimas décadas, cuando mucho, e investigan ecosistemas que han sido alterados sustancialmente por actividades humanas, por décadas, siglos o, posiblemente, más. La paleobiología, arqueología e historia proporcionan contexto ecológico histórico a la biología de la conservación, la remediación y restauración. Argumentamos que la integración explícita de la ecología histórica con la conservación puede ayudar a unificar disciplinas relacionadas de paleobiología de la conservación, arqueobiología de la conservación e historia ambiental. Diferencias en la resolución espacial y temporal y la extensión (escala) de datos prehistóricos, históricos y modernos aun son obstáculos para la integración de la ecología histórica y la biología de la conservación, pero las extensiones temporales prolongadas de datos ecológicos históricos pueden ayudar a establecer líneas de base más completas para la restauración, documentar un rango histórico de variabilidad ecológica y ayudar*

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*a la determinación de condiciones futuras deseadas. Utilizamos la pesquería del ostión oriental (*Crassostrea virginica*) de la Bahía de Chesapeake (E.U.A.) para demostrar la utilidad de los datos ecológicos históricos para dilucidar la conservación del ostión y la necesidad de un método de conservación que trascienda límites disciplinares. Los estudios ecológicos históricos de Chesapeake han documentado declinaciones dramáticas (tanto como 99%) en la abundancia de ostiones de inicios a mediados de los 1800, cambios en el tamaño de ostiones en respuesta a diferentes niveles de nutrientes del siglo dieciséis al diecinueve y reducciones sustanciales en las tasas de acreción de ostiones (de 10 mm/año a 0 mm/año) desde el Holoceno Tardío a tiempos modernos. Una mejor integración de diferentes conjuntos de datos ecológicos históricos y una mayor colaboración entre paleobiólogos, geólogos, arqueólogos, historiadores ambientales y ecólogos para definir diseños de investigación estandarizados y metodologías ayudarán a unificar perspectivas de la biología de la conservación prehistóricas, históricas y modernas.*

**Palabras Clave:** Bahía de Chesapeake, ecología histórica, historia ambiental, líneas de base variables, paleobiología de la conservación, paleozoología aplicada, restauración

## Introduction

Ecologists and resource managers require new ways to establish ecological baselines (reference conditions) and understand the long-term evolutionary and ecological responses of ecosystems to anthropogenic activities and natural climatic variability (Jackson 2001; Willis & Birks 2006; Jackson & Hobbs 2009). Paleobiology, archeology, history, and other disciplines offer insights into ecosystem change that can inform contemporary ecosystem management and challenge long-held assumptions about the limited influence of humans on Earth's ecosystems in the distant past (e.g., Lyman 2006; Szabó 2010; Dietl & Flessa 2011). Such historical ecological data document ecosystem structure and function through time, with and without human influence. These data also highlight the fact that ecological baselines and human perceptions of ecological conditions often lack historical perspective and may not account for long-term changes that may span decades, centuries, or millennia (i.e., shifting baselines) (Pauly 1995; Papworth et al. 2009; Jackson et al. 2011).

Scholars from the social and natural sciences have used long-term historical ecological records to help accomplish conservation goals (Dietl & Flessa 2009; Lotze et al. 2011; Lyman 2012). The use of data on past ecosystem structure and function to manage biological diversity has increased substantially, but questions remain about how best to apply historical ecological data to conservation goals and transcend differences in the temporal extent and resolution of historic, prehistoric, and modern data (Meine 1999; Szabó & Hédl 2011; Lyman 2012). As the application of historic and prehistoric data to conservation has grown, so has the number of terms associated with this research, including *historical ecology*, *applied historical ecology*, *applied paleoecology*, *applied paleozoology*, *applied zooarcheology*, *conservation paleobiology*, *conservation zooarcheology*, and *environmental history*. Differences in the intellectual development of these individual fields of inquiry may limit the full contribution of long-term data sets to contemporary ecological knowledge and fragment approaches that could be unified by similar goals and methods. One of the practical challenges facing historical ecology is effective integration of approaches from these different disciplines (i.e., paleobiology, archeology, history, and ecology) to help inform conservation.

We reviewed recent developments and progress in historical ecology, conservation paleobiology, and conservation archeobiology and argue that historical ecology can help unify paleobiology, archeology, and history with conservation biology. We focused on the need for transdisciplinary collaborations (i.e., those that transcend disciplinary boundaries) that apply standardized methods to create more dynamic and complete pictures of ancient and modern ecosystem structure and function. Using the eastern oyster (*Crassostrea virginica*) fishery in the Chesapeake Bay as a case study, we examined the progress that has been made in applying historical ecological data to conservation, the limitations of current data for understanding long-term changes and resilience in oyster populations, and the possibility of a more integrated transdisciplinary approach.

## Definitions and Methods of Historical Ecology

Although the term *historical ecology* dates back to at least the 1950s (e.g., Nichols 1956), its uses, definitions, and applications have multiplied in recent years. To Crumley (1994; Gragson 2005), *historical ecology* has multiple connotations and is most simply the integration of ecology and history. *Historical ecology* has also been broadly defined as the study of the "interactions through time between societies and environments and the consequences of these interactions for understanding the formation of contemporary and past cultures and landscapes" (Balée 2006:76). Others have defined it as the use of "historical knowledge in the management of ecosystems" (Swetnam et al. 1999:1189; Egan & Howell 2001) or as a tool to help establish reference conditions that may assist in framing management goals (Bürgi & Gimmi 2007). We advocate a broad definition of historical ecology as the use of historic and prehistoric data (e.g., paleobiological, archeological, historical) to understand ancient and modern ecosystems, often with the goal of providing context for contemporary conservation. A fundamental goal of historical ecology is to understand past and present human-environment interactions (Balée 2006; Szabó & Hédl 2011), but it is also concerned with understanding natural variation before and after human arrival (Dietl & Flessa 2011).

Historical ecologists analyze a wide range of data from many disciplines (Table 1) (Lotze et al. 2011). A key component of historical ecology is the use of written accounts, pictorial sources, and other historical documents to investigate past ecosystems or organisms and the role of natural and anthropogenic processes in shaping those systems (Szabó & Hédl 2011). For instance, McClenachan (2009) used photographs from a 50-year period to document changes in the sizes and identity of fishes caught during a long-standing sport-fishing competition in Florida (U.S.A.). Others have relied on historical log books, journals, restaurant menus, and other documents to examine past environmental conditions and their relation to conservation. These include the abundances of wild animals observed by Lewis and Clark in 1804–1806 (Martin & Szuter 1999), the productivity of the cod (*Gadus morhua*) fishery in the Gulf of Maine (U.S.A.) in 1861 (Alexander et al. 2009), changes in the abundance and cost of marine species consumed by restaurant patrons from 1850 to 2006 (Jones 2008), Native American use of fire in prehistoric and historic times (Anderson 2006), and changes in river fauna during the last 400 years (Humphries & Winemiller 2009). Perspectives from anthropology, ethnohistory, and archeology also provide insight into the ways traditional ecological knowledge, or the practices and beliefs of aboriginal, indigenous, or traditional peoples, may help improve the management of ecosystems (Bürgi & Gimmi 2007; Lepofsky 2009; Lauer & Aswani 2010).

## Conservation Paleobiology

Dietl and Flessa (2009, 2011) and Flessa (2002) set a research agenda for the newly emerging field of conservation paleobiology. *Conservation paleobiology* is "a synthetic field of research that applies the theories and analytical tools of paleontology to the solution of problems concerning the conservation of biodiversity" and can, theoretically, extend back to the origin of life (Dietl & Flessa 2011:30). Conservation paleobiologists draw on data from the last few decades to millions of years ago to investigate ecological baselines, geographic range shifts, extinction, and phenotypic responses to natural perturbations (Dietl & Flessa 2011). Ecosystems examined range from freshwater (Smol 2009), to shallow marine (Kidwell 2009; Kowalewski 2009), to terrestrial (Swetnam et al. 1999; Hadly & Barnosky 2009; Jackson et al. 2009), and studies incorporate faunal, floral, genetic, and geochemical data (Koch et al. 2009). For example, sediment cores from Alaskan lakes (U.S.A.) provide a 2200-year record of sockeye salmon (*Oncorhyncus nerka*) abundance that suggests long-term, climate-driven fluctuations in population size dwarf recent decadal variability in population size (Finney et al. 2002). Walbran et al. (1989) argue that the recent outbreak of crown-of-thorns starfish (*Acanthaster planci*) on the Australian Great Barrier Reef is similar to other outbreaks during the last 8000 years. Holocene cave faunas from the U.S. Great Basin provide data on the response of populations of small mammals to climate change in the past and inform predictions about future responses (Terry et al. 2011).

Dietl and Flessa (2011) differentiate conservation paleobiology from historical ecology and argue that paleobiological data extend beyond the Pleistocene and are often unrelated to human activities. However, Jackson and McClenachan (2009) link paleobiology with historical ecology and emphasize paleontology has some advantages over archeology, history, and other approaches to

**Table 1. Primary subfields of historical ecology, data sets, and research prospects and limitations of data.**

| *Discipline* | *Primary data sets* | *Time range* | *Comments and limitations* |
|---|---|---|---|
| Environmental history | archival written sources, printed sources, pictorial sources | dependent on area of study; potentially for a few millennia, but generally from last 200–500 years | limited by observations recorded in written texts, journals, menus, photographs, and drawings; human-selected descriptions |
| Conservation archeobiology | animal bones, teeth, and shells and plant macroremains, pollen, and phytoliths | potentially from origins of humans (~5 ma), but commonly from the Holocene (10,000 years ago to present) | human-selected assemblages of organisms in an ecosystem; limited by preservation and presence of ancient peoples, but may also include analyses of off-site materials to help separate cultural from natural processes |
| Conservation paleobiology | animal bones, teeth, and shells and plant macrofossils, pollen, phytoliths, diatoms, etc. | potentially from origins of life on Earth, but generally from Pleistocene and Holocene | limited by preservation conditions; potential to describe completely natural systems |

historical ecology because paleobiological deposits and remains are generally natural accumulations. Despite some differences, conservation paleobiology overlaps with archeological research on historical ecology (Lyman 2006; Jackson & McClenachan 2009; Koch et al. 2009).

## Conservation Archeobiology

To our knowledge, the term *conservation archeobiology* has not been used before. However, the terms *conservation zooarcheology* and *applied paleozoology*, which emphasize the application of archeological (and paleontological) animal remains (bones and teeth) to achieve conservation objectives, have gained acceptance (Lyman & Cannon 2004; Wolverton et al. 2011; Lyman 2012). We follow previous usage of these terms, but expand them to include botanical remains (pollen, phytoliths, and macrobotanical remains) and geochemical data (stable isotopes and ancient DNA). *Conservation archeobiology* is the analysis of plant and animal remains, artifacts, geochemistry, genetics, and other related data from archeological sites to help guide conservation biology and restoration.

Conservation archeobiology has developed in parallel with conservation paleobiology and the 2 can be effectively integrated. Conservation archeobiological researchers have investigated a variety of aquatic ecosystems and organisms including ancient and modern red abalone (*Haliotis rufescens*) in California (U.S.A.) (Braje et al. 2009), freshwater mollusks (Unionidae) in Texas (U.S.A.) (Randklev et al. 2010), and northeastern Pacific Coast kelp forests, Pacific and Caribbean coral reefs, and global near-shore fishes and other marine organisms (Rick & Erlandson 2008; Erlandson & Rick 2010). In terrestrial ecosystems, studies range from the formation of anthropogenic landscapes in the Amazon (Heckenberger et al. 2008) to the effects of climate change on reindeer (*Rangifer tarandus*) (Grayson & Delpech 2005) and millennial patterns in the alteration of plant communities and animal populations in the Mississippi River Valley (U.S.A.) (Smith 2009).

A major difference between archeological and paleobiological data is that the former are generally the result of human activities. Most materials in an archeological site relate to human subsistence, construction, trade, and other activities. However, archeologists routinely collect sediment cores, macrobotanical remains, phytoliths, and faunal materials from archeological sites or nearby areas (e.g., lake sediments) that can help evaluate natural and human influences on environmental change. Archeological data are valuable for estimating prehistoric abundance of key taxa through time and under varying intensities of human exploitation, anthropogenic landscape alteration, and natural climatic variation (Hayashida 2005; Frazier 2007; Lyman 2012). They may also illuminate the long-term formation of novel ecosystems under human pressure (Dean 2010).

## Issues of Scale

Determining the time frame and extent of reference ecosystems is a key aspect of ecological restoration. A generalized scheme of macroscale (>10,000 years), mesoscale (<10,000 years), and microscale (human lifetime or shorter) offers a way to subdivide different time frames that can be used to establish conservation goals (Callicott 2002; Wolverton et al. 2011). Ecologists and historians provide microscale data; archeologists, paleobiologists, and historians contribute data at the mesoscale; and paleobiologists and archeologists provide the macroscale data. Comparing data from these overlapping scales can help delineate the influence of anthropogenic and nonanthropogenic processes on ecosystems and organisms.

Although questions remain about the spatial and temporal resolution of historical ecological data, the longer time series may outweigh potential problems of resolution by elucidating long-term ecological and evolutionary patterns that can help inform conservation in the near and long term (Lyman 2012). These data can also help establish the historical range of variability or the different environmental conditions that occurred over time (Szabó 2010). They may also help researchers transcend what Szabó and Hédl (2011) call the "pre-1800 dilemma"; that is, the dearth of data from before the 1800s. The compilation of as much ancient and modern data as possible, within an integrated and well-defined research design by interdisciplinary teams, is a crucial step toward providing more complete ecological baselines that integrate data from different periods. Although past ecological conditions generally cannot be recreated, historical ecological data can help assist in determining desired future conditions on the basis of past ecosystems and conditions.

## Archeology, Paleobiology, and Conservation on the Chesapeake Bay

We used the eastern oyster (*Crassostrea virginica*) fishery in the Chesapeake Bay (U.S.A.) as a case study through which to evaluate the integration of paleobiological, archeological, and historical data to inform management decisions and to demonstrate the progress in historical ecology thus far and the promise of a more unified approach in the future (Fig. 1). Studies of the sedimentary and paleontological record of the bay have been conducted for almost 40 years and reveal a history of increased sediment and nutrient runoff that led

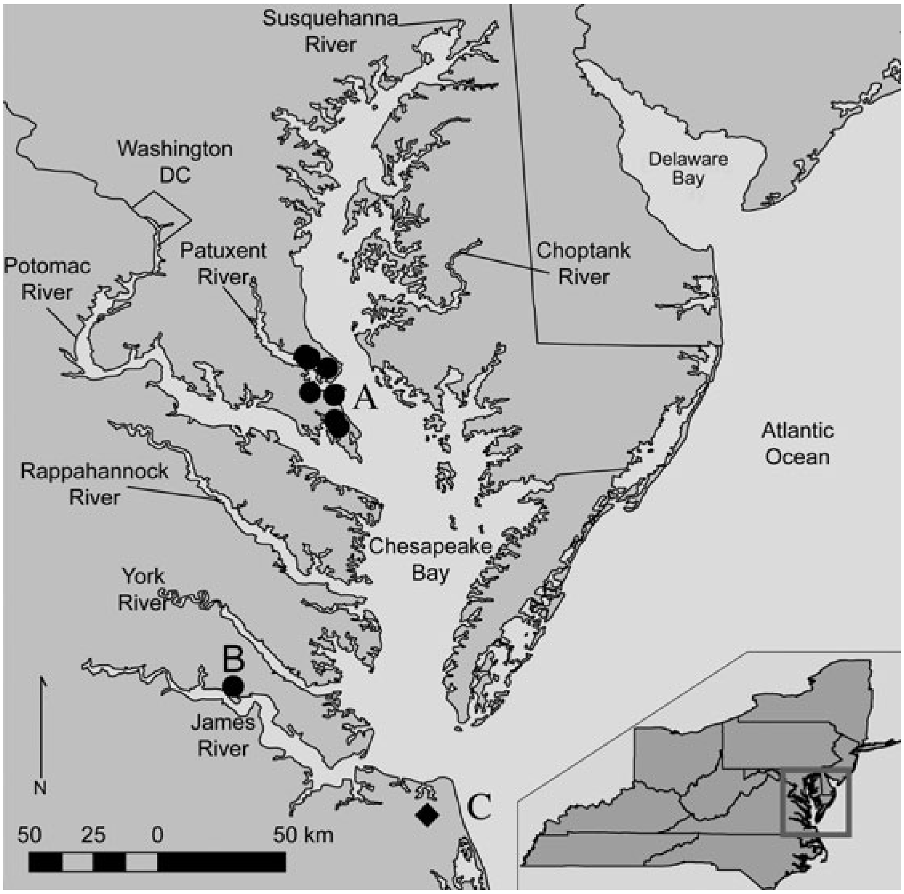

*Figure 1. Chesapeake Bay region, major tributary rivers, and location of archeological (dots) and paleontological (diamonds) sites discussed in the text (inset, square, study area) A, historic and prehistoric sites on Patuxent and Potomac Rivers analyzed by Kirby and Miller (2005); B, historical well, where oysters were dumped by people at Jamestown and analyzed by Harding et al. (2010); C, Gomez Pit, a Pleistocene paleontological site reported by Kirby (2001).*

to algal blooms, seasonal hypoxia, and a shift from top-down to bottom-up trophic control of ecosystem structure (Brush 2001; Zimmerman & Canuel 2002; Willard & Cronin 2007). Many of the changes observed in the Chesapeake Bay are similar to those noted in bays and estuaries around the world (Jackson et al. 2001; Lotze et al. 2006; Beck et al. 2011). In addition to reconstructing the sedimentological, paleontological, and geochemical history of the bay, researchers have investigated archeological sites and historical documents to explore the distribution, technology, and culture of Native American peoples and more recent European and American settlers (Miller 1986, 2001; Walsh 2001; Lotze 2010). Although the majority of studies focus on reconstructing the bay's geology and human occupation, a handful of studies highlight the potential applicability of these data to conservation, particularly to oyster management (e.g., Kirby 2004; Kirby & Miller 2005; Mann et al. 2009*b*).

Oysters have played a crucial role in the maintenance of Chesapeake Bay ecosystems, water quality, and food webs since the bay's formation over 8000 years ago and during previous interglacial periods (Fig. 2) (Kennedy et al. 1996; Kirby 2001; Miller 2001). The oyster fishery once thrived, but oyster abundances in the bay have plummeted as a result of unsustainable harvesting, increased sediment load, and disease (Hargis & Haven 1999; Luckenbach et al. 1999; Wilberg et al. 2011). Oyster management has traditionally relied heavily on the reseeding and reestablishment of oyster reefs (Bartol & Mann 1999; Breitburg et al. 2000; Mann 2000), but these efforts are hampered by the fact that reefs were dramatically altered by benthic dredging long before managers could observe the reefs (Kirby 2004). In their attempts to reconstruct the structure and function of oyster reefs in the bay, ecologists have relied primarily on recent benthic monitoring and historical records of their distribution and abundance. Recently researchers have also conducted cultural assessments of the interests and objectives of different stakeholders (e.g., fishers, the public, scientists) in oyster restoration (Paolisso & Dery 2010).

Although data are limited, research results highlight the advantage of combining paleontological, archeological, and historical approaches and the need for further research. For example, one approach to assessing the status and recovery potential of modern oysters is to quantify growth of individuals and reefs. Assessment of modern Chesapeake Bay oysters suggests that shell height (i.e., length) increases approximately 17–25 mm/year (Kirby & Miller 2005; Harding et al. 2008; Mann et al. 2009*a*). These data also suggest reefs are generally no longer actively accreting (Mann et al. 2009*b*), although estimates of accretion of oyster shells vary considerably as a function

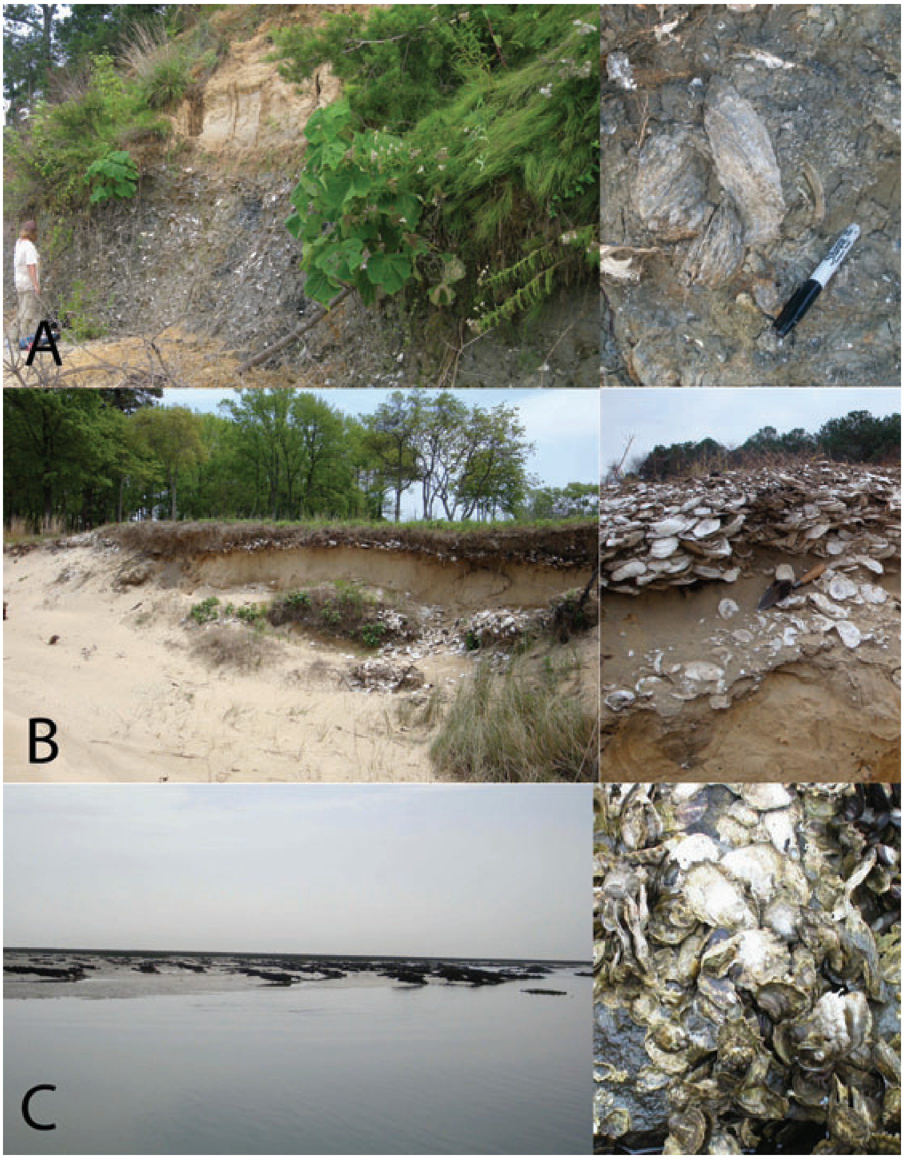

*Figure 2. Ancient and modern assemblages used in studies of the historical ecology of the Chesapeake Bay (U.S.A.) oyster fishery: (a) Pleistocene oyster reef deposit along the Piankatank River near Dutton, Virginia, and close-up of the deposit, (b) Late Holocene prehistoric archeological deposit of oysters collected by Native Americans on the eastern shore of Maryland and close-up of the deposit, (c) living oyster reefs exposed at low tide on the eastern shore of Virginia and close-up of reef.*

of covariates such as location, salinity, nutrients, and harvesting. Even though these growth rate data are useful, they are for a relatively short period of the bay's history (<1000 years) and from a fairly limited geographical extent that includes only portions of the James, Patuxent, and Potomac Rivers. These data leave unanswered questions that are important for understanding the resilience and historical range of variability of Chesapeake oysters over centuries and millennia. What were the average growth and accretion rates of Chesapeake oysters before the widespread establishment of major oyster diseases in 1949, before widespread dredging started in 1870, before massive clearance of native vegetation for agriculture by European settlers in the late 1800s, and before the several millennia of Native American harvest?

Researchers have provided the answers to some of these questions, at least for portions of the bay and particular time intervals. For example, Kirby and Miller (2005) sampled sixteenth century to modern oyster specimens preserved in archeological sites along the St. Mary's and Patuxent Rivers in Maryland. They divided specimens into 4 time intervals (<AD 1760, 1760–1860, 1861–1920, >1920) to measure the effect of anthropogenic eutrophication on growth rates. They found that oyster growth increased during the early stages of eutrophication in the 1700s to early 1800s before decreasing precipitously after 1860 (Fig. 3). Precolonial (before AD 1600s) growth rates (and by extension mean body sizes) were also somewhat higher than colonial growth rates (Mann et al. 2009*b*; Harding et al. 2010), and Pleistocene (400,000–250,000 years ago) rates may have been similar (Kirby et al. 1998). However, these data come from different geographic locations with different paleoclimates and were analyzed with different techniques, and evidence for the Pleistocene rates consists of just 2 specimens. Reef accretion also declined at estimated rates of 10 mm/year in the late

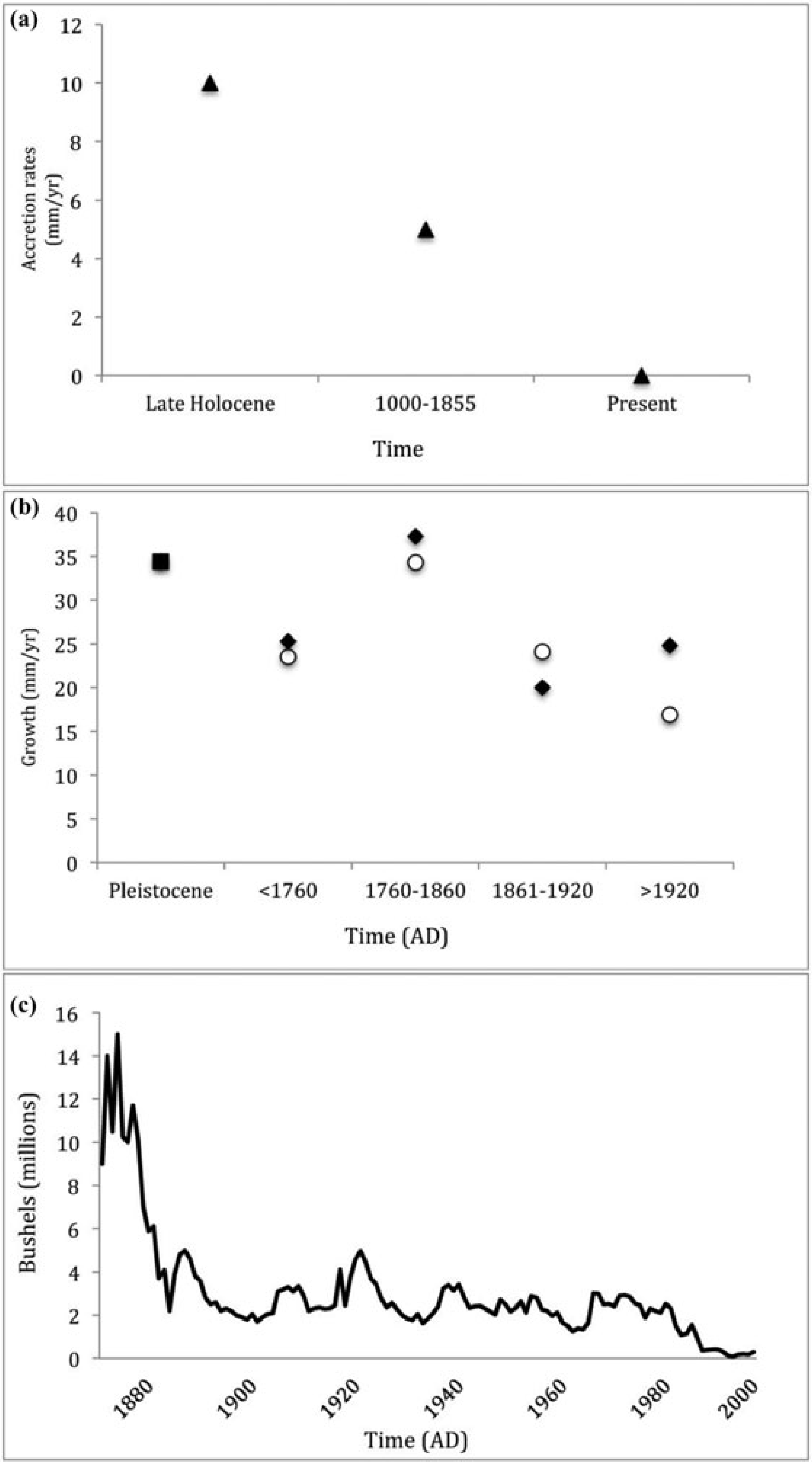

*Figure 3. Oyster (a) reef accretion rates (Mann et al. 2009b), (b) shell growth-rate estimates (circles, Patuxent River; diamonds, St. Mary's River [Kirby & Miller 2005]; square, Gomez Pit, Virginia [Kirby 2001]), and (c) harvest levels (1 bushel is approximately 23 kg) over the last 2 centuries of catch records from commercial fisheries (Maryland Department of Natural Resources [Rothschild et al. 1994]).*

Holocene (on the basis of extrapolation from estimates of sea level rise) (Mann et al. 2009*b*) and 5 mm/year from AD 1000 through 1855 (on the basis of sub-bottom profiling of the James River) (DeAlteris 1988), and effectively there is no growth in the same location today (Fig. 3) (Mann et al. 2009*b*). Five millimeters per year is approximately the equivalent of adding 975 bushels (approximately 22,400 kg) of oysters per hectare (390 bushels [approximately 9000 kg] of shell per acre) of river bottom per year as a repletion action—which current oyster restoration efforts do not come close to achieving (Mann et al. 2009*b*). These results highlight the potential utility of historical ecological data for quantifying the extent of oyster population decline and for providing baselines for recovery. However, few of these data are currently available for Chesapeake Bay oysters and there is great need for methodological standardization across paleobiology, archeology, environmental history, and modern ecology.

In a related example, archeological oysters from a Colonial well on Jamestown Island have made it possible to reconstruct the demography of oysters circa AD 1600, which corresponds to the early phases of European colonization of the area (Harding et al. 2008, 2010). Comparison of historical and modern data on age structure of oysters in the same river (Mann et al. 2009*a*, 2009*b*) indicates that older age classes currently are effectively absent. Older oysters may have died from diseases that became established in the river in the past 60 years (Andrews 1996; Burreson & Calvo 1996; Ford & Tripp 1996). Changes in oyster demography over time, however, also may be influenced by changes in salinity and temperature, Native American harvesting, and other factors.

Historical and recent surveys (e.g., Baylor 1896; Haven & Whitcomb 1983) provide a wealth of information regarding the distribution and productivity of oyster reefs, but relatively little is known about the geographic extent and density of oyster deposits before the late 1800s, after bay oysters had already been intensively harvested in commercial fisheries for decades. This is a classic example of the shifting-baselines syndrome (Pauly 1995); reference conditions for oysters are based on ecosystems already heavily influenced by commercial enterprises and limited data on oyster ecology during the preceding centuries and millennia. By combining forces, archeologists and paleobiologists could contribute a much-needed, although obviously more piecemeal, approach to geographic oyster surveys that encompasses longer periods. To our knowledge, there has been no attempt to synthesize spatially explicit occurrence data on shell midden and natural oyster deposits in the Chesapeake region. Such data are useful for establishing reference conditions for restoration and documenting the response of oysters to natural changes in salinity and temperature before the introduction of diseases in 1949 and for establishing conditions under varying intensities of human harvest, including subsistence-based Native American and colonial exploitation and later commercial harvesting. Depending on the temporal resolution of these data it may even be possible to track changes in oyster distribution resulting from Pleistocene sea-level change.

Historical ecological data on Chesapeake Bay oyster growth rates, oyster reef accretion rates, and the intensity of human exploitation of oysters have provided insight into modern oyster conservation because they document the long-term ecological responses and resilience of oysters to changes in nutrient loads, salinity, sedimentation, and other factors (Kirby & Miller 2005; Mann et al. 2009*b*; Harding et al. 2010). They have also helped determine trends and declines in commercial exploitation over the last 150 years (Rothschild et al. 1994; Wilberg et al. 2011). Comparisons among modern, historical, archeological, and paleobiological data on oysters in the Chesapeake, however, are complicated by differences in sampling methods and temporal and spatial resolution—primarily because data were generally not collected to track oyster growth rates, reef accretion rates, geographic distribution of oysters, body size of oysters, or oyster density over time.

We argue that future research on the historical ecology of Chesapeake Bay oysters and in historical ecology more generally needs to better integrate the goals and methods of the different fields of inquiry of historical ecology. An important future direction is increased collaboration between paleobiologists, geologists, archeologists, historians, and ecologists to create more standardized experimental designs and methods. The challenges are substantial, but the potential payoff is enormous because this integration may help untangle fundamental questions about the effects of anthropogenic versus natural climatic forcing and provide deeper temporal context that can help manage for long-term ecological change and instability.

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