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Towards a Historical Ecology of Intertidal Foraging in the Mafia Archipelago: Archaeomalacology and Implications for Marine Resource Management

Patrick Faulkner^{1,2*}, Matthew Harris³, Othman Haji⁴, Alison Crowther^{2,3}, Mark C. Horton⁵, and Nicole L. Boivin²

Abstract. Understanding the timing and nature of human influence on coastal and island ecosystems is becoming a central concern in archaeological research, particularly when investigated within a historical ecology framework. Unfortunately, the coast and islands of eastern Africa have not figured significantly within this growing body of literature, but are important given their historically contingent environmental, social, and political contexts, as well as the considerable threats now posed to marine ecosystems. Here, we begin developing a longer-term understanding of past marine resource use in the Mafia Archipelago (eastern Africa), an area of high ecological importance containing the Mafia Island Marine Park. Focusing on the comparatively less researched marine invertebrates provides a means for initiating discussion on potential past marine ecosystem structure, human foraging and environmental shifts, and the implications for contemporary marine resource management. The available evidence suggests that human-environment interactions over the last 2000 years were complex and dynamic; however, these data raise more questions than answers regarding the specific drivers of changes observed in the archaeomalacological record. This is encouraging as a baseline investigation and emphasizes the need for further engagement with historical ecology by a range of cognate disciplines to enhance our understanding of these complex issues.

Keywords: eastern Africa, Juani Island, Iron Age, archaeomalacology, marine resource use

Introduction

Human impacts on oceans and coastal margins from over-exploitation, urbanization, industrialization, and resulting pollution have caused habitat loss, reduced species diversity, and accelerated oceanic and atmospheric warming on a global scale (as summarized by Jackson et al. 2001). While these issues have garnered worldwide attention, the contemporary situation can be viewed as part of a much longer-term history of humans exploiting coasts and islands (Braje et al. 2017; Jackson et al. 2001). The timing and nature of human interactions with coastal and island ecosystems has become a focal point of

archaeological inquiry, particularly when embedded within historical ecology and/or applied zooarchaeology. Historical ecology is an interdisciplinary approach combining long-term historical perspectives with ecology to understand ecosystem evolution, natural and anthropogenic environmental modifications, and human-environmental interactions (Balée and Erickson 2006; Crumley 1994). As such, historical ecology is particularly effective for framing research agendas focused on the types of issues noted above in a range of terrestrial and aquatic environments (Boivin et al. 2016; Braje and Rick 2013; Fitzpatrick and Keegan 2007).

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Possible multidirectional changes in past socio-economic organization may be recognized within a historical ecological approach, broadening the scope and significance of zooarchaeological research, feeding long-term data into the development of more effective conservation, management, and environmental policies (Balée 2006; Braje et al. 2017; Rick and Lockwood 2013). Schwerdtner Máñez et al. (2014:1–2), for example, note five key areas of inquiry within the historical ecology of marine environments, including assessing the relative importance of key drivers of environmental change, understanding the significance of marine resources for human societies, and considering how historical information can be used to improve future management. In reviewing the range of potential threats to modern marine environments, Crain et al. (2009:57) also suggest that understanding the cumulative effects of multiple threats to marine ecosystems must be a research priority. Zooarchaeology and historical ecology can make a significant contribution in these areas, providing insights into ecosystem change, human ecodynamics, and the assessment of ecological benchmarks for a range of marine taxa (e.g., Douglass et al. 2018, 2019; McKechnie et al. 2014; Wolverson et al. 2016).

The aim of this paper is to develop an understanding of past marine mollusk use at the Juani Primary School site in the Mafia Archipelago (eastern Africa), an area contained within the Mafia Island Marine Park. Detailed analyses and interpretations of the Sealinks Project investigation at this site are presented elsewhere (Crowther et al. 2016). However, in summary, the site contained rich ceramic assemblages alongside abundant faunal remains dominated by fish and marine mollusks. Based on preliminary analyses from a single trench, the mollusks reduce in density and richness from the Early Iron Age (EIA, circa first–sixth centuries CE) to the Middle Iron Age–Late Iron Age (MIA-LIA, circa seventh–

fifteenth centuries CE), with similar trends apparent in the fish data from all four trenches. Marine and terrestrial tetrapods are relatively scarce through the EIA and MIA-LIA, with small game (e.g., duiker) and marine turtle dominant. Archaeobotanical evidence indicates crops in very small quantities, all of which are attributed to the MIA-LIA, indicating a lack of convincing agricultural evidence for the EIA. Based on these data, Crowther et al. (2016) interpret the economic structure as representing an initial EIA maritime adaptation during the phase of island colonization, followed by a mixed herding/farming economy in the MIA-LIA that continued to include significant marine resources.

Here, we expand on the previous archaeomalacological analyses to focus on trends in human foraging and human-environment interactions from the EIA to the present and, in doing so, consider the implications of these data for resource management. Following Contreras (2016), rather than concentrating on whether environments influenced humans or vice versa, we explore how humans and their environments interacted. As such, we emphasize the interaction of humans and their environment within a specific context, taking a temporal approach to investigate the nature of intertidal foraging and to isolate potential variability or stability in these behaviors. Archaeomalacological research in eastern Africa is in an early stage of development (e.g., Douglass 2017; Faulkner et al. 2018a, 2018b; Msemwa 1994), meaning that the past use of these resources remains relatively poorly understood. In contrast, archaeological research in other coastal regions has demonstrated the influence that human foraging can have on mollusk abundance, richness, and diversity, and how these effects contribute to broader ecosystem alterations (e.g., Giovas et al. 2010; Jerardino 2016; Jerardino and Marean 2010; Kyriacou et al. 2015). As marine invertebrates fill a crucial role within marine ecosystems (e.g., habitat complexity, trophic structure), baseline

data on long-term molluscan richness and diversity has implications for contemporary resource use, marine habitat structure, and ecosystem/resource management (Peacock et al. 2012).

Background

Mafia Archipelago: Environmental Context

The Mafia Archipelago is located 20 km off the southern coast of Tanzania (Figure 1), 120 km southeast of Dar es Salaam, and separated from the southern extent of the Rufiji Delta on the mainland by the shallow Mafia Channel (Andersson and Ngazi 1995:476; MPRU 2011:8; TCMP 2003:53). The Archipelago comprises a chain of sandstone and coral rag islands (e.g., Bweeju, Chole, Jibondo, Juani, and Mafia Islands) and a number of smaller reefs (e.g., Mange and Tutia Reefs) (MPRU 2011:8; TCMP 2001:11–12). Each island has different biological and physical characteristics, resulting in diverse contemporary socio-economic structures across the region (Andersson and Ngazi 1995:477, 1998:689), and likely influencing the configuration of past economic activities. For example, the current inhabitants of Chole Island primarily focus on agriculture supplemented by marine resources, while, on Jibondo Island, the principal economic resources are fish, octopus, sea cucumber, and marine mollusks. On Juani Island, the fertile calcareous soils promote plant growth, with the abundance of timber for firewood making the island a favored location for burning coral for lime production (Andersson and Ngazi 1995:477).

A significant development for marine ecosystem and resource management in this region was the establishment of the Mafia Island Marine Park (MIMP) in 1995 (Figure 1). Encompassing ~822 km², this area contains the highest marine biodiversity in Tanzania and potentially the richest in eastern Africa (Andersson and Ngazi 1995:476; Moshy and Bryceson 2016:3).

The high productivity of the Mafia Island ecosystem is partly due to the nutritional supply flowing from the Rufiji Delta (TCMP 2003:53), with the MIMP containing coral reefs, mangroves, sea grasses, and lagoons (Andersson and Ngazi 1995:476). Habitat and species diversity are higher in the eastern part of the Archipelago and the Chole Bay area, in particular, comprises a mosaic of marine ecosystems. Hard reefs are located to the southwest of Mafia Island and a 33-km fringing reef extends down the length of the Mafia, Juani, and Jibondo Island coastlines (TCMP 2001:13). Seagrass beds around Mafia Island contain a high diversity of marine organisms, including fish, crustacea, and mollusks (TCMP 2001:25–26). The subtidal areas throughout Chole Bay are shallow (less than 20 m below mean tide levels) and are relatively sheltered from extreme environmental conditions, resulting in species-rich coral- and sponge-dominated reefs, considerable seagrass patches, mangroves, and intertidal flats (MPRU 2011:8, 10). Dense mangrove forests are found in the northeast of Chole Bay, as well as fringing Chole Island and the northwest coast of Juani Island (Lewis et al. 2011:7; MPRU 2011:11; TCMP 2001:18, 20).

Contemporary Marine Resource Use and Mollusk Foraging

Long-term ecological and marine resource use studies have been undertaken around the Mafia Archipelago by the Frontier Tanzania Association, the University of Dar es Salaam, and the MIMP, focused primarily on coral reefs and associated fauna (e.g., within Chole Bay and around Utende) (Gutmann Roberts 2014; Hemsworth 2015; Jones and Fanning 2010). These investigations and the literature published on marine resource management have been concentrated on coral reefs, fish, marine mammals and reptiles, octopus, and large crustacea (e.g., *Scylla serrata*) (see Barnes et al. 2002; Garpe and Öhman 2003; Guard and Mgaya 2002; Jiddawi

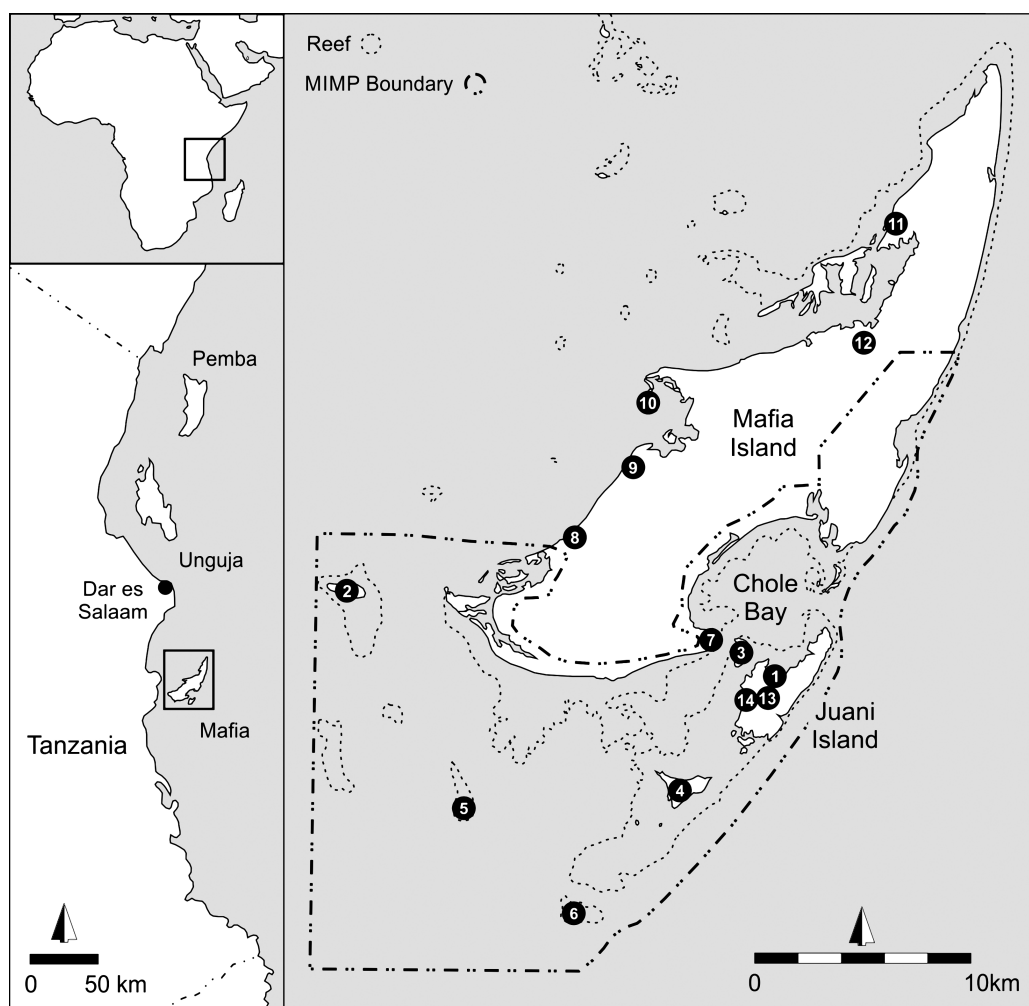


Figure 1. Map of the Mafia Archipelago showing locations mentioned in the text and the Mafia Island Marine Park (MIMP) boundary. 1: Juani Primary School; 2: Bwejuu Island; 3: Chole Island; 4: Jibondo Island; 5: Mange Reef; 6: Tutia Reef; 7: Utende; 8: Kilindoni; 9: Mfuruni; 10: Ras Kichevi; 11: Kanga; 12: Kironawe; 13: Ukunju Cave; 14: Kua Ruins.

and Öhman 2002; Kamukuru et al. 2005; Moshy and Bryceson 2016; Muhando and Rumisha 2008; Mwaipopo 2008). Where invertebrate density and diversity has been recorded, the focus has largely been on sea urchins and crown-of-thorns starfish (*Acanthaster planci*) as indicator species of reef health, anemones, octopus, sponges, shrimp, nudibranchs, and sea cucumbers. Bivalves and gastropods have been recorded largely to phylum except for a small number of commercially important taxa (Fosuah and Steer 2009:38; Gutmann

Roberts 2014:28–29; Hemsworth 2015:17, 28; Jones and Fanning 2010:20). While it has been noted that significant numbers of marine invertebrates occur within the MIMP, and along the east African coast, more broadly, few detailed analyses of marine invertebrates have been undertaken (Fabricius 2005; MPRU 2011; Richmond 2001).

Based on qualitative surveys undertaken across the Archipelago in 1995, the most important marine resources in terms of income and/or food supply were

coral collection, finfish, and octopus, with sea cucumber harvested for export only (Andersson and Ngazi 1995:479–480; MPRU 2011:13). Marine mollusk collecting and sea cucumber harvesting involved similar numbers of people, and although the consumptive value was low for mollusks, the productive income generated was only lower than that reported for finfish and octopus (Andersson and Ngazi 1995:480; Coughanowr et al. 1995:455). The Mafia Archipelago qualitative surveys also indicated a shift away from some marine resources between 1993 and 1998, with increased consumption of fish and agricultural products and the virtual disappearance of intertidal resources linked to high exploitation levels (Andersson and Ngazi 1998:690–691; Christie 2011:102; MPRU 2011:13). It has been suggested that the extensive intertidal flats within the MIMP were once abundant in mollusks and other invertebrates and, although there is a lack of detailed distribution and density data available (Muhando and Rumisha 2008:65), these resources are now viewed as having been overexploited (MPRU 2011:11, 19).

The impacts of commercial harvesting of marine mollusks have been of key concern within the MIMP and along the eastern African coast, particularly since many of the commercially collected gastropod taxa are large and slow growing. Examples of these commercial taxa include *Cypraea tigris*, *Monetaria annulus* (syn. *Cypraea annulus*), *Cypraeacassis rufa*, *Chicoreus ramosus*, *Pleuroploca trapezium*, and various *Conus* species, many of which make a significant contribution to the income of coastal inhabitants (Muhando and Rumisha 2008:10). A study on the effects of shell collection on the abundance of gastropods on the Tanzanian coast found that commercially valuable species were less abundant on shores in Dar es Salaam and Zanzibar in comparison with Mafia Island (Newton et al. 1993:242–243; Nordlund et al. 2010:400). Mollusk

collection across the Mafia region for the ornamental or curio market has largely been viewed as being opportunistic and/or sustainable rather than intensive and systematic (e.g., Fosuah and Steer 2009:38; Lewis et al. 2011:35). However, this may not have always been the case throughout the Archipelago (Horrell et al. 1996:54). For example, *C. tigris* were a focal taxon harvested for the marine curio market in the early to mid-2000s and, although a ban on collection was in place within the MIMP, 250 kg of illegally collected cowries were impounded in 2006–2007 (Hemsworth 2015:21; Mwaipopo 2008).

Detailed modern socio-economic and socio-ecological research on marine mollusks is unfortunately lacking from the Mafia Archipelago but some insight into modern mollusk resource use is available. Carrying out ethnographic observations and qualitative surveys of contemporary marine resource use, Christie (2011) collected data within Chole Bay and around Juani Village, as well as around Kilindoni and Mfuruni on the western side of Mafia Island. A similar approach was taken by Brigden and Steer (2009) around Ras Kichevi, also on the west coast of Mafia Island, producing comparable results to those of Christie (2011). It was noted that intertidal harvesting was largely undertaken by women and children during low tide, with some incidental collection by fishermen (who harvested *Cypraeidae*, *C. ramosus*, and *P. trapezium*). *Terebralia palustris* was also collected by men, largely for bait and/or lime production, although women were also involved in harvesting this taxon and *C. ramosus* for subsistence (Brigden and Steer 2009:19; Christie 2011:126). The main mollusks collected from the intertidal zone included *Anadara antiquata*, *Isognomon ephippium*, *Nerita textilis*, *Volema pyrum* (syn. *V. paradisiaca*), and *Polinices mammilla*. Other species collected included *Architectonica perspectiva* as traditional medicine (Brigden and Steer 2009:21) and *M. annulus* (largely by children), the latter also having a significant commercial export

value (Christie 2011:127). Large piles of *M. annulus* were recorded by Brigden and Steer (2009:19–20), having been collected during periods of poor weather in an opportunistic fashion by adult fishermen. A range of taxa within the Cypraeidae were also collected from the intertidal zone for the curio trade, with *Cassis cornuta*, *Phalium glaucum*, and *C. rufa* collected sporadically for that purpose from deeper water (Brigden and Steer 2009:20).

Previous Archaeomalacological Research

Although shell deposits appear to be an important component of the coastal archaeological record across the Mafia Archipelago, few detailed archaeomalacological analyses have been undertaken. Field research on Mafia Island by Chami (2000:208–210) and by Wynne-Jones (2006:7–8) on Mafia and Chole Islands resulted in the identification of significant shell deposits, although details on the taxonomic composition and abundance are not available. Further surveys on Mafia Island by Christie (2011:163–164, 166) recorded shell deposits dominated by *A. antiquata*, *T. palustris*, and *V. pyrum* around Mfuruni, with several more largely comprised of *T. palustris* recorded near Kirongwe. Based on this evidence, combined with oral histories indicating the significant development of mangrove forests in the last hundred years around Mfuruni, Christie (2011:172, 181–186, 2013:116) suggests that mollusk foraging shifted from a focus on *A. antiquata*, *I. ephippium*, and *V. pyrum* (open intertidal) to *T. palustris* (mangroves) due to coastal ecosystem shifts.

Comparatively more information on the invertebrate fauna is available from excavations on Juani Island, particularly Chami's (2000, 2004) investigations at Ukunju Cave, Kinunda Cave, and Juani Primary School, and Christie's (2011, 2013) analyses of the Kua Ruins assemblages. Small numbers of molluscan fauna, identified largely to family level, are reported by Chami (2000:212, 2004:88, 95), including one marine bivalve

(Cardiidae), one terrestrial mollusk (*Tropidophora* spp.), and five marine gastropods (Cypraeidae, Neritopsidae, Strombidae, Terebridae, and Turbinellidae [syn. Vasiidae]). The lack of detail in the reporting of these assemblages makes their interpretation difficult, but the range of taxa falls in line (at higher taxonomic levels) with the dominant species recorded by other researchers. Over 15 mollusk species were recorded by Christie (2013:108) from her excavations at Kua Ruins, with the seven most frequently occurring taxa quantified and presented in detail, including *V. pyrum*, *T. palustris*, *N. textilis*, *C. ramosus*/*P. trapezium*, *C. tigris*, *A. antiquata*, and *M. annulus*. Aimed at investigating status differentiation, Christie (2013:115) recorded higher proportions of mollusks from the lower status units in Area 1 (1325–1451 cal CE) compared with Area 2 (1520–1950 cal CE). Christie (2013:115) cited contemporary informants in interpreting these assemblages, who indicated mollusk consumption was preferred only when access to higher ranked resources was restricted.

Methods

Juani Primary School: Site Description, Excavation, and Chronological Phasing

Located on the north coast of Juani Island, the Juani Primary School site is positioned on a flat raised terrace fronting a narrow beach, sheltered by dense mangroves and an expansive tidal flat (Figure 2). Four 2x2 m trenches were excavated in 2012 in the northern area of the site (JS12-03, JS12-04, JS12-05, JS12-06). These trenches were hand excavated in controlled stratigraphic sequence using the single context method, with thicker contexts excavated in smaller arbitrary units for greater vertical and chronological control. All excavated materials were dry-sieved (3 mm) on site, with bulk soil sampling (30–60 liters per context) implemented for flotation (0.5 mm) and wet-sieving (1 mm) to maximize recovery.

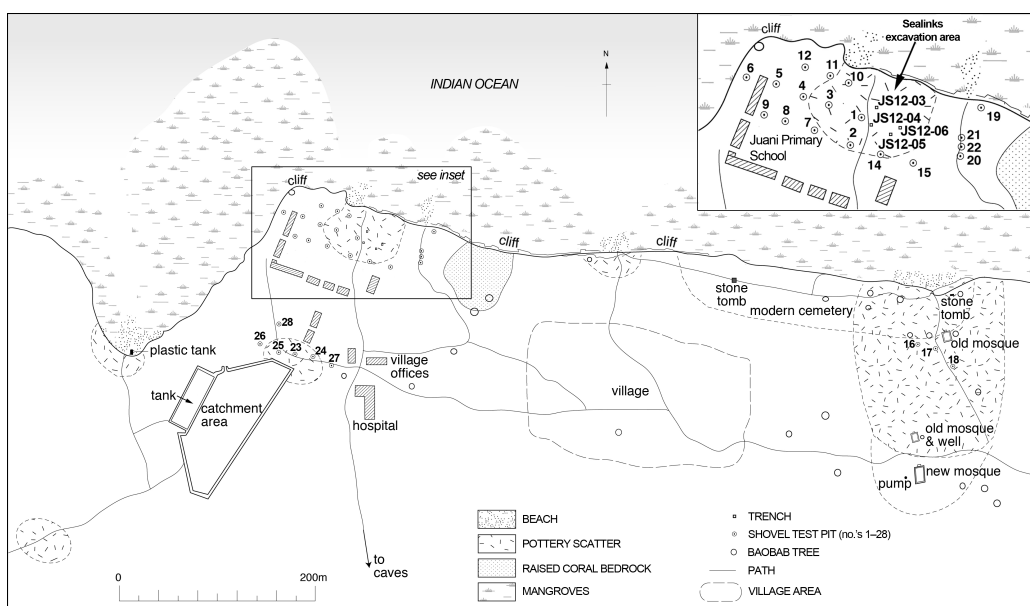


Figure 2. Juani Primary School location and site map.

The stratigraphic and chronological sequence for Juani has been detailed in Crowther et al. (2016) and, as such, is only briefly outlined here. The identifiable stratigraphy across all four trenches was similar, with the upper topsoil layer containing mixed modern and archaeological materials representing the LIA-Post-LIA phase. This upper portion of the deposit was followed by a sequence of reddish-brown sandy silts containing much of the archaeological evidence for occupation. Underlying the LIA-Post-LIA contexts was a MIA-LIA phase (c. 880–1200 cal CE) with a small number of Tana Tradition and Kwale ceramics, overlying the EIA deposits (385–540 cal CE) characterized by Kwale ceramics, a dense midden deposit, and very small quantities of slag from iron working. Based on the recovery of daub from the EIA and MIA-LIA contexts, it is likely that both phases represent small-scale occupation in earth-and-thatch structures.

Archaeomalacological Data Collection

The Juani Primary School invertebrate fauna were analyzed at the House of Wonders Museum (Beit-el-Ajaib) in

Stone Town, Zanzibar, in 2013 and 2015. As physical reference collections were not available in Zanzibar, the material was identified to the lowest possible taxonomic level using published material (e.g., Abbott and Dance 1998; Richmond 2011; Robin 2008, 2011; Rowson et al. 2010; Spry 1964, 1968). Those specimens that did not retain diagnostic features for species level attribution were assigned to the appropriate higher taxonomic level (e.g., genus or family) or one of the indeterminate categories (Harris et al. 2015; Szabó 2009:186). All nomenclature has been standardized with reference to the World Register of Marine Species (WoRMS Editorial Board 2016).

The following analyses are based on Minimum Number of Individuals (MNI) calculation. Following Harris et al. (2015) and Giovas (2009), MNI was recorded using a range of taxon-specific Non-Repetitive Elements (NRE). Bivalve NREs (following siding) included the umbo/beak, the anterior and posterior portions of the hinge/dentition, and the anterior and posterior adductor muscle scars. A range of gastropod NREs were used depend-

ing on shell morphology, including the spire, aperture, aperture lip, posterior and anterior canals, and the umbilicus. The Cypraeidae base and labum, the Neritidae columellar deck, and the Turbinidae, Neritidae, and Pomatiasidae calcified opercula were also included. The Polyplacophora (chiton) MNI calculation was based on the highest counts of the apex of the anterior and mucro of the posterior valves (Giovas 2009:1560). Those specimens that were taxonomically identifiable but did not retain the necessary NREs for MNI calculation were noted as being present and an MNI of 1 assigned per individual context (Giovas 2009:1562; Jerardino and Marean 2010:413). As excavation of the Juani deposits was undertaken stratigraphically, with each context interpreted as a discrete depositional unit within a broader chronological phase, the MNI was calculated for each context and summed per chronological phase. To ensure independence of relative abundance data, MNI calculations per context and chronological phase within each trench were based on the NRE appropriate to the highest common taxonomic level.

Diachronic changes in habitat representation were analyzed by assigning all taxa to one of seven habitat categories (see further discussion below). Non-specific (i.e., genera, family) identifications were assigned multiple habitat categories to account for inter-family variation in life habits (following Harris and Weisler 2017). Several taxa identified to higher levels were also assigned multiple habitats to represent the different locations in which these taxa may be encountered by foragers. The MNI for each habitat category was summed in two ways. First, MNI for the seven distinct habitat categories was summed for each phase. This leads to an artificial inflation of MNI for the total assemblage due to the inclusion of some taxa in multiple habitats. To account for this, the totals for each habitat category (i.e., treating multiple habitat assignments as distinct categories)

were also summed as a separate dataset. A chi-square test was conducted on each dataset to assess change over time.

Sample representativeness was assessed using nestedness analysis and visual inspection of species area curves. These types of analytical approaches can assist in determining whether taxonomic composition and characteristics of archaeological assemblages are representative of past ecological communities (e.g., Lyman 2008; Peacock et al. 2012; Wolverton et al. 2015). Nestedness assesses whether samples represent nested subsets, where assemblages with lower richness should nest within those with higher richness, thereby indicating those samples were drawn from the same community. Nestedness measures this relationship via temperature, whereby 0° represents perfectly nested subsets and 100° represents no nestedness (Ulrich et al. 2009; Wolverton et al. 2015:502). Plotting assemblage richness (NTAXA) against sample size (MNI) should indicate sampling to redundancy: when no new taxa are added with increasing sample size, the curve should asymptote, indicating that the assemblage is taxonomically representative (Lyman 2008). Finally, we use multiple measures of richness and diversity to further assess the characteristics of the molluscan assemblages, with these indices calculated using Palaeontological Statistics (PAST) version 3.13 (Hammer et al. 2001). For these measures, the identified taxonomic categories are grouped to the highest common level to ensure independence in taxonomic classification (Lyman 2008). Richness is evaluated through NTAXA, with the Shannon index (H) and Simpson's index ($1-D$) used to investigate assemblage heterogeneity and evenness. Following Harris and Weisler (2017), random permutation tests of relative abundance were carried out using PAST v3.13 to test for significant differences in each diversity measure by chronological phase. This test uses a randomization procedure based on pooling the original samples to deter-

mine whether the differences observed in the original data could have occurred by random sampling (Hammer and Harper 2007:33–36).

Results

Assemblage Structure and Shifts in Taxonomic and Habitat Representation

The total invertebrate assemblage recovered from Juani Primary School comprised 5095 individuals (MNI) and has been attributed to a large number of taxonomic categories (Supplementary Table 1). Of the 150 invertebrate taxonomic categories recorded, 65 are to species level (22 marine bivalves, seven terrestrial, and 36 marine gastropods at 3490 [68.5%] MNI), 46 to genus level (one freshwater, four terrestrial, and 25 marine gastropods, one freshwater and 15 marine bivalves at 776 [15.2%] MNI), and 33 to family or subfamily level (one freshwater and eight marine bivalves, two terrestrial and 22 marine gastropods at 629 [12.4%] MNI). The Decapoda (crab), Cirripedia (barnacle), and Polyplacophora have been recorded to class or infraclass level (at 104 [2.0%] MNI), and there are three indeterminate categories (bivalve, gastropod, and landsnail at 96 [1.9%] MNI). Juvenile individuals and those exhibiting signs of predatory drilling or hermitting have been quantified separately, but are not included in the above overview as distinct taxonomic categories. These taxa likely represent incidental collection (i.e., potential foraging by-products) or natural incorporations into the deposit. The Cirripedia, Decapoda, and indeterminate categories have also been included in the list of incidental taxa as high levels of fragmentation and weathering preclude their potential economic assessment. The incidental categories comprise a significant component of the overall assemblage at 35.6% (1816 MNI), highlighting the importance of taphonomic assessment of shell assemblages where the aim is to investigate relative shifts in economic use.

Given the ambiguity in the origin of the incidental categories, and our focus on economic resources, these incidental taxa are excluded from further analyses.

The Juani economic assemblage comprises 3279 MNI from 128 taxonomic categories. Here, we define economic taxa in an inclusive sense, using the term to encompass subsistence species and those used for medicine, trade, and/or decoration (Faulkner et al. 2018a). With the need for more detailed archaeological and socio-ecological research across the region, further classification of the molluscan assemblages into dietary, medicinal, ornamental categories, etc., would be speculative. We have taken a more conservative approach to the following analyses in defining economic molluscan taxa, but one that still represents nearshore foraging and the exploitation of certain habitat zones. The 20 dominant taxa (Figure 3A) represent 82.8% of the economic sample (2716 MNI), with the top four taxa consisting of *Nerita balteata*, *Pinctada* spp., *Atactodea striata*, and *Nerita polita*. The 20 sub-dominant taxa contribute 300 MNI (9.2%) to the assemblage, and the remaining 88 minor taxonomic categories contribute 263 MNI (8.0%). Of note are those taxa recorded in modern socio-ecological surveys and/or archaeological assemblages, with contributions to the economic assemblage ranging from 0.3% (*C. ramosus*) to 5.2% MNI (*N. textilis*), although none clearly dominates, as would be expected based on previous discussions of their economic significance.

There are important differences in the proportional abundance of the dominant and sub-dominant taxa at Juani by phase (Figure 3A and 3B), illustrating change through time in the structure of the foraging economy. While decreasing in overall abundance, several taxa increase proportionally from the EIA to the LIA-Post LIA, with the most dramatic increases seen in *A. striata* (4.3–43.3% MNI) and *M. annulus* (1.5–9.5% MNI). Several other taxa, including the Lucinidae, Cerithiidae, *Monetaria*

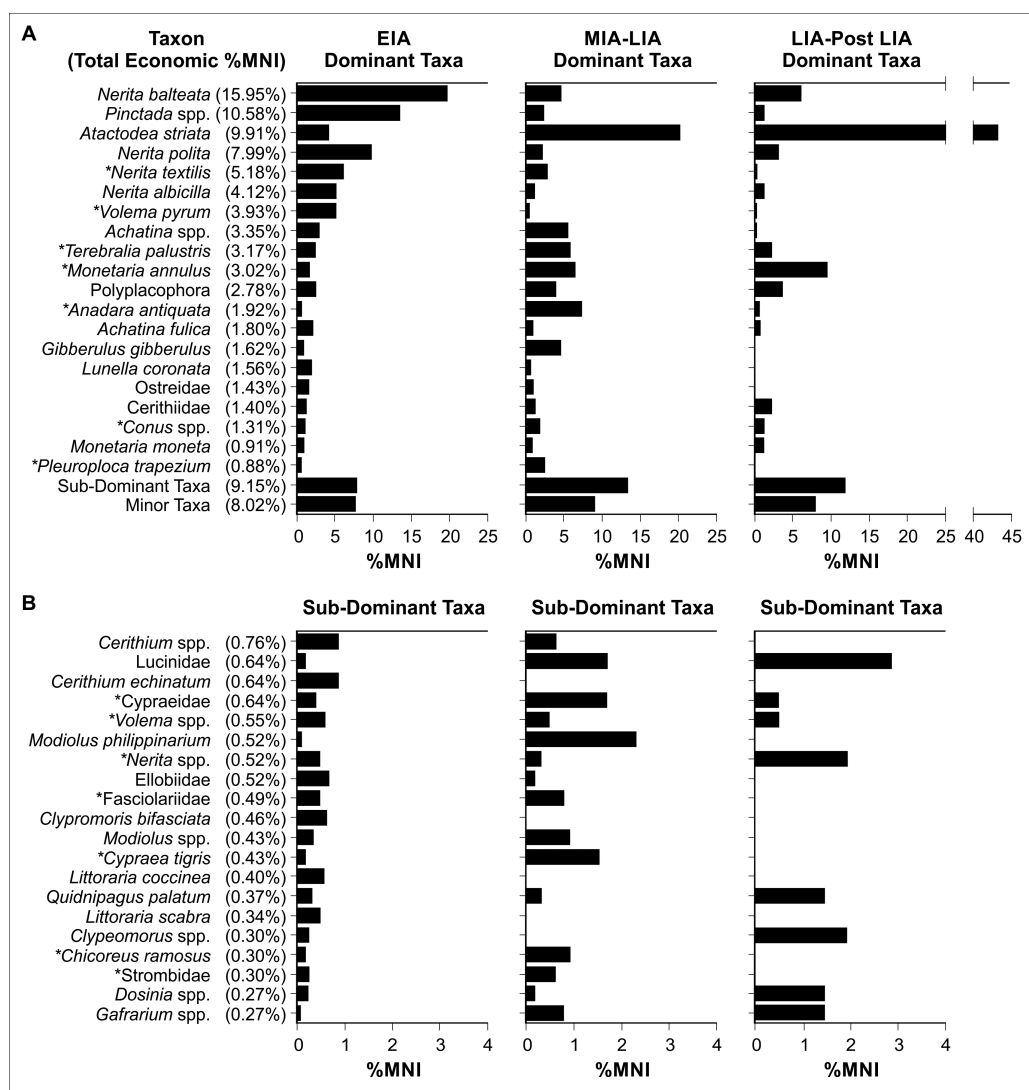


Figure 3. Juani chronological phase dominant (A) and sub-dominant mollusc taxa (B) by %MNI. * indicates taxa previously recorded archaeologically or in socio-ecological surveys.

moneta, *Quidnypagus palatum*, *Dosinia* spp., and *Gafrarium* spp., also exhibit a proportional increase through the Juani sequence, albeit at a reduced degree (0.5–2.7% increase). Several taxa peak in the MIA, only to decline into the LIA-Post-LIA (Polyplacophora, Cypraeidae, *C. tigris*, *A. antiquata*, and *Conus* spp.), and there are 13 taxa that occur in the EIA and/or MIA but disappear entirely into the LIA-Post LIA (e.g., *C. ramosus*, *P. trapezium*, and Strombidae). Finally, the most significant decline

in proportional abundance from the EIA to the LIA-Post LIA occurs in *N. balteata* (19.9–0.5% MNI) and *Pinctada* spp. (13.6–0.1% MNI). The variable contribution of the dominant/sub-dominant species at Juani through time likely reflects a combination of shifting foraging strategies (for both dietary and non-subsistence purposes) coupled with changes in near shore marine habitat and resource availability.

The representation of habitat categories (as illustrated for Chole Bay and adjacent to

the Juani site in Figure 4A) across the three phases parallels these changes in taxonomic abundance. Two general and significant trends exist in the habitat data; an increase in the representation of intertidal sand and mud flats, and a decrease in exploitation of coral rubble substrates (Figures 4B and 4C). A chi-squared test indicated a significant association between phase and habitat category (MNI) (χ^2 (6, $n = 4035$) = 113.89, $p < 0.001$, $V = 0.12$). In both grouped and ungrouped habitat summations, taxa found in sand and mudflat environments account for a minimum 53.5% MNI across all phases

and peak in the LIA-post LIA, accounting for 72.9% MNI. Examination of adjusted residuals for grouped habitats shows a significant increase in sand/mudflat taxa in the LIA-Post LIA, accompanied by a significant decrease in coral rubble taxa from the MIA-LIA onwards. In the MIA-LIA phase, there is a significant increase in taxa that could have been foraged from seagrass/algae, coral reefs, and sand habitats. Finally, while adjusted residuals showed that the change was not significant, all habitats aside from sand/mud flat decrease in the LIA-Post LIA period.

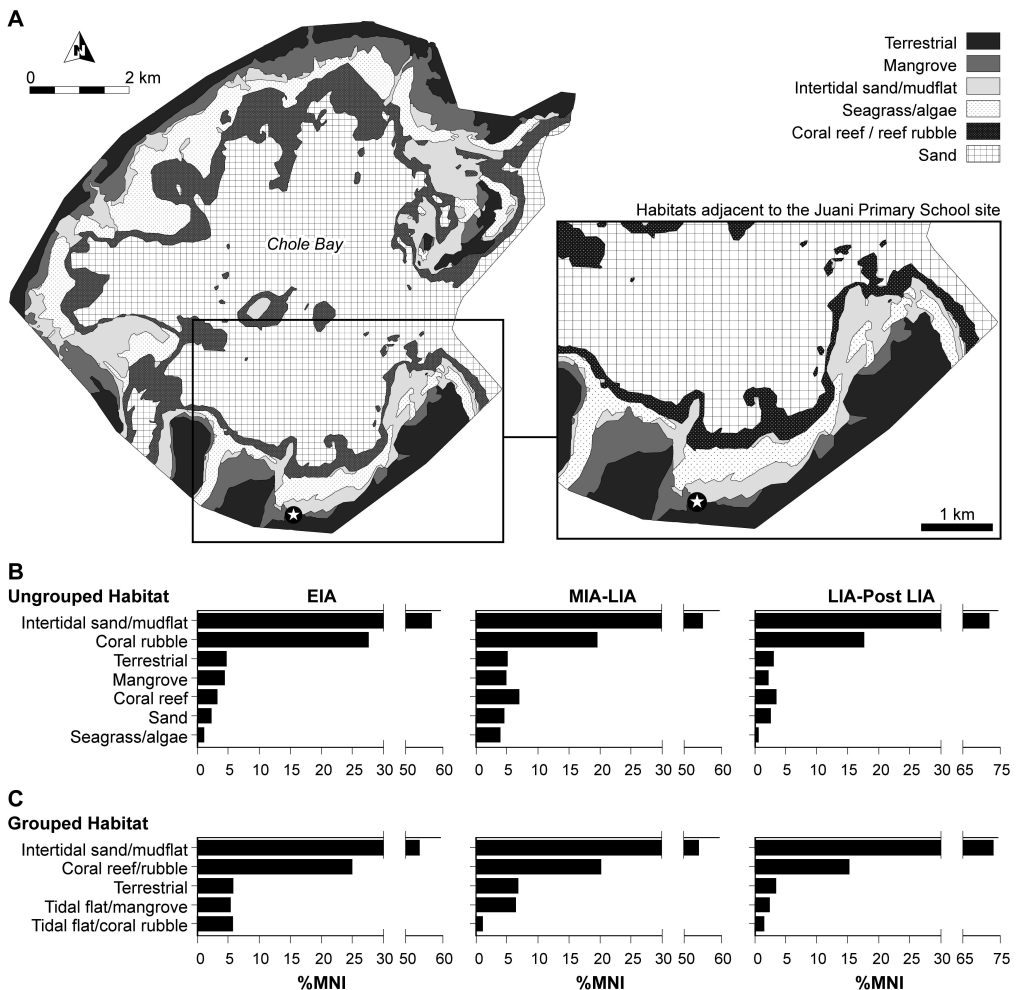


Figure 4. Habitat distribution in Chole Bay (A); Ungrouped (B) and grouped (C) habitat representation through time at Juani.

Shell Density, Assemblage Richness and Diversity

Each of the economic taxonomic categories have been combined to the highest common level for analyses of assemblage density, richness, and diversity. Nestedness analyses (Supplementary Tables 2–4) also indicate highly nested assemblages, with low temperature values for the EIA ($T = 13.98^\circ$), MIA-LIA ($T = 18.25^\circ$), and LIA-Post LIA ($T = 22.89^\circ$). Visual inspection of the species area curves (Figure 5A) indicates that each of the phase assemblages have been sampled to redundancy. Thus, following Wolverton et al. (2015:503), the invertebrate assemblages for each chronological phase are seen to be representative.

Economic shell density is calculated by aggregating the MNI data from each

context by chronological phase, deriving density estimates (MNI/m^3) based on the total excavated volume per phase. These data (Figure 5B) show a clear decline through time, from 422.6 MNI/m^3 in the EIA to be almost halved in the MIA-LIA (221.6 MNI/m^3), with a slight decrease into the LIA-Post LIA (168.9 MNI/m^3). This reduction in shell density through the sequence is mirrored by assemblage richness (Figure 5B), albeit with a less substantial decrease from the EIA (42 NTAXA) to the MIA-LIA (37 NTAXA), but a considerable decline into the LIA-Post LIA (21 NTAXA). This again reinforces the trends in taxonomic representation throughout sequence, with a clear reduction in the range of taxa represented through time. In terms of assemblage diversity (Figure 5B), the Shannon

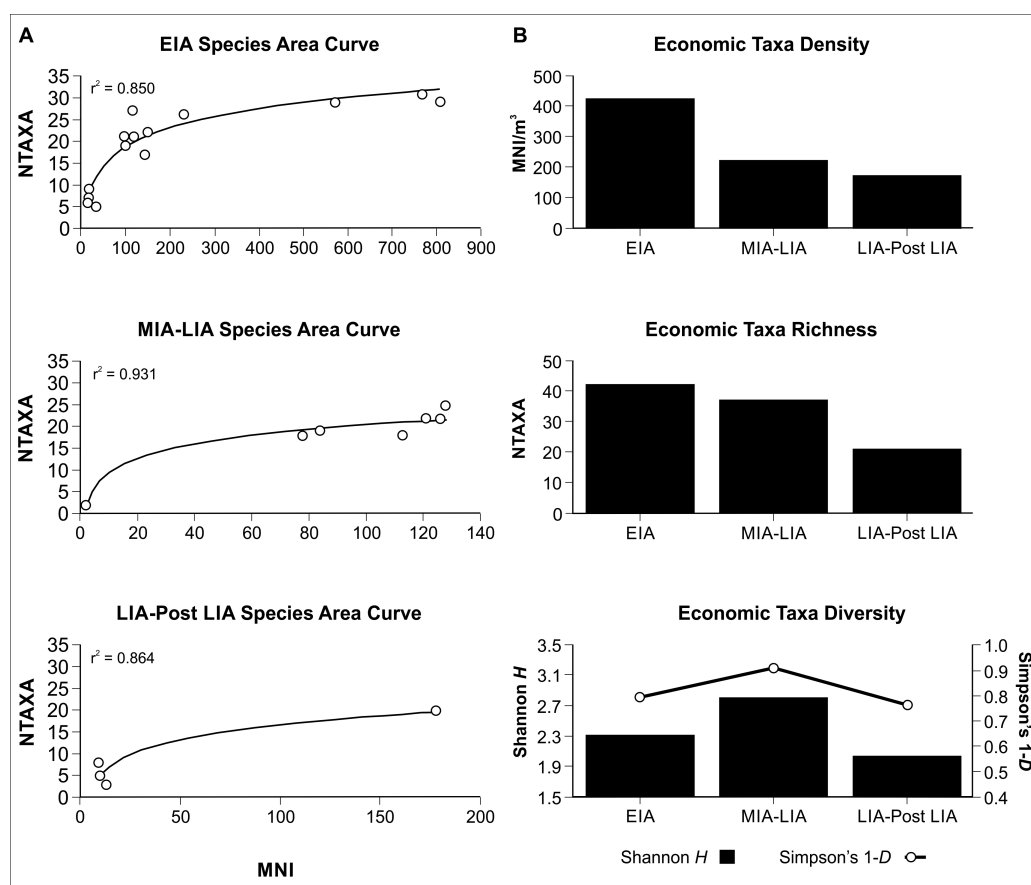


Figure 5. Juani chronological phase species area curves (A) and economic taxa density, richness, and diversity (B).

(*H*) and Simpson's (1-*D*) indices show very similar trends through time but deviate from those seen in density and richness. Both measures increase from the EIA (*H* = 2.30; 1-*D* = 0.79) into the MIA-LIA (*H* = 2.79; 1-*D* = 0.91), followed by a reduction in both diversity measures into the LIA-Post LIA (*H* = 2.02; 1-*D* = 0.76). Paired diversity permutation tests report significant differences between the EIA and MIA-LIA (*H*, *p* = 0.001; 1-*D*, *p* = 0.001), and between the MIA-LIA and LIA-Post LIA (*H*, *p* = 0.001; 1-*D*, *p* = 0.001), but not between the EIA and the LIA-Post LIA (*H*, *p* = 0.03; 1-*D*, *p* = 0.2093). Diversity/evenness is therefore similar between the earliest and most recent chronological phases represented at Juani, even though there is a substantial decrease in both density and assemblage richness. Again, these trends likely reflect a combination of habitat structure, resource availability, and the type of intertidal foraging strategies implemented through time.

Discussion

Diachronic Variability in Mollusk Harvesting

The Juani Primary School archaeomalacological assemblages demonstrate significant changes through time, emphasizing variability in the exploitation of invertebrate resources in this part of the Mafia Archipelago. From initial EIA occupation through to the recent LIA-Post LIA period, there is a clear reduction in shell density, concomitant with a trend of decreasing taxonomic richness. Both measures of heterogeneity indicate that the molluscan assemblage becomes more diverse/even in the MIA-LIA compared with the EIA, with a subsequent decline into the LIA-Post LIA. In the context of shifting taxonomic representation between these phases, we see a slight reduction in the breadth of invertebrate resources exploited in the MIA-LIA but, more importantly, where the foraging strategy is less focused on a small number of taxa, becoming more evenly distrib-

uted across the range of species exploited (evidenced by increasing diversity and evenness). The continued reduction in richness in the LIA-Post LIA, combined with decreasing assemblage diversity, suggests a further switch in the marine mollusk foraging strategy, likely influenced by natural species availability within the dominant marine environments. These changes see corresponding shifts in the habitats being exploited, with an increasing emphasis on intertidal sand/mudflats and a decrease in the coral rubble/reef zones, with reductions in the abundance of taxa from all other habitat areas between the MIA-LIA and LIA-Post LIA. Taxonomic richness naturally increases with substratum rugosity (e.g., Beck 2000; Kovalenko et al. 2012); an associated decrease in species richness would be expected with less foraging in coral/rock habitats. This does not fully explain the combination of trends in density, richness, diversity, and taxonomic composition through time. A further explanation for these trends relates to changes in foraging behavior linked to the exploitation of near vs. distant habitats through time, associated with field processing and transportation of resources (e.g., Bettinger et al. 1997; Bird et al. 2002; Giovas 2016), with these possibilities also raised in recent analyses of molluscan assemblages from Zanzibar (Faulkner et al. 2018a, 2018b). Although further regional archaeological data are required to evaluate this suggestion, these data reinforce the interpretation of the molluscan assemblage differences between the EIA and MIA-LIA presented in our earlier study (Crowther et al. 2016), while also demonstrating that variability in the observable trends in density, richness, and diversity continued into the LIA-Post LIA.

Although comparatively poorly preserved (and not available for the LIA-Post LIA), the vertebrate faunal and archaeobotanical evidence for the EIA and MIA-LIA at Juani provides further context for understanding changes in the inverte-

brate assemblages. The abundance of fish remains also decreases from the EIA (249 NISP) to the MIA-LIA (43 NISP), possibly indicating less intensive fish exploitation through time. There is, however, similarity in the range of fish taxa exploited, particularly those from coral and nearshore bay habitat zones, as well as the presence of Chondrichthyes (shark, ray) in both the EIA (35 NISP) and the MIA-LIA (5 NISP) (Crowther et al. 2016). Domesticated animals are virtually absent from the EIA and MIA-LIA at Juani, other than a possible caprine tooth and caprine-sized mammal bone in the EIA. The tetrapod assemblage is dominated by wild taxa (primarily bovids, suni [*Neotragus moschatus*], and duiker), with green sea turtle (*Chelonia mydas*) recovered from the EIA contexts (Crowther et al. 2016). Importantly, the archaeobotanical evidence indicates a lack of domesticated crops in the EIA, with the introduction of crops of African origin (cowpea [*Vigna unguiculata*], sorghum [*Sorghum bicolor*], baobab [*Adansonia digitata*]) during the MIA. Preliminary anthracological data also highlights the presence of mangrove taxa (Rhizophoraceae) in both the EIA and MIA-LIA, likely used for building materials and/or fuel (Crowther et al. 2016).

Drawing on the key conclusions presented by Crowther et al. (2016), and highlighted above relative to the broader Juani economic evidence, mollusks appear to be a significant staple component of an EIA economy focused on foraging and hunting. While a range of habitat areas were exploited, mollusks were primarily gathered from two main environmental zones (sand/mudflats and coral reef/rubble), likely reflecting the higher productivity of these areas to the north of Juani Island and within Chole Bay. The relative importance of mollusk resources, in line with the fish and tetrapod assemblages, appears to decline in the MIA-LIA with domestic crop introduction and increasing agricultural activity. During this period, mollusks form one component of an economy charac-

terized by expanding dietary breadth and diversity within the context of increasing food production and integration into broader Indian Ocean trade networks (Crowther et al. 2016; Fleisher et al. 2015). While mollusk foraging was focused on the nearshore, intertidal sand/mudflats, and coral habitats, the increasing abundance of taxa from all other marine habitat zones suggests a more generalized, indiscriminate foraging strategy in operation (evidenced by decreasing shell density and higher diversity index values for the MIA-LIA). Although vertebrate faunal and archaeobotanical data are not available for the LIA-Post LIA phase, a significant shift in emphasis to foraging within sand/mudflats and decreasing exploitation of mollusks from all other habitat zones suggests a further transitional period at Juani whereby the economic importance of mollusks further decreased. This interpretation needs to be viewed tentatively, as spatial reconfiguration of economic activity (e.g., field processing, differential transportation) would also have a bearing on these patterns, as would shifts in subsistence versus trade/ornamental use of shell. It appears, however, that, in this last phase, the relative contribution and the broad economic role of mollusks begin to approximate that seen in some of the modern socio-economic observations (e.g., Brigden and Steer 2009; Christie 2011)—albeit with considerably higher taxonomic richness at Juani, forming what appears to be a more minor and supplementary economic component.

Importantly, Andersson and Ngazi (1998:687, 692) have made the point that one way to cope with higher levels of economic uncertainty and loss of environmental predictability in coastal environments is to diversify production between increasingly separate ecosystems. Although based on contemporary observations, this is consistent with the interpretations presented by Crowther et al. (2016) for EIA populations dropping domesticates from their economy in favor of hunting

and foraging to facilitate initial colonization/occupation, followed by the MIA-LIA adoption of a mixed agricultural-foraging lifestyle. Positioning these interpretations within the regional archaeomalacological evidence is difficult given the lack of comparative detail in previously reported assemblages. Differences in the biological and physical structure of each island in the Archipelago and the resulting diversity in socio-economic activity, however, suggests that the same trends occurring through time and space are unlikely. In fact, variability in economic structure across eastern Africa is becoming apparent with increasingly detailed zooarchaeological analyses (e.g., Douglass et al. 2018; Faulkner et al. 2018a, 2018b; Prendergast et al. 2016, 2017). At Juani, we see important differences through time in mollusk foraging and economic behavior, a process that has implications not just for our understanding of past human behavior, but also for modern conservation and resource management in the MIMP.

Implications for Contemporary Resource Management

One potential implication of the Juani Primary School archaeomalacological data for marine resource management in the MIMP relates to the “shifting baseline syndrome,” referring to changes through time in how ecosystem benchmarks are measured (via empirical biological data) and/or perceived (at a generational level or by individuals) relative to previously established reference points (Papworth et al. 2009:95). The key issue with a shifting baseline is that the established reference condition represents only specific recent historical points in time, which themselves have arisen from earlier significant changes to the ecosystem (e.g., Klein and Thurstan 2016; Papworth et al. 2009; Pauly 1995). As recognized by numerous researchers, archaeological data can therefore contribute to the recognition and resolution of shifting baselines by providing long-term historical evidence (e.g., Dietl et al. 2015;

McKechnie et al. 2014; Rick and Lockwood 2013). Our archaeomalacological data are suggestive (rather than being definitive) of shifting baselines on the northern coast of Juani Island, with important changes in shell density, taxonomic composition, richness, and diversity across the three defined occupation phases at Juani through time. Significantly, there appears to be a considerable difference when comparing this evidence with modern data on mollusk harvesting, a trend related to observations of modern economic transitions in the region (Andersson and Ngazi 1998:686). As noted above, species richness decreases from the EIA to the MIA-LIA (NTAXA = 42–37), and again into the LIA-Post LIA (NTAXA = 21), which contrasts with lower richness recorded in the modern socio-economic surveys on Mafia Island by Brigden and Steer (2009) (NTAXA = 12) and Christie (2011) (NTAXA = 9). Many of the modern taxa appear within the Juani archaeological record (Figure 3), although they occur at a low proportion of the total assemblage (0.3–5.2% MNI) and decrease into the LIA-Post LIA (except for *M. annulus*). Four taxa appear in the modern species list that do not occur archaeologically (*A. perspectiva*, *C. cornuta*, *C. rufa*, and *P. glaucum*), the latter three species linked to modern shell curio trade. This is suggestive of a further shift in mollusk foraging from the LIA-Post LIA to now, with a focus on a very restricted number of predominantly large taxa for subsistence to supplement fishing and agriculture, and increasing (potentially opportunistic) harvest of non-dietary species within the modern economy.

This is particularly relevant to the Mafia Island Marine Park, where a key research area highlighted in the General Management Plan relates to understanding “traditional and recent” resource use practices (MPRU 2011:28). Acquiring a longer-term perspective for the assessment of the sustainability of marine resource use within the MIMP is important given that a range of resources, including mollusks, have been

seen to be declining due to destructive resource use and overexploitation (MPRU 2011:31–32). The Juani evidence provides an understanding of historical variability in resource use, documenting potential shifting baselines, and contributes to understanding past and present biodiversity (Dietl et al. 2015:89–91; Peacock et al. 2012). Of relevance to these last two points, and what we cannot do at this stage with the available data, is disentangle human impacts from natural processes and provide resolution on anthropogenic and/or natural drivers behind the long-term economic changes in this area. Most marine ecosystem changes are caused by multiple drivers that interact in historically contingent, complex, and potentially cumulative ways. As such, our ability to distinguish natural variability through time from human influence or impacts becomes critical (e.g., Braje et al. 2017; Giovas et al. 2010; Schwerdtner Máñez et al. 2014:2–3).

From the data available, it is unlikely that the diachronic variability identified in the Juani archaeomalacological dataset relates to direct human impacts on mollusk populations via predation pressure. This is particularly the case for the EIA and the MIA-LIA, where generalized foraging strategies incorporated a range of taxa from different habitat zones, suggesting a minimization of impacts by avoiding an intensive focus on a single taxon, functional group, or ecological niche (e.g., Braje and Erlandson 2013; Giovas 2016; Harris and Weisler 2017). Given that mollusk harvesting appears to decrease in intensity through time, and particularly within the LIA-Post LIA, resource depression alone is unlikely to be driving the taxonomic and habitat shifts into this period. As noted above, given the significant socio-economic transitions that occurred from the MIA through to the Post LIA, it is more likely that multiple drivers, both direct and indirect, were influencing the foraging economy structure through time. A key point made by Crowe et al. (2000:284), relative to modern

commercial harvesting but of relevance for the LIA-Post LIA, is that while the number of mollusks removed may be comparatively low, the cumulative effects can be considerable when harvesting is systematic and repeatedly focused on a small number of species (Hockey and Bosman 1986). Apart from direct effects of human exploitation on target species, foraging also likely has indirect effects on other non-exploited taxa and, therefore, the entire population within certain habitat zones (Crowe et al. 2000:284). In fact, the cumulative effects of a range of behaviors during the Iron Age in this region may have been significant, a fact that is well illustrated via modern observations of marine resource use in the Mafia Archipelago.

Modern exploitation pressure on a range of marine resources in the MIMP have been seen to have resulted in reduced environmental productivity and biodiversity (MPRU 2011:5). This is a complex process, combining increasingly specialized, intensive, direct, and often destructive exploitation of marine species to meet market-driven demand (Andersson and Ngazi 1998:692). For example, during the 1980s and 1990s, dynamite fishing and beach-seine nets caused significant subtidal damage to benthic habitats (MPRU 2011:13). Live coral mining for local use and commercial sale, although now reduced, causes loss of reef habitat, a reduction in fish abundance and diversity, and, through the reduction of the reef hydrodynamic barrier, increases beach, seagrass bed, and mangrove forest erosion (Dulvy et al. 1995:361–363). High levels of mangrove exploitation (for boat building, house construction, and firewood in lime production from mined coral) also causes erosion to near-shore marine environments, disrupting habitat productivity and the reproductive cycle of invertebrate taxa (MPRU 2011:23; TCMP 2001:18, 20). Finally, the collection of octopus, mollusks, and seaweed in intertidal and shallow subtidal reef flats can cause habitat damage

via trampling (Crowe et al. 2000:285–286; MPRU 2011:22). Taken together as a set of interactive and cumulative processes, the potential degree of ecosystem disruption and reduction in biodiversity becomes apparent. Several of the processes noted above would also have been in operation during Iron Age occupation at Juani, particularly mangrove and coral exploitation for construction materials, but the long-term implications of these factors, in combination with near-shore foraging behavior and broader socio-economic shifts, are unknown.

Conclusion

Following Contreras (2016), what we can say, based on the Juani Primary School archaeological data, is that human-environment relationships (and particularly human foraging in near-shore marine environments) were complex and dynamic, and likely linked to a range of mutually influential drivers (both environmental and behavioral). Building on the archaeological data presented here, there are initial implications for identifying potential shifting baselines. These data add to our understanding of the significance of the full spectrum of marine resources through time and space in the Mafia Archipelago, but determining the combination of drivers of change in the past needed to facilitate the reconstruction of past ecosystems is required. While we have provided a baseline understanding of the long-term socio-economic patterns in marine invertebrate use, the connection of these data to modern resource management raises more questions than answers. Given that our data have been generated from a single archaeological sequence, we need to further explore how representative these data are of broader archaeological trends across the Archipelago, and how representative they may be of potential ecosystem shifts through time. To enhance our understanding of these long-term records for

contemporary management in the MIMP, we clearly need higher-resolution archaeological, modern socio-economic, and ecological data for marine invertebrate resource use, density, and distribution from across the region, coupled with the integration of environmental and climatic data from modern studies and the archaeological record. These are important considerations; as noted by Schwerdtner Máñez et al. (2014:4), bioregional histories need to be developed for specific marine environments to allow comprehensive historical baselines to be developed.

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References Cited

- Abbott, R. T., and S. P. Dance. 1998. *Compendium of Seashells*. Odyssey Publishers, El Cajon, California.
- Andersson, J. E., and Z. Ngazi. 1995. Marine Resource Use and the Establishment of a Marine Park: Mafia Island, Tanzania. *AMBIO* 24:475–481.
- Andersson, J. E., and Z. Ngazi. 1998. Coastal Communities' Production Choices, Risk Diversification, and Subsistence Behavior: Responses in Periods of Transition: A Case Study from Tanzania. *AMBIO* 27:686–693.

- Balée, W. 2006. The Research Program of Historical Ecology. *Annual Review of Anthropology* 35:75–98.
- Balée W., and C. L. Erikson, eds. 2006. *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*. Columbia University Press, New York.
- Barnes, D. K. A., N. K. Dulvy, S. H. Priestley, W. R. T. Darwall, V. Choisel, and M. Whittington. 2002. Fishery Characteristics and Abundance Estimates of the Mangrove Crab *Scylla serrata* in Southern Tanzania and Northern Mozambique. *South African Journal of Marine Science* 24:19–25.
- Beck, M. W. 2000. Separating the Elements of Habitat Structure: Independent Effects of Habitat Complexity and Structural Components on Rocky Intertidal Gastropods. *Journal of Experimental Marine Biology and Ecology* 249:29–49.
- Bettinger, R. L., R. Malhi, and H. McCarthy. 1997. Central Place Models of Acorn and Mussel Processing. *Journal of Archaeological Science* 24:887–899.
- Bird, D. W., J. L. Richardson, P. M. Veth, and A. J. Barham. 2002. Explaining Shellfish Variability in Middens on the Meriam Islands, Torres Strait, Australia. *Journal of Archaeological Science* 29:457–469.
- Boivin, N., M. A. Zeder, D. Q. Fuller, A. Crowther, G. Larson, J. M. Erlandson, T. Denham, and M. D. Petraglia. 2016. Ecological Consequences of Human Niche Construction: Examining Long-Term Anthropogenic Shaping of Global Species Distributions. *Proceedings of the National Academy of Sciences* 113:6388–6396.
- Braje, T. J., and J. M. Erlandson. 2013. Human Acceleration of Animal and Plant Extinctions: A Late Pleistocene, Holocene, and Anthropocene Continuum. *Anthropocene* 4:14–23.
- Braje, T. J., T. P. Leppard, S. M. Fitzpatrick, and J. M. Erlandson. 2017. Archaeology, Historical Ecology and Anthropogenic Island Ecosystems. *Environmental Conservation* 44:286–297.
- Braje, T. J., and T. C. Rick. 2013. From Forest Fires to Fisheries Management: Anthropology, Conservation Biology, and Historical Ecology. *Evolutionary Anthropology* 4:116–121.
- Brigden, K., and M. D. Steer, eds. 2009. *A Survey of Biodiversity and Anthropogenic Pressures Existing on a Large Intertidal Habitat at Ras Kichevi, Mafia Island, Tanzania*. Frontier Tanzania Marine Research Programme Report 124. The Society for Environmental Exploration, London, United Kingdom.
- Chami, F. A. 2000. Further Archaeological Research on Mafia Island. *Azania: Archaeological Research in Africa* 35:208–214.
- Chami, F. A. 2004. The Archaeology of the Mafia Archipelago, Tanzania. In *African Archaeology Network: Reports and Views*, edited by F. A. Chami, G. Pwiti, and C. Radimilahy, pp. 73–101. Dar es Salaam University Press, Dar es Salaam, Tanzania.
- Christie, A. C. 2011. Exploring the Social Context of Maritime Exploitation in the Mafia Archipelago, Tanzania: An Archaeological Perspective. Unpublished Doctoral Dissertation, Department of Archaeology, University of York, York, England.
- Christie, A. C. 2013. Exploring the Social Context of Maritime Exploitation in Tanzania between the 14th–18th c. AD: Recent Research from the Mafia Archipelago. In *Prehistoric Marine Resource Use in the Indo-Pacific Regions*, edited by R. Ono, A. Morrison, and D. Addison, pp. 97–122. Terra Australis 39. ANU Press, Canberra, Australia.
- Contreras, D. 2016. Correlation Is Not Enough: Building Better Arguments in the Archaeology of Human-Environment Interactions. In *The Archaeology of Human-Environment Interactions: Strategies for Investigating Anthropogenic Landscapes*, edited by D. Contreras, pp. 17–35. Routledge, New York.
- Coughanowr, C. A., M. N. Ngoile, and O. Linden. 1995. Coastal Zone Management in Eastern Africa Including the Island States: A Review of Issues and Initiatives. *AMBIO* 24:448–457.
- Crain, C. M., B. S. Halpern, M. W. Beck, and C. V. Kappel. 2009. Understanding and

- Managing Human Threats to the Coastal Marine Environment. *Annals of the New York Academy of Sciences* 1162:39–62.
- Crowe, T. P., R. C. Thompson, S. Bray, and S. J. Hawkins. 2000. Impacts of Anthropogenic Stress on Rocky Intertidal Communities. *Journal of Aquatic Ecosystem Stress and Recovery* 7:273–297.
- Crowther, A., P. Faulkner, M. E. Prendergast, E. M. Quintana Morales, M. Horton, E. Wilmsen, A. M. Kotarba-Morley, A. Christie, N. Petek, R. Tibesasa, and K. Douka. 2016. Coastal Subsistence, Maritime Trade, and the Colonization of Small Offshore Islands in Eastern African Prehistory. *The Journal of Island and Coastal Archaeology* 11:211–237.
- Crumley, C. L., ed. 1994. *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of American Research Press, Santa Fe, New Mexico.
- Dietl, G. P., S. M. Kidwell, M. Brenner, D. A. Burney, K. W. Flessa, S. T. Jackson, and P. L. Koch. 2015. Conservation Paleobiology: Leveraging Knowledge of the Past to Inform Conservation and Restoration. *Annual Review of Earth and Planetary Sciences* 43:79–103.
- Douglass, K. 2017. The Diversity of Late Holocene Shellfish Exploitation in Velondriake, Southwest Madagascar. *The Journal of Island and Coastal Archaeology* 12:333–359.
- Douglass, K., A. R. Antonites, E. M. Quintana Morales, A. Greal, M. Bunce, C. Bruwer, and C. Gough. 2018. Multi-Analytical Approach to Zooarchaeological Assemblages Elucidates Late Holocene Coastal Lifeways in Southwest Madagascar. *Quaternary International* 471:111–131.
- Douglass, K., J. Walz, E. Quintana Morales, R. Marcus, G. Myers, and J. Pollini. 2019. Historical Perspectives on Contemporary Human-Environment Dynamics in South-east Africa. *Conservation Biology* 33:260–274. DOI:10.1111/cobi.13244.
- Dulvy, N. K., D. Stanwell-Smith, W. R. T. Darwall, and C. J. Horrill. 1995. Coral Mining at Mafia Island, Tanzania: A Management Dilemma. *AMBIO* 24:358–365.
- Fabricius, K. 2005. Effects of Terrestrial Runoff on the Ecology of Corals and Coral Reefs: Review and Synthesis. *Marine Pollution Bulletin* 50:125–146.
- Faulkner, P., M. Harris, A. K. Ali, O. Haji, A. Crowther, M. C. Horton, and N. L. Boivin. 2018a. Characterising Marine Mollusc Exploitation in the Eastern African Iron Age: Archaeomalacological Evidence from Unguja Ukuu and Fukuchani, Zanzibar. *Quaternary International* 471:66–80.
- Faulkner, P., M. Harris, O. Haji, A. K. Ali, A. Crowther, C. Shipton, M. C. Horton, and N. L. Boivin. 2018b. Long-term Trends in Terrestrial and Marine Invertebrate Exploitation on the Eastern African Coast: Insights from Kuumbi Cave, Zanzibar. *Journal of Island and Coastal Archaeology*. [online]. <https://doi.org/10.1080/15564894.2018.1501442>.
- Fitzpatrick, S. M., and W. F. Keegan. 2007. Human Impacts and Adaptations in the Caribbean Islands: An Historical Ecology Approach. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 98:29–45.
- Fleisher, J., P. Lane, A. LaViolette, M. Horton, E. Pollard, E. Quintana Morales, T. Vernet, A. Christie, and S. Wynne-Jones. 2015. When Did the Swahili become Maritime? *American Anthropologist* 117:100–115.
- Fosuah, E. N., and M. D. Steer, eds. 2009. *An Assessment of the Coral Reefs on Western Mafia Island, Tanzania*. Frontier Tanzania Marine Research Programme Report 125. The Society for Environmental Exploration, London, United Kingdom.
- Garpe, K. C., and M. C. Öhman. 2003. Coral and Fish Distribution Patterns in Mafia Island Marine Park, Tanzania: Fish-Habitat Interactions. *Hydrobiologia* 498:191–211.
- Giovas, C. M. 2009. The Shell Game: Analytic Problems in Archaeological Mollusc Quantification. *Journal of Archaeological Science* 36:1557–1564.
- Giovas, C. M. 2016. Though She Be but Little: Resource Resilience, Amerindian Foraging, and Long-Term Adaptive Strategies in the Grenadines, West Indies. *The Journal of Island and Coastal Archaeology* 11:238–263.

- Giovas, C. M., S. M. Fitzpatrick, M. Clark, and M. Abed. 2010. Evidence for Size Increase in an Exploited Mollusc: Humped Conch (*Strombus gibberulus*) at Chelechol ra Orrak, Palau from ca. 3000–0 BP. *Journal of Archaeological Science* 37:2788–2798.
- Guard, M., and Y. D. Mgaya. 2002. The Artisanal Fishery for *Octopus cyanea* Gray in Tanzania. *AMBIO* 31:528–536.
- Gutmann Roberts, C. 2014. *Frontier Tanzania Marine Research Programme: Utende, Mafia Island, Tanzania. 24th March – 16th June 2014*. TZM Phase 142 Science Report. London, United Kingdom.
- Hammer, Ø., and D. A. T. Harper. 2007. *Paleontological Data Analysis*. Blackwell Publishing, Malden, MA.
- Hammer, Ø., D. A. T. Harper, and P. D. Ryan. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica* 4:1–9.
- Harris, M., and M. Weisler. 2017. Intertidal Foraging on Atolls: Prehistoric Forager Decision-Making at Ebon Atoll, Marshall Islands. *The Journal of Island and Coastal Archaeology* 12:200–223.
- Harris, M., M. Weisler, and P. Faulkner. 2015. A Refined Protocol for Calculating MNI in Archaeological Molluscan Shell Assemblages: A Marshall Islands Case Study. *Journal of Archaeological Science* 57:168–179.
- Hemsworth, R. 2015. *Frontier Tanzania Marine Research Programme: Utende, Mafia Island, Tanzania. 15th December 2014 – 16th March 2015*. TZM Phase 151 Science Report. London, United Kingdom.
- Hockey, P. A. R., and A. L. Bosman. 1986. Man as an Intertidal Predator in Transkei: Disturbance, Community Convergence and Management of a Natural Food Resource. *Oikos* 46:3–14.
- Horrill, J. C., W. R. Darwall, and M. Ngoile. 1996. Development of a Marine Protected Area: Mafia Island, Tanzania. *AMBIO* 25:50–57.
- Jackson, J. B., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, and T. P. Hughes. 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 293:629–637.
- Jerardino, A. 2016. On the Origins and Significance of Pleistocene Coastal Resource use in Southern Africa with Particular Reference to Shellfish Gathering. *Journal of Anthropological Archaeology* 41:213–230.
- Jerardino, A., and C. W. Marean. 2010. Shellfish Gathering, Marine Paleoecology and Modern Human Behavior: Perspectives from Cave PP13B, Pinnacle Point, South Africa. *Journal of Human Evolution* 59:412–424.
- Jiddawi, N. S., and M. C. Öhman. 2002. Marine Fisheries in Tanzania. *AMBIO* 31:518–527.
- Jones, L., and E. Fanning, eds. 2010. *Assessing the Health of Mafia Island's Marine Ecosystems*. Frontier Tanzania Marine Research Programme Report 129. The Society for Environmental Exploration, London, United Kingdom.
- Kamukuru, A. T., T. Hecht, and Y. D. Mgaya. 2005. Effects of Exploitation on Age, Growth and Mortality of the Blackspot Snapper, *Lutjanus fulvivlamma*, at Mafia Island, Tanzania. *Fisheries Management and Ecology* 12:45–55.
- Klein, E. S., and R. H. Thurstan. 2016. Acknowledging Long-Term Ecological Change: The Problem of Shifting Baselines. In *Perspectives on Oceans Past*, edited by K. Schwerdtner Máñez and B. Poulsen, pp. 11–29. Springer, Dordrecht, The Netherlands.
- Kovalenko, K. E., S. M. Thomaz, and D. M. Warfe. 2012. Habitat Complexity: Approaches and Future Directions. *Hydrobiologia* 685:1–17.
- Kyriacou, K., J. E. Parkington, M. Will, A. W. Kandel, and N. J. Conard. 2015. Middle and Later Stone Age Shellfish Exploitation Strategies and Coastal Foraging at Hoedjiespunt and Lynch Point, Saldanha Bay, South Africa. *Journal of Archaeological Science* 57:197–206.
- Lewis, E., B. Margerison, B. Sobkowiak, and E. Fanning, eds. 2011. *A Biophysical Survey of Three New Marine Reserves in Mafia Island, Tanzania*. Frontier Tanzania Marine Research Programme Report 128. The Society for Environmental Exploration, London, United Kingdom.

- Lyman, R. L. 2008. *Quantitative Paleozoology*. Cambridge University Press, Cambridge, England.
- McKechnie, I., D. Lepofsky, M. L. Moss, V. L. Butler, T. J. Orchard, G. Coupland, F. Foster, M. Caldwell, and K. Lertzman. 2014. Archaeological Data Provide Alternative Hypotheses on Pacific Herring (*Clupea pallasii*) Distribution, Abundance, and Variability. *Proceedings of the National Academy of Sciences* 111:E807–E816.
- Moshy, V. H., and I. Bryceson. 2016. Seeing Through Fishers' Lenses: Exploring Marine Ecological Changes within Mafia Island Marine Park, Tanzania. *SAGE Open* 6:1–18.
- MPRU (Marine Parks and Reserves Unit). 2011. Mafia Island Marine Park General Management Plan. United Republic of Tanzania, Ministry of Livestock and Fisheries Development. Available at: marineparks.go.tz/reports/MIMP%20GMP.pdf. Accessed on May 7, 2019.
- Msemwa, P. J. 1994. *An Ethnoarchaeological Study on Shellfish Collecting in a Complex Urban Setting*. Unpublished Doctoral Dissertation, Department of Anthropology, Brown University, Providence, RI.
- Muhando, C. A., and C. K. Rumisha. 2008. *Distribution and Status of Coastal Habitats and Resources in Tanzania*. WWF-Tanzania, Dar es Salaam, Tanzania.
- Mwaipopo, R. N. 2008. *The Social Dimensions of Marine Protected Areas: A Case Study of the Mafia Island Marine Park in Tanzania*. Samudra Monograph. International Collective in Support of Fishworkers. Chennai, India.
- Newton, L. C., E. V. H. Parkes, and R. C. Thompson. 1993. The Effects of Shell Collecting on the Abundance of Gastropods on Tanzanian Shores. *Biological Conservation* 63:241–245.
- Nordlund, L., J. Erlandsson, M. de la Torre-Castro, and N. Jiddawi. 2010. Changes in an East African Social-Ecological Seagrass System: Invertebrate Harvesting Affecting Species Composition and Local Livelihood. *Aquatic Living Resources* 23:399–416.
- Papworth, S. K., J. Rist, L. Coad, and E. J. Milner-Gulland. 2009. Evidence for Shifting Baseline Syndrome in Conservation. *Conservation Letters* 2:93–100.
- Pauly, D. 1995. Anecdotes and the Shifting Baseline Syndrome of Fisheries. *Trends in Ecology and Evolution* 10:430.
- Peacock E., C. R. Randklev, S. Wolverton, R. A. Palmer, and S. Zaleski. 2012. The "Cultural Filter," Human Transport of Mussel Shell, and the Applied Potential of Zooarchaeological Data. *Ecological Applications* 22:1446–1459.
- Prendergast, M. E., E. M. Quintana Morales, A. Crowther, M. C. Horton, and N. L. Boivin. 2017. Dietary Diversity on the Swahili Coast: The Fauna from Two Zanzibar Trading Locales. *International Journal of Osteoarchaeology* 27:621–637.
- Prendergast, M., H. Rouby, P. Punnwong, R. Marchant, A. Crowther, N. Kourampas, C. Shipton, M. Walsh, K. Lambeck, and N. L. Boivin. 2016. Continental Island Formation and the Archaeology of Defaunation on Zanzibar, Eastern Africa. *PLoS ONE* 11:e0149565.
- Richmond, M. D. 2001. The Marine Biodiversity of the Western Indian Ocean and its Biogeography: How Much do We Know? In *Marine Science Development in Tanzania and Eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania, 28 June – 1 July 1999*, edited by M. D. Richmond and J. Francis, pp. 241–261. IMS/WIOMSA, Zanzibar, Tanzania.
- Richmond, M. D. 2011. *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands*. SIDA, WIOMSA, Dar es Salaam, Tanzania.
- Rick, T. C., and R. Lockwood. 2013. Integrating Paleobiology, Archeology, and History to Inform Biological Conservation. *Conservation Biology* 27:45–54.
- Robin, A. 2008. *Encyclopedia of Marine Gastropods*. ConchBooks, Hackenheim, Germany.
- Robin, A. 2011. *Encyclopedia of Marine Bivalves, Including Scaphopods, Polyplacophora and Cephalopods*. ConchBooks, Hackenheim, Germany.

- Rowson, B., B. H. Warren, and C. F. Ngereza. 2010. Terrestrial Molluscs of Pemba Island, Zanzibar, Tanzania, and its Status as an "Oceanic" Island. *ZooKeys* 70:1–39.
- Schwerdtner Máñez, K., P. Holm, L. Blight, M. Coll, A. MacDiarmid, H. Ojaveer, B. Poulsen, and M. Tull. 2014. The Future of the Oceans Past: Towards a Global Marine Historical Research Initiative. *PLoS ONE* 9:p.e101466.
- Spry, J. F. 1964. *The Sea Shells of Dar es Salaam: Part II Pelecypoda (Bivalves)*. Reprinted from Tanganyika Notes and Records 63. Tanzania Society, Dar es Salaam.
- Spry, J. F. 1968. *The Sea Shells of Dar es Salaam. Part I. Gastropods*. Reprinted from Tanganyika Notes and Records 56. Tanzania Society, Dar es Salaam.
- Szabó, K. 2009. Molluscan Remains from Fiji. In *The Early Prehistory of Fiji*, edited by G. Clark and A. Anderson, pp. 183–211. Terra Australis 31. ANU EPress, Canberra, Australia.
- TCMP (Tanzania Coastal Management Partnership). 2001. *Tanzania State of the Coast 2001: People and the Environment*. Working Document 5059 TCMP, Dar es Salaam, Tanzania. [online] URL: https://www.crc.uri.edu/download/TZ_SOC_2001.pdf.
- TCMP (Tanzania Coastal Management Partnership). 2003. *Tanzania State of the Coast Report 2003: The National ICM Strategy and Prospects for Poverty Reduction*. Coastal Management Report # 2002 TCMP, Dar es Salaam, Tanzania. [online] URL: <https://www.oceandocs.org/handle/1834/796>.
- Ulrich, W., M. Almeida-Neto, and N. J. Gotelli. 2009. A Consumer's Guide to Nestedness Analysis. *Oikos* 118:3–17.
- Wolverton, S., L. Nagaoka, and T. C. Rick. 2016. *Applied Zooarchaeology: Five Case Studies*. Eliot Werner Publications, New York.
- Wolverton, S., C. Otaola, G. Neme, M. Giardina, and A. Gil. 2015. Patch Choice, Landscape Ecology, and Foraging Efficiency: The Zooarchaeology of Late Holocene Foragers in Western Argentina. *Journal of Ethnobiology* 35:499–518.
- WoRMS Editorial Board. 2016. World Register of Marine Species [website]. Available at: <http://www.marinespecies.org> at VLIZ.
- Wynne-Jones, S. 2006. Reconstructing the Long-Term History of the Mafia Archipelago. Unpublished report submitted to COSTECH and the Antiquities Department, Ministry of Natural Resources and Tourism, Tanzania.