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The Challenges and Future of Environmental Archaeology in Mauritius

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Abstract
This paper considers the value of past and prospective applications of key environmental archaeological and earth science fields relating to the historical ecology of Mauritius and the Mascarene islands more broadly: palaeoecology, geoarchaeology, zooarchaeology and climate studies. The contribution of each subfield is outlined with the aim of demonstrating the potential value of an integrated environmental archaeological approach for developing a long-term understanding of the human ecology of Mauritius and its associated islands. The paper considers the potential and limitations of existing approaches and data, as well as future challenges. Beyond solely reconstructing the nuances of anthropogenic impact on the environment in relation to the island's history of settlement, we argue that environmental archaeology can contribute to an understanding of "biocultural diversity" as an integral element of Mauritian heritage, bridging the divide between cultural and natural heritage.

Keywords Environmental Archaeology · Mauritius · Palaeoecology · Biocultural Heritage

Introduction

Environmental archaeology is concerned with understanding past human ecology and draws on a diverse range of "ecofacts" acquired from sites of human occupation, as well as from their associated landscapes. At both the site and off-site level,

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environmental archaeology draws on a range of specialisms encompassing diverse categories of ecofacts, from pollen, phytoliths and plant seeds, through to animal bone, invertebrate remains, raw materials used for fuel and construction, archaeological soils, and isotopic records of temperature and precipitation trapped in sediments (O'Connor and Evans 2005). Each category of ecofact provides a different type of information, which contributes to an understanding of the ecological history of any given human community. Environmental archaeology is readily aligned with Late Quaternary sciences that examine much broader timespans, and in the case of Mauritius for example, encompasses the island's environmental and geological history before human colonization (de Boer et al. 2013b, 2014).

While environmental archaeological data is largely derived from terrestrial sites, which are the foci of human occupation, there is also an important maritime component of island archaeology which includes submerged or partially submerged structures and settlements, geomorphological changes in the shoreline to understand relative sea level changes over time, and shipwrecks. The latter are archaeological sites with their own suite of ecofacts, but they are also complex present-day marine habitats. All these fragmented datasets must be drawn together and integrated, alongside written and artistic sources, and oral knowledge, for a holistic understanding of past human ecology. Each dataset has a variable chronological resolution, and so a multitemporal and multiscalar approach is required, situating well-documented short-term trends within long-term perspectives (Harris and Thomas 2016).

This paper outlines past and prospective applications of four key archaeological and earth science fields relating to the historical ecology of Mauritius and the Mascarene islands more broadly: palaeoecology, geoarchaeology, zooarchaeology and climate studies. In so doing, the paper aims to demonstrate the potential value of an integrated environmental archaeological approach for developing a long-term understanding of the human ecology of Mauritius and its associated islands. Key questions this paper poses are where and how can different techniques from environmental archaeology be usefully employed to further this aim? What are the limitations of existing approaches and data? What are the challenges in furthering our understanding? Beyond solely reconstructing the nuances of anthropogenic impact on the environment in relation to the island's history of settlement, it is argued that environmental archaeology can contribute to an understanding of "biocultural diversity" as an integral element of Mauritian heritage, bridging the divide between cultural and natural heritage.

Environmental Histories and Archaeologies of Small Islands

Environmental archaeology, when considered in the context of evolutionary studies, has been framed as niche construction or landscape domestication (i.e., the process of creating a habitat that may be driven by specific economic or ideological needs, mediated by the opportunities and constraints of the natural environment) (Clement 2014). Environmental archaeology is often framed as the study of palaeoeconomies, as the environment is largely understood as an economic asset for past societies.

However, trends in exploitation are mediated by ideology, cultural value systems and social relations, as much as pragmatism.

In the case of islands, one of the defining archaeological contributions has been the study of anthropogenic impact on their specialized environments (Erlandson and Fitzpatrick 2006; Fitzpatrick et al. 2015). This impact is determined by the interaction of highly specific variables, including physiogeography and ecology, human population density, technology, and social organization; essentially each case is unique and presents its own opportunities and challenges in the study of its environment (Braje et al. 2017). Multiproxy studies of the environmental impact of human colonization of small islands have demonstrated visible changes in their ecological histories, and while most studies conducted in the twentieth century focused on Mediterranean and Pacific islands with comparatively little work done on African islands (Mitchell 2004, 2022), this situation has begun to change in the last decade (e.g., Castilla-Beltrán et al. 2019; Culley et al. 2021; de Boer et al. 2013a; Morales et al. 2013).

Small islands, with constrained physical boundaries and finite natural resources, are particularly sensitive to human exploitation. Due to the genetic constraints of their plant and animal populations, providing limited capability for short-term adaptation, small islands have been identified as places where rapid extinction events are most likely to occur following anthropogenic pressure (e.g., Morales et al. 2009). Islands are often regarded as self-contained ecosystems, but those with long-term human occupation are not wholly isolated and must be understood within a broader ecological and cultural context, which includes the maritime environment (Rainbird 2007).

The Mascarene islands were created by two episodes of volcanic activity (the so-called "older" and "younger" series), and their native environments were shaped by the colonization of plant and animal species. Birds reached the Mascarenes through protracted island-hopping across the Indian Ocean littoral, associated in turn with flora dispersals (Agnarsson and Kuntner 2012; Kainulainen et al. 2017). Yet the most dramatic ecological changes took place over the last four centuries following human colonization (Seetah et al. 2022). Mauritius provides us with the archetypal case of extinction, with the disappearance of the dodo occurring within approximately 80 years following permanent human settlement, and a substantial range of native flora and fauna becoming extinct within a period of a few centuries (Cheke and Hume 2010; Cheke 2013). The accidental and deliberate introduction of invasive species through human agency dramatically transformed its ecosystems; the present-day ecology of Mauritius is a product of connection, rather than isolation. Trends in exploitation were driven by a range of cultural attitudes that were imported with enslaved (mainly African), indentured (mainly Indian) and colonial (Dutch, French, British) communities, and the creolized value systems that developed. Indeed, the western Indian Ocean can be viewed as a single zone of interaction; some have even argued the same global communication networks that facilitated colonization and exploitation have offset the negative historical impacts of deforestation, soil, and biodiversity loss (Norder et al. 2017). Although the colonial strategy of deforestation and plantation overshadows any discussion of the island's environmental history, it is the responses of these diverse communities that archaeologists can potentially access at multiscalar levels, from the landscape down to individual settlements and single households.

In recent decades, the environmental history of Mauritius has attracted serious attention from scholars resulting in synthetic overviews, as well as more focused research emphasizing different species and habitats (Cheke 1987; Cheke and Hume 2010; Hume 2006, 2007; Toth 1994). Studies of early human impact on the island's ecology converge on the extinction of the dodo, following initial colonization over the course of the seventeenth century (Rijsdijk et al. 2015). Subsequently, historians in particular have focused on the intensive colonial exploitation of the island for sugar, powered by the labor of enslaved and indentured people, as well as the harvesting of ebony (Carter 2006). These studies provide a detailed narrative of environmental transformation connected with colonial strategies of economic exploitation and demographic change; most important of which was the introduction of sugar cane. Population growth from 1638, along with the conversion of the island's dense tropical woodland into plantations, resulted in a well-documented process of deforestation, with the most intensive clearance taking place in the latter half of the nineteenth century. Most of the native forest cover was depleted by 1935, with estimates suggesting that around 95.6% of native vegetation has been lost since humans first arrived (Hammond et al, 2015). As a result, Mauritius has become an important case study in the global history of deforestation and environmental degradation, connected with European colonial expansion and industrialisation (Florens et al. 2012, 2016, 2017).

Already in the years leading up to independence from Britain in 1968, the need to conserve the fragile ecosystems of Mauritius and its outlying islands was recognized with the designation of nature reserves; however, serious conservation policies only began from the 1980s. Today, Mauritius is globally recognized as a biodiversity hotspot, with an interconnected array of coral reefs, lagoons, mangroves, and seagrass meadows. The island contains unique species of plants and animals which have endured over four centuries of human presence (Florens et al. 2012). The island is also recognized as having one of the most vulnerable island floras in the world, with 89% of endemic species considered threatened (Ministry of Environment and Sustainable Development 2010: 7). The state, through the Ministry of Environment and Sustainable Development and the National Parks and Conservation Service, as well as the Mauritian Wildlife Foundation which was established through the Durrell Foundation, has promoted the protection and restoration of endangered plant and animal species. This has included the removal of exotic species, as well as the protection and rewilding of select habitats. The island's maritime environments, which have become increasingly popular for tourism, are recognized as particularly vulnerable, prompting the need for developing sustainable ecotourism (Manfio and Seetah, this volume; Seetah in press-a). This vulnerability was recently highlighted by the MV Wakashio's oil spill in July 2020 on the reefs off the southeast coast, in close proximity to Ile aux Aigrettes, a coralline limestone island designated as a nature reserve (De Rosnay et al. 2021; Naggea and Miller 2023). In March 2021, another vessel, the fishing trawler FV Lu Rong Yuan Yu, ran aground on the island's western reefs off Pointe-aux-Sables, although its hull was not breached.

Environmental Archaeology of Colonial Island Landscapes

Rewilding projects, effectively aimed at “turning back the clock,” as well as preserving existing levels of biodiversity, are conservation priorities. Nuanced understanding of Mauritius’ environmental history, and how it has been shaped by human activity, is therefore integral to the island’s future conservation policies. Much of this has been informed by a variety of written, cartographic, and artistic sources, as well as fossils and specimens scattered across a number of museums (Hume and Jones 2005). On the other hand, contributions from environmental archaeology of the historical period have remained comparatively limited to date (Boer et al. 2013a). Below are outlined four critical areas of research that would have significant impact both in providing essential baseline evidence, and also, evidence on the changing ecological context aligned with human activity.

Palaeoecology

Recent human colonization of remote island environments has typically resulted in the drastic modification of their ecosystems. The story from Mauritius echoes that of other oceanic islands across the globe where the arrival of humans is followed by deforestation, the introduction of non-native plants and animals, agricultural expansion and economic exploitation, resulting in sustained environmental degradation and a significant loss in indigenous vegetation cover and biodiversity (Seetah et al. 2022).

Palaeoecological study as part of integrated multidisciplinary research has focused on the timing, rate, nature and scale of anthropogenic impact on the physical landscapes and endemic flora and fauna of oceanic island environments, including but not limited to the following interlinked themes:

- Biodiversity and habitat loss
- The impact of invasive species
- Soil degradation
- Climate change
- Past fire regimes and changes in role and frequency
- Establishing environmental baselines as a guide to habitat conservation and restoration strategies.

Historical sources provide a generalized account of the flora of Mauritius and the impact of human colonization on the landscapes, particularly the forests which originally covered the island (Baker 1877; Bojer 1837). Broad vegetation zones across the island, defined by rainfall and altitude, comprised rainforests in upland areas, semidry forests at lower altitudes and palm rich woodland on the sheltered “leeward” side of the island. Those areas of highest altitude supported patches of heath and shrubby grassland, while rocky shores, sand dunes, estuaries, marsh, and mangrove swamps characterized the coast (Cheke and Hume 2010; Vaughan and Wiehe 1937).

Human impact was initially small-scale prior to the first colonization by Dutch settlers in 1638. The island was apparently initially used as a refreshing post by Arab, and later during the 1500s, by Portuguese traders. Dutch settlers introduced new crops and animals and began to clear the forests, focusing initially on the exploitation of ebony. The pace and scale of deforestation accelerated during the eighteenth century under French rule driven primarily by the introduction of plantations and the cultivation of sugar cane. However, even during this time there was some recognition of the vulnerability of tropical island ecosystems and economies resulting from colonization, habitat loss, and the over-exploitation of resources (Grove 1996). On Mauritius, these concerns led to some early measures by the French administration to conserve forests and regulate land use, even as they initiated practices that escalated deforestation and coral loss (Carey 2018). This was influenced by an emerging environmental awareness, albeit primarily employed toward ensuring the longer-term economic sustainability of the island. Sugar production became the backbone of the economy under the British who took control of the island from the French in 1810, further driving drastic reductions in forest cover over the course of the nineteenth century. Consequently, although forests cover approximately 18% of the present-day landmass of Mauritius, less than 2% of these are classified as good quality native woodland and none is classified as primary (Baider et al. 2010).

Modeling of forest loss on Mauritius has relied in large part on historical data which is limited by its low spatial and temporal resolution; furthermore, many endemic species will have been lost before being scientifically documented. However, palaeoecology, involving the analysis of pollen, spores, and other microfossils from peat and lake sediments has been increasingly applied on oceanic islands to reconstruct transformations in vegetation and land use and inform on issues of conservation ecology in relation to past biodiversity and human impact (e.g., Connor et al. 2012; de Nascimento et al. 2009, 2015; Froyd et al. 2014; Nogue et al. 2013; Nogue 2017). In island contexts such as Mauritius, where only small, degraded remnants of the natural flora remain (Florens et al. 2012), palaeoecology is a vital tool for establishing precontact environmental baselines and investigating the rate and scale of habitat loss and landscape change resulting from human colonization. These data in turn provide an important ecological lens for understanding the process of colonization.

The last decade has seen a small but important series of palaeoecological studies undertaken on cores recovered from both upland and lowland settings across Mauritius variously covering the last 38,000 years (de Boer et al. 2013a, 2013b, 2014, 2015; Van der Plas et al. 2012) (Fig. 1). These studies provide a valuable long-term perspective on vegetation responses to past climate change and the environmental impact of colonization, though evidence for the latter is largely restricted to sequences from upland settings. At the Kanaka Crater, the top of a 10-m-long sediment sequence included pollen of introduced species such as *Osbeckia octandra*, native to East Asia, and an increase in Poaceae, considered likely to reflect cultivation of sugar cane (Van de Plas et al. 2012). Evidence for anthropogenic activity was also recorded from the top 0.15 of a 1.15 m sequence from Le Pétrin, an area of upland heathland a few kilometers to the west of the Kanaka Crater. Non-native plant species were present, including sugar cane, pine, and tea, occurring alongside

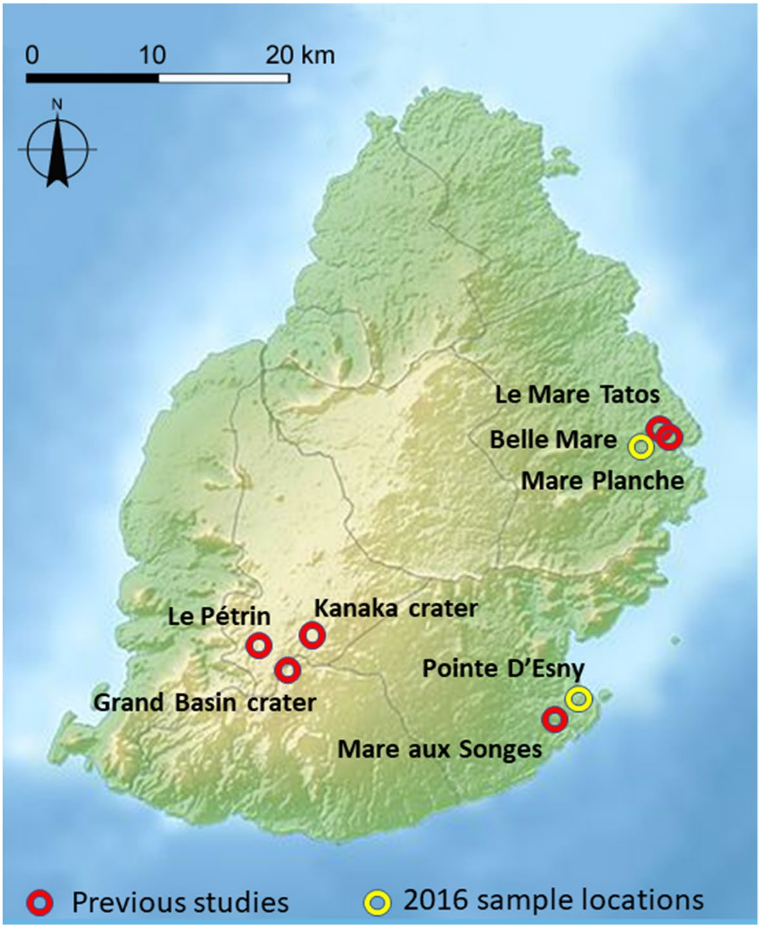

Fig. 1 Map of Mauritius showing the location of previous palynological studies and prospection by the authors in 2016

evidence for an increasingly open component to the vegetation and charcoal derived from burning (de Boer et al. 2013a).

The evidence for human impact in upland sequences currently has no lowland parallel due to absent and/or poor pollen preservation from deposits covering the period of human colonization and settlement of Mauritius. Pollen was largely absent from the Mare Tatos sequence covering the last 500 years (de Boer et al. 2014), while at Mare aux Songes, the infilling of the marsh with dolerite boulders (a malaria control measure) largely disturbed the last 4,000 years of deposits (de Boer et al. 2015). Recent coring by the authors in 2016 also recovered sequences from lowland wetlands at Point D'Esny, Grand Port District, in the south of Mauritius, and Belle Mare, Flacq District, close on the east coast (Fig. 2). Pollen was poorly preserved in both sequences, though the upper samples from Belle Mare included

Fig. 2 Examining a core taken with a Russian Corer in Point D'Esny, Mauritius. Photograph by Krish Seetah

aquatic pollen of *Potamogeton*, fern spores and variable quantities of microscopic charcoal. Charcoal was also recorded from the Mare Tatos, Flacq District, sequence (located in the wider Belle Mare region) though rarely occurring prior to human colonization. Three phases of elevated fire incidence were recorded (c. 1630–1747, 1787–1833, and 1950+) which Gosling et al. (2017) argue corresponded to periods of intensified human activity documented in historical records during and since the seventeenth century. Fire played an important role in clearing land of trees for cultivation, particularly sugar cane, contributing to habitat fragmentation and species extinction. Moreover, the process of forest clearance also led to significant soil erosion and a change in rainfall patterns and water supply. The links between deforestation, sugar cane monoculture, and soil erosion were recognized during the eighteenth century (Norder et al. 2017) and experienced on other oceanic islands from the Canaries to the Caribbean (e.g., Grove 1996; Pratt 2015); this continues to be an issue in South America where sugar cane is widely grown for use in biofuel production (Youlton et al. 2016).

Existing palaeoecological studies emphasize the challenges and opportunities of undertaking research on Mauritius. Developing a more detailed understanding of the environmental impact of human settlement across Mauritius requires comparable palaeoecological data from multiple sites across multiple landscape zones. Currently, evidence for human impact derives largely from upland sites marginal to settlement where pristine habitats will have endured longest, while comparable data is so far lacking from those lowland areas occupied earliest, settled most intensively, and modified most extensively. The small number of pollen studies from lowland wetlands all exhibit poor pollen preservation in the uppermost deposits, including those sediments covering the period of human settlement. Numerous wetlands have been mapped at lower altitudes across Mauritius, although these are more likely to have been negatively impacted by agricultural, industrial, and residential development (see Mamoun et al. 2013). To date, only one study has included plant macro fossils from Mauritius, the most significant result of this analysis being the recovery of Chickpea, *Cicer arietinum*, from the Trianon Sugar Estate, which was associated with provisioning following the influx of indentured laborers (Seetah et al. 2015). The recovery of Chickpea, or Bengal gram, was considered an import. Spanish cherry (cf. *Mimusops elengi*), in the form of a desiccated seed, was also recovered from the same sample, although preservation details suggested the seed could have been a modern contaminant (Morales-Mateos, n.d.). The regular use of sieving and flotation in excavations is likely to significantly increase the number of recovered plant macrofossils in the future, as well as microfauna (Fig. 3).

Geoarchaeology

While a number of studies have focused on the application of palaeoecological techniques for reconstructing the environmental history of Mauritius, the application of geoscience techniques as part of a broader geoarchaeological approach remains an underused but invaluable tool for further study on the island. Geoarchaeology is primarily concerned with the application of an earth-sciences approach in archaeology, adopting a range of geoscience techniques. This includes the use of ground investigation and soil data, deposit modeling, geochemistry, thin section petrography and micromorphology, mineralogy, particle-size and organic matter content analyses. The aim of these techniques is to characterize and interpret deposits (soils and sediments) and materials in both on- and off-site contexts. The value of environmental and geoarchaeological techniques, where a significant overlap exists in both

Fig. 3 Sieving at excavations in Le Morne, Mauritius. Photograph by Krish Seetah

the application and integration of techniques and specialists, is in their ability to investigate processes and activities occurring at multiple spatial and temporal scales, from individual sites to the landscape-scale. Together they represent a toolbox of techniques which can both target and help to inform the scope and development of relevant archaeological research questions.

Thin-section micromorphology enables the *in-situ* study of the sedimentary matrix of the depositional environment. This is particularly useful for analyzing the formation processes of archaeological deposits and the depositional context of micro-refuse for ascertaining uses of settlement space. The technique has been widely applied to understand and interpret the use of settlements in relation to activities inside and outside of buildings, alongside middening practices, the development of cultural landscapes, and the reworking of archaeological stratigraphy by post-depositional processes (Macphail 2014). Micromorphology is particularly useful for studying microfossils in their depositional context, especially phytoliths. These are plant microfossils that are formed of biogenic silica: as plants grow, they absorb silica from the soil and deposit it within their cell structure. When plant remains decay, phytoliths are left behind in the soil, and generally preserve well in archaeological deposits unless soils and sediments are highly alkaline (i.e., pH9). Phytoliths can be useful tools for understanding crop processing and animal husbandry activities and grass phytoliths, in particular, can be identified to species, with differentiation between C3 and C4 grasses. This makes their study particularly valuable in Mauritius where the presence and processing of sugar cane, a C4 grass, could be readily identified in suitably preserved contexts.

Established petrographic methods using visual, microscopic, and geochemical techniques to examine the characteristics of rocks, have been successfully employed in archaeology for decades to identify and source ancient stone, brick, and mortar materials in various regions of the world. This has involved high resolution thin-section comparative microscopic analysis for understanding stone sourcing, ICP-AES geochemical preparation and statistical analysis for examining clay in ceramic building materials, with multivariate statistical techniques used to group and discriminate geochemical data. For Mauritius, extraction and raw material sourcing, especially coral and basalt for buildings and infrastructure, could be usefully studied from this perspective. Extraction represents an important component of natural resource exploitation.

The geochemical analysis of multielemental enrichments has been widely applied in archaeology to examine the use of settlement space, to identify specific activities such as metalworking and animal husbandry, and to investigate anthropogenic impact in off-site contexts (see Bintoff and Degryse 2022 for a recent review). In lake and bog sediments, geochemical techniques that identify fluctuations in calcium and titanium, for example, are used to examine the effects of anthropogenic pollution, and those associated with precipitation, sedimentation, and erosion processes.

In addition to site-based studies, geoarchaeology provides a powerful means of understanding the physical landscape and the connections between land use and environmental change. Existing palaeoecological data emphasize the scale of woodland clearance in Mauritius resulting from European settlement and the broader labor diaspora. Reductions in forest cover inevitably leave soils vulnerable to erosion, resulting in landscape degradation. The risks to agricultural and economic sustainability from deforestation and soil erosion were well understood in the eighteenth century and remain leading contributors to land degradation (Grove 1995). Across the globe there is a strong relationship between soil erosion and changes in land use (Vanwallenghem et al. 2017) and deforestation has been shown in modern examples to result in positive feedbacks that reduce the resilience of tropical ecosystems to continued soil erosion (e.g., Flores et al. 2019). Under extreme examples, persistent soil erosion leads to the development of degraded ecosystems and permanent shifts in vegetation and soils with reduced capacity to support former plant communities (e.g., Mieth and Bork 2005; Rull 2020).

Recent modelling by Norder et al. (2017) has sought to quantify cumulative historic soil loss on Mauritius as a means of informing on potential mitigation measures to offset further loss. Historic soil loss was modeled on the basis of anthropogenic activity, albeit based on the limited available historical data, versus a natural baseline scenario in the absence of deforestation. The results not surprisingly emphasize the significantly higher levels of soil erosion resulting from human agencies since the early seventeenth century when compared against a natural baseline. In addition, on Round Island, an understanding of the mechanisms controling soil erosion are seen as key in efforts to conserve and manage ecosystems susceptible to the erosive impact on soils from overgrazing by goats and rabbits, as well as rainfall (Hedding et al. 2019). Geoarchaeological investigation of the sedimentary record therefore has an important role to play in providing an increased scientific time depth to studies of the links between soil erosion, deforestation, and other agencies, including faunal and climate impacts.

Erosion results in the mobilization of soils and sediment which can accumulate in capture points and preserve important sedimentary archives for studying past landscape change. In situations of topographic variation, soils may be eroded downslope, accumulating at the base of valleys and slopes as colluvium, or washed into rivers and reworked as alluvium, where sediment can be fluvially transported and accumulate in sedimentary basins such as lakes and other wetland habitats. Other basins may have more restricted catchments, isolated from fluvial or estuarine inputs and deriving from accumulations of in-situ vegetation and localised lateral inputs of sediment. The impact of land use, climate, and sea-level may also lead in other examples to periods of increased input of sediment under marine and aeolian processes.

The sedimentary archive therefore plays a critical role in understanding the history and relationships between vegetation change, land use, soil erosion and land degradation. Detailed visual and textural descriptions of deposits can be combined with analysis of the physical properties of sediments, for example including changes in organic and minerogenic matter which may reflect changes in land use.

Geochemical signals in sediments can provide important supporting evidence for land use alongside more traditional palaeoecologically based landscape reconstructions. Geochemical analysis has been applied previously at Mare Tatos, though primarily to trace marine versus terrestrial inputs (de Boer et al. 2014). Previous studies have shown the value of a combined approach to landscape reconstruction as well as the sensitivity of geochemical techniques where palaeoecological data are inconclusive or absent entirely (e.g., Lomas-Clarke and Barber 2007). Intensifying land use is likely to result in the increased mobilisation and erosion of mineral sediments, accumulating in capture points such as wetland basins that may be enriched in elements indicative of human impact; these include elements such as titanium which is a reliable indicator of past soil erosion, or Phosphorus, which although mobile and susceptible to lateral fluxes, is strongly related to industrial and agricultural pollution. The geochemical evidence requires careful consideration of the processes likely to influence the geochemical record and which may include ranges of both vertical (atmospheric) and lateral (erosive) inputs reflecting a complex interplay of natural and anthropogenic agencies. Suitable sedimentary archives may also be contained within alluvial deposits preserved in river valleys/floodplains and estuaries, or colluvial deposits preserved in relevant topographic settings. In cases, alluvium and slopewash may be extensive enough to bury or partially mask archaeological sites and deposits with associated potential for preserved ecofacts.

Finally, sediment ancient DNA (sedaDNA) is rapidly becoming an important technique for reconstructing palaeoenvironments. This provides a complementary, albeit highly localised, diachronic snapshot of plant and animal species, as well as microbial communities, within the vicinity of sampled sites (Larson et al. 2019; Pedersen et al. 2021; Taberlet et al. 2012). These are typically lakes, but the technique can also be applied to buried soils and sealed archaeological contexts. In most cases, the technique allows for a significant increase in the number of taxa recorded at sites, compared to pollen, plant macrofossils, phytoliths, and faunal remains. SedaDNA has rarely been used in the tropics, and while initial studies have demonstrated its viability, they have reinforced the need for developing suitable DNA reference libraries covering past and present flora and fauna (Dommain et al. 2020). SedaDNA has also been recognized as a powerful tool for conservation (Boessenkool et al. 2014). Given the limited palaeoenviromental data from Mauritius to date, this could become an influential technique for enhancing the reconstruction of ecological biographies of specific sites within the island's landscapes and littoral.

Zooarchaeology

Our knowledge of the depletion of Mauritius' endemic wildlife is derived primarily from a range of taxonomic texts and illustrations, as well as collections in museums which include taxidermized specimens. This has been complemented by intensive biological studies of modern populations in the island's terrestrial and aquatic environments. Mammal, bird, reptile, amphibian, and fish species have all been impacted by human activity since colonization, either through direct exploitation or indirectly as a result of habitat fragmentation and transformation. Of the 52 known native species of vertebrates on the island, 24 are now extinct. The only remaining native mammal species on the island, previously widespread on the Mascarenes, is the Mauritian fruit bat (*Pteropus niger*). All other mammals present on the island today have been historically introduced, either accidentally as in the case of rats, or deliberately as in the case of dogs, cats, livestock, and Rusa deer. Twelve out of a recorded 30 species of birds, and 12 of 17 native, terrestrial reptile species remain today. Some 1,700 marine species, including 786 fish, have been recorded in

Mauritian waters, as well as two species of marine turtles (Ministry of Environment and Sustainable Development 2010: 7; Ramen 2012; Staub 1993; Terashima 2001).

Animal bones represent one of the most abundant "ecofacts" on archaeological sites. In most cases they are the end result of human depositional activities and subsequently affected by various taphonomic processes; they do not necessarily reveal a direct ecological reflection of species in the immediate environment. Since they are largely the end result of human agency, they also represent a small number of species selected for exploitation. The study of archaeological animal remains offers insights into the exploitation of species for primary (e.g., meat and skin) and secondary products (e.g., wool, dairy, and traction power). To date, a small number of assemblages of animal bones have been recovered from archaeological sites in Mauritius and its associated islands, dating from the seventeenth through to the nineteenth centuries. The most comprehensive of these studies was undertaken on materials recovered from Fort Frederick Hendrik and comprised a late seventeenth-century assemblage dominated by domesticated and introduced species, in particular Rusa deer, but also the more typical cattle, goat and pig. Fish were also an important component of the diet, as were other marine vertebrates such as sea turtle and the now extinct dugong. No native terrestrial birds were recovered, nor native terrestrial tortoises (Peters et al. 2009), suggesting the iconic dodo and two species of giant tortoise were already in a serious state of decline.

To date, few studies of animal bones associated with laboring peoples have been published, and where these have been reported, they are generally associated only loosely with human habitation. Specific practices of animal processing (i.e., highly comminuted bone) have been linked to maroon sites (Chowdhury 2015), and materials from rock shelters in Macondé have been investigated for potential connections to maroonage (Abungu et al. 2018); however, the animal bone finds themselves were not published in detail. More complete analysis was undertaken on remains recovered from the Aapravasi Ghat Immigration Depot, Port Louis, providing evidence of food waste, but also the use of traction from cattle and water buffalo (Joglekar et al. 2013). Once again, while this assemblage was larger, permitting a more detailed assessment, the association with laboring peoples is relatively loose, not least because the stratigraphic integrity of the site has been called into question (Summers 2011). The most significant assemblage from the islets of Mauritius derives from Ile de la Passe, a strategically important site off the southeastern coast of the island, is the coastal area around Mahebourg. The French were the first to construct defensive installations here from 1725, with the British making further additions up to and during WWII. The bone assemblage from the site provides evidence not only of consumption patterns, but also of local, small scale, bone working industries (Summers, this volume).

Animal bone also contributes to our understanding of the ecological history of exploited species, with the appearance and disappearance of taxa in the archaeological record resulting from introductions and extinctions. Due to its isolation and the subsequent development of a unique fauna, early historical scientific interest focused on the island's bird life, especially the dodo and related extinct birds (Clark 1866; Newton and Gadow, 1893; Strickland and Melville 1848) the extinct terrestrial tortoises (Haddon 1880), reported already at that stage from museum collections curated by Alfred Haddon, and the reptiles of Rodrigues, of which the tortoises were said to be so abundant that some 2–3,000 could be seen in congregation (Gunther 1879). These historical accounts offer a rich repository from which to better understand the route, scale, and rapidity of extinction events. However, they also offer important points to better assess the socioecological, and cultural development of the island. For example, one Admiral Kempinfelt, visiting the island in 1761, recounts how thousands of tortoises were shipped to Mauritius from Rodrigues "for the service of hospitals" (reported in Gunther 1879: 452). One can only assume this was for their dietary benefits. Recent research on animal-based therapies (ABT) suggests that Mauritians retain important and useable knowledge of zootherapy (Mootoosamy and Mahomoodally 2014), which may itself have historical roots given that no one would have been immediately familiar with the island's flora as a source of medicine and this knowledge would have had to develop over time. Thus, it is possible that early colonists, both laboring and elite, deferred to animal-based therapies grounded in familiarity. By the time Fort Frederik was built, it appears many local endemic faunae were already extinct or close to dying out. However, the fascination with the singular fauna of the island, dominated by the dodo, has led to much recent and important discoveries about the morphology, and possible habits and ethology, of this iconic emblem of extinction (Hume et al. 2015; Janoo 2005; Meijer et al. 2012; Rijsdijk et al. 2015).

With the accumulation of larger assemblages of animal bone, it will become possible to conduct complementary biomolecular studies. The analysis of stable isotopes has been successfully applied to archaeological bone with the aim of reconstructing dietary patterns and mobility. While many studies have focused on reconstructing past human diets, isotopic data extracted from the bones of mammals and fish is also shedding important light on exploitation and management strategies (e.g., Madgwick et al. 2019), as well as the feeding behavior of wild species and how this relates to extinction trends (e.g., Van Der Sluis et al. 2014).

Invertebrate remains are also encountered on archaeological sites where preservation conditions are good and recovery techniques are thorough. Insects are largely represented by wing cases and molluscs by shells, both of which provide a sensitive indicator of local environmental conditions. The island's diverse habitats have supported a broad range of insects and molluscs, which are more sensitive than most vertebrates to ecological degradation as well as climatic fluctuations. Of particular note are 39 native species of butterfly, and 82 native species of land snail, from an originally recorded 125 species. Evidence of mollusc, especially gastropod, exploitation has been noted from both Fort Frederik and Ile de la Passe.

Unfortunately, interest in iconic species that met their demise with the onset of colonization has done little to stimulate a more general emphasis on zooarchaeological studies on Mauritius. Studies of materials from Fort Frederick in particular, as well as the other sites mentioned above, are beginning to lay the groundwork for a more comprehensive and much needed global view of primary exploitation and resource use strategies for the island. However, while faunal remains from Bras d'Eau (see Haines, this volume, for site details) and Moulin a Poudre, and the Le Sirius and Le Coureur shipwrecks (see Manfio, this volume) are currently under analysis, few other assemblages to date have provided the potential to shed new light on the daily diets and husbandry practices of the island's inhabitants, or on human-animal relationships more generally.

Climate

Small islands have long been regarded as particularly vulnerable to climatic fluctuations, which stress ecosystems and prompt their human populations to shift their exploitation strategies, particularly regarding food. As a result, climate has often been invoked as playing a major role in shaping human culture on islands (e.g., Nunn and Britton 2001). Where islands have had pre-colonial human societies, palaeoenvironmental studies have been used to map past resilience, particularly in the context of climate change, with the aim of tackling future climate vulnerability (e.g., Douglass and Copper 2020). For Mauritius and the other Mascarene islands, there was no precolonial relationship with the environment. The establishment of permanent settlement in the seventeenth century corresponds to the global "Little Ice Age," which continues to be reevaluated, and which, in the Indian Ocean, has been largely studied from the perspective of monsoon events (e.g., Hong et al. 2003). Today, there is an abundant literature on the projected impact of climate change on Mauritius' economic vulnerability, particularly concerning fundamental elements such as freshwater resources (Boojhawon and Surroop 2021), food security (Brizmohun 2019; Ramlall 2014), and tourism (Mahadew and Appadoo 2019). Future work on climate proxies from Mauritius and other small islands in the western Indian Ocean, derived from lakes, corals, and written records, will provide an essential backdrop to the environmental and cultural changes observed in the four centuries of settlement, and whether this played a determinant role in human exploitation strategies. The dramatic transformation of the island's environment provides a useful measure of historical resilience. Work utilizing climate proxy evidence has the potential to be applied in varied ways to better assess not only the ecological impacts of colonisation, but also as a baseline for improving our knowledge of major social events, such as epidemic disease (Seetah 2018). The integration of multiple climatic data sets, from the archival as well as biological records, also has potential applications for contemporary understanding of disease through modeling (Seetah et al. 2020).

Future Pathways: Environmental Archaeology, Biocultural Heritage, and Diversity

The range of techniques encompassed by the field of environmental archaeology has the potential to contribute new knowledge to multiple aspects of Mauritius' socio-ecological history, as well as to that of the other Mascarene islands, especially Réunion and Rodrigues, and beyond to other small islands in the Indian Ocean (Table 1). At the same time, environmental archaeologists can also contribute to the ongoing discussion on conservation, policy making, and bridging the divide between cultural and natural heritage. In 2010, the Ministry of Environment and Sustainable Development highlighted the principal threats to the remaining native environments of

Table 1 Summary of environmental archaeology techniques referred to in this paper. Kubiena refers to tins used for taking micromorphology samples; monoliths refers to single blocks of sediment/soil; NPPs refers to non-pollen palynomorphs

Deposit/Site type	Sample type	Dating potential	Technique
Waterlogged sediment	Boreholes, monoliths	AMS 14C, Pb210	Pollen, NPPs, Fungal spores, geochemistry, microfauna, molluscs, charcoal, aDNA, isotopes for palaeoclimate studies
Buried Soils	Boreholes, kubiena, bulk samples, column samples	AMS 14C, OSL	Plant macrofossils, snails, pollen, NPPs, geochemistry, charcoal, phytoliths, aDNA
Occupation deposits	Kubiena, bulk samples, column samples	AMS 14C, OSL, U-Series	Plant macrofossils, animal bones (mammal, birds, fish reptiles), insects, snails, pollen, NPPs, geochemistry, charcoal, phytoliths
Historic buildings	Structural remains	AMS 14C (mortar)	Petrography
Quarries	Bulk samples	n/a	Petrography
Marine	Corals	AMS 14C, U/Th	Palaeoclimate studies
Caves	Speleothems	AMS 14C, U/Th	Palaeoclimate studies

Mauritius and the Mascarenes were loss of biodiversity, and the degradation or loss of habitat. These were driven by continued land clearance, invasive species, habitat modification, the effects of pollution and the unfolding impact of climate change, with effective responses limited by socioeconomic and logistical constraints. In light of these challenges, what is the role for environmental archaeology?

Across the world, conservation and sustainability policies have drawn on environmental history to provide a baseline for habitat preservation and reconstruction. Island archaeology, in particular, has long been concerned with conservation in relation to historical ecology (Crumley 1994; Davis 2010; Fitzpatrick et al. 2015; Lane 2010). Where palaeoecology has been connected with restoration ecology, it has engaged with environmental legacies for the purposes of social and environmental justice. This is certainly the case for Mauritius, where there is a clear awareness of the general history of human impact on plants, animals, soils, and waterways. Toth (1994: 100) highlighted the value of environmental history as providing "useful lessons for the future of Mauritius and perhaps many other small islands," and indeed, this is integral to the state's conservation and restoration policies. Much of the landscape of Mauritius today can be framed as "biocultural heritage," which represents the legacy of human activity associated with colonization and colonial exploitation strategies. This has effectively resulted in a domesticated environment with a degraded biodiversity. However, this "biocultural heritage" is presented at odds with and decoupled from "natural heritage," which can be defined as the preanthropogenic Mauritian environment. This dichotomy between (bio)cultural and natural heritage is found across the world but is arguably more pronounced on small islands with comparatively recent histories of human occupation.

As environmental archaeologists increasingly engage with the ecological legacy of colonialism, the long-term socioecological consequences of exploitation, they can inform about the present and potential futures of environmental change. This is especially relevant where the legacies of colonialism continue to shape modern social and environmental challenges (Wallman et al. 2018). Environmental archaeology could reconnect biocultural with natural heritage, or at the very least inform the discussion due to the time depth and expertise involved. Biocultural spaces could be readily mapped using Historic Landscape Characterisation (HLC), a tool that is increasingly used to bridge archaeology, heritage, and landscapes (Turner 2006). This could be framed as "biocultural diversity," which would link different aspects of cultural diversity with the use of natural resources and identify how these links promote and maintain both cultural and biological diversity. The value of environmental archaeology for informing sustainable resource management and assessing vulnerability has been particularly highlighted for small islands, where a nuanced understanding of their long-term socioecological histories can directly feed into future decision making (Brewington et al. 2015; Rivera-Collazo et al. 2018).

The promotion of biocultural diversity in Mauritius could be readily implemented at sites managed by the National Parks and Conservation Service, which include protected habitats that also contain visible traces of cultural heritage. The best example of a terrestrial site is Bras d'Eau National Park, created in 2011, which brought together within an area of just under 500 ha what could be defined as a biocultural landscape. This encompasses a diverse range of rare flora and woodland habitats, particularly low land dry dwarf forests, small stands of ebony and mangroves, as well as bird species, including the endemic paradise fly catcher (*Terpsiphone bourbonnensis)*. Within this "natural" landscape are the remnants of a colonial sugar plantation, including a well-preserved sugar mill (Haines 2019, this volume). In fact, the environmental history of Bras d'Eau is that of Mauritius in microcosm, with intensive deforestation giving way to sugar and timber plantations. Archaeological investigation of settlement traces in places such as Bras d'Eau, including the study of the full suite of recovered ecofacts, therefore has the potential to tell the story of how humans have shaped the Mauritian environment. From the perspective of local education and tourism, this would raise the visibility of what is deemed both cultural and natural heritage.

The same approach could be used for maritime sites. Shipwrecks as artificial structures with historical biographies that have subsequently developed natural ecosystems are prime examples of biocultural heritage. Shipwrecks and artificial reefs help to create and maintain biodiversity for a range of microbiomes, promoting the development of new habitats by providing hard substrate for a host of organisms at different tropic levels (Hamdan et al. 2021; Zintzen et al. 2008). Research in coastal waters around Belgium identified some 224 species, of which 46 were new to the coastal marine fauna of the region (Zintzen et al. 2008). Mauritius is considered to have the highest marine species endemism in the western Indian Ocean faunal Province; however, recent work within the local has shown the scale of risk to local endemics. Taking a more holistic point of view, artificial reefs and shipwrecks are not simply Fish Aggregating Devises (FADS); they serve as habitats and nurseries for a range of vertebrate and invertebrate species and could play a vital role in support a broad range of endemics (McClanahan et al. 2021). Given these varied benefits, wrecks and reefs could legitimately be envisaged as "micro-biodiversity/cultural hotspots" (Naggea and Seetah, in press).

The promotion of the island's natural and cultural heritage for economic purposes are an integral element of the Mauritian state's policy: tourism is regarded as the "third pillar" of the Mauritian economy. While under the political stewardship of the Ministry of Tourism, these are nonetheless separated into heritage tourism and ecotourism. An environmental archaeology perspective can bring these two together under the umbrella of "biocultural diversity." Currently, a defined program of data integration engaging a range of stakeholders has been spearheaded by the Department of the Continental Shelf and Maritime Exploration Zone (Badel et al., in press) and members of the MACH project, with a local maritime archaeologist (von Armin and la Hausse in press). An initial meeting at the Indian Ocean Rim Association (IORA) outlined various ways that underwater cultural heritage (UCH) could be integrated into the Marine Spatial Plan for Mauritius. During this meeting, two action points were ratified to protect and valorize UCH (Seetah, in press-b), and subsequent collaboration has already led to development of a GIS integrating evidence of over 1200 ships known from historical records to have wrecked in the lagoon waters around the island (Manfio and Seetah, this volume). In addition to providing important geospatial data that could be used in ecological assessment of how wrecks contribute to biodiversity enrichment, this work also has particular relevance for the movement of laboring peoples, especially given Mauritius's role in slave trading (Manfio and von Armin 2020).

We conclude this paper with a set of recommendations on practical steps to progress environmental archaeology on Mauritius in support of the broader research aims and objectives outlined above. They are arranged in order of priority.

Recommendations

- Highest priority should be given to targeted excavations of key archaeological sites representing a range of socioeconomic groups to recover assemblages of plant remains and animal bones. The use of sieving and flotation of archaeological contexts to maximise the collection of micro ecofacts, especially plant macrofossils and the remains of small mammals, birds, and fish.
- A preliminary resource assessment of the biocultural potential of Mauritius and its associated islands. This would identify suitable locations for scientific investigation, utilizing existing available data (e.g., wetland inventories, ground investigation data, soil mapping) and fieldwork at targeted locations.
- Identification of capture points in the landscape which may preserve suitable sedimentary archives, including alluvial deposits preserved in river valleys/floodplains and estuaries, or colluvial deposits preserved in relevant topographic settings. The latter may be extensive enough to bury or partially mask archaeological sites and deposits.
- Obtaining suitable samples from targeted sites. Samples should be recovered and assessed with an initial focus on dating potential and preservation of key proxies (e.g., pollen and non-pollen palynomorphs, plant macrofossils, charcoal, and microfauna).
- The current preservation bias in palaeoenvironmental reconstructions from upland settings requires a focus on suitable sites from lowlands and locations related to the earliest phases of colonization.
- Palaeoenvironmental and geochemical analysis should focus on producing studies with a high sample and temporal resolution, preferably to a decadal scale for integration with historical data.
- Development of a DNA reference library for the past and present flora and fauna of the Mascarene islands. This will facilitate sediment DNA studies from a range of natural and archaeological sites, both terrestrial and maritime.
- Multispectral assessment of both the cultural and biodiversity value of the shipwrecks, providing a comparative index across different regions of the lagoon, especially important within the context of the island's marine endemism.
- Extraction and raw material sourcing, especially of coral and basalt for buildings and infrastructure, should be recognizsed as an important component of natural resource exploitation. Provenancing studies of historical building fabric should accompany conservation programes.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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