Connecting Continents

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IN RECENT YEARS, THE consequences of climate warming have become a topic of considerable interest to archaeologists and historians. Climatic changes have the potential to impact our world in numerous ways, underscoring the complexity of trying to understand how ecological systems (precipitation, temperature, and geology) interact with each other. Of these concerns, one of the more pressing is the potential risk to human health that a warmer climate may result in. Given the well-studied nexus between disease and historic globalization events, it is surprising that historical archaeologists have paid little attention to this topic. Taking another view, while climate change is a process that is in constant flux and has been since deep antiquity, the changes wrought on our environment by humans over the last five hundred years have arguably had the greatest impact on the modern world. Thus, this period should be a key focus of climate change research.
In this chapter, I present a study that illustrates how historical archaeologists can use techniques developed by environmental scientists to better understand the ecological consequences of colonization on Mauritius. In addition to discussing environmental impacts, as they can be determined from climate proxy data, I also outline how these same datasets can be used to improve our knowledge of the historical spread of disease, in this case malaria, and potentially contribute to future disease control. The study outlined here is nested within the Mauritian Archaeology and Cultural Heritage (MACH) project, and although at present we must consider this a theoretical exercise, it is one based on well-established methodological precedent, with active analysis of human skeletal bone. The research presented here capitalizes on the specific nature of the archaeological sites the MACH project is working on (i.e., cemeteries), from which we have been able to recover human remains. It also takes advantage of the ability to undertake a range of climate analyses using samples derived from coastal and terrestrial coring. As set out in the introduction to this volume, the research is interdisciplinary and integrates datasets and perspectives from archaeology, history, and environmental science, with applicability at the local, regional (i.e., Indian Ocean basin), and global levels, where malaria is prevalent. Further, it aims to underscore the potential insights that a better understanding of diseases in the region might reveal, and how these could improve our knowledge of the processes of demographic transformations at a range of geographic scales.

CONNECTED ISOLATION: THE PARADOX OF ISLANDS

Historical research has long conceptualized the connected nature of islands and their communities, while archaeology, approaching islands from the perspective of artifacts, also emphasizes the way that material exchanges result in connectivity. However, when approached from the viewpoint of environmental science, the tendency has been to see islands as constrained zones, particularly when discussing geography. This is obviously true within the context of physical space and can be beneficial to research as it permits control over spatial variables. Particularly within the modern setting, and despite their often-small size, islands are rarely truly isolated, and their connections to global networks have increasingly resulted in negative implications for the local communities.
This takes the form of increased dependence on imported products, and particularly problematic, a reliance on nonlocal raw materials required for construction. While these issues illustrate the role that island communities themselves can and do play in modifying local landscapes, particularly through processes of modernization, of far greater impact are the potentially devastating consequences for islands that global climate change could initiate. Rising sea levels, alongside changes to patterns of precipitation and increased sea-surface and air temperatures, have the potential to overstrain already limited resources. In addition, policies developed at an international level may in fact limit the ability of local governments to make decisions regarding the best way to safeguard their environment. This has the potential to exacerbate damage to vulnerable ecological systems. In short, island communities need evidence that helps to frame, archaeohistorically, how local landscapes have been modified during and after the colonial period.4

ECOLOGICAL SYSTEMS AND COLONIZATION

At a practical level, the above begs the question: What actually catalyzes change to island ecology? Large-scale historical transformation is evident as a consequence of colonial administrative policy, and this has taken the form of the near-complete conversion of island landscapes, for example, as a consequence of intensified monocrop agriculture.5 However, recent research is increasingly cognizant of the extent to which more subtle drivers of change can influence island ecosystems. In particular, while the destructive role of exotic introduced fauna is well known, it is now apparent that their influence has far-reaching, long-term ramifications. The main culprits are rats, pigs, and ungulates, in particular, cattle, and deer, with carnivores like the small Indian mongoose and cats playing a more direct role in reducing native fauna.6 There are many complexities in how these species interact with and impact island ecology, and it has been suggested, for example, that the negative effect of rats has been exaggerated.7 Rats were, and continue to be, an unintentional introduction; large ungulates, on the other hand, and in particular cattle, were deliberately introduced as a source of nutrition and for traction. Their role from a historical standpoint, in Brazil as a case in point but applicable to many geographic locations in the Indian Ocean as well, has been considered critical to colonial expansion.8 Their
direct impact on island ecosystems takes many forms, and it has been suggested that “ungulate herbivory is a chronic, landscape-scale disturbance capable of influencing plant communities as much as episodic events such as fire. Consequently, ungulate herbivory has the potential to facilitate the invasion and establishment of exotic plants.” In addition to their destructive impacts on flora, at a more discreet level, cattle have been shown to facilitate the expansion of other exotic faunal species, as demonstrated in Australia with cane toads.

The specific behavior patterns of pigs have also been shown to have a particularly detrimental impact. Their rooting activities during periods of feeding disturb soil layers, and can cause major disruption to the establishment of seedlings, aeration of the soil, and natural decomposition. In spite of the large array of destructive actions exotics have initiated, including extirpating native flora, preying on indigenous fauna, and facilitating the establishment of new invasive species, the most devastating long-term impact of ungulates and other introduced animals is likely to take the form of novel behaviors that they undertake in new environments. This point is particularly important for small islands that have historically lacked large, terrestrial herbivores.

THE CONTEXT OF DISEASE IN THE COLONIAL WORLD

Understanding disease in the colonial setting is far from simple. Aside from the fact that “colonial medicine” and medical practice of the day was itself a different entity in terms of how disease was conceived of, when compared to the modern world, there is also the issue of the very different ways in which individual colonial powers treated those afflicted with illness, and indeed, the extent to which they integrated local medical traditions. In effect, this captures an aspect of how imperial forces chose to interact with indigenous communities: the Portuguese actively engaged with Indian healers, pundits, in Goa, while the far more industrialized British implemented regimes that generally took little account of local practices.

For the purposes of this chapter, one point in particular is worth noting. One of the main pillars of medical development during colonial rule rested on the deployment of skilled medical practitioners into newly colonized regions as a means of assessing the impacts of disease, primarily on the health of westerners, but also on the health of the
laboring classes. A feature that is particularly important is the speed with which these doctors transition from reporting that disease impact was “generally comparable to Europe” to stating that these regions were effectively a “white man’s graveyard.” While this latter descriptor was used widely to describe Africa during early exploration, it was subsequently adopted to describe the Caribbean, for example, and illustrates the rapidity with which a range of diseases migrated with the transatlantic slave trade, a so-called Africanizing of the disease environment. Not only does this model illustrate how African diseases, principally malaria and smallpox, migrated across the Atlantic, it also showed how, later, Atlantic diseases, such as syphilis, transitioned into South Asia.

In terms of geographic spread, alongside malaria, smallpox, cholera, and yellow fever were quickly disseminated around the globe as a consequence of improved transportation. These diseases became an important focal point for colonial administration, principally because they caused high death rates for westerners, particularly soldiers, but also because they drastically reduced the available workforce. Understanding the underlying mechanisms of transmission for individual diseases, how to control their spread, and ultimately how to cure the sick became a major preoccupation of the administration for the simple fact that these diseases decimated populations, often on a cyclical basis. It quickly became apparent that the environmental component was critically important, both at the larger panregional scale in terms of moving diseases along with people, but also at the local scale, with regard to practices adopted for agriculture that then influenced and augmented the spread of disease. Two examples from Mauritius illustrate this situation: By retaining standing water for irrigation of plantations, the risk of malaria infection was increased as these reservoirs provided ideal habitats for the larvae of mosquitoes. Similarly, the poor sanitation and lack of clean drinking water for residents of Port Louis resulted in outbreaks of cholera.

The massive demographic reconfigurations that epitomized the historical period created new disease environments where neither the local population nor incoming groups were prepared for the devastating consequences of new, or new forms, of diseases. James L. A. Webb succinctly summarizes the significance of disease: “Historians of Africa have credited the difficult disease environment of tropical Africa with a vital role in shaping the history of African civilizations.”
statement is just as significant for and applicable to small islands in the Indian Ocean, and indeed, the colonial world more generally. What is absent is the assessment of the skeletal record, alongside the historical and environmental, to better understand the populations most likely to be affected by disease, and the outcomes in terms of physiological implications as well as inferred socioeconomic ramifications. This is where archaeology has a potentially important role to play. Although the present chapter focuses on malaria because of the specific circumstances of the materials we have available for study, much work exists on other major “plague” diseases, and similar approaches could be adopted to better understand their individual influence on historic population structure, administrative policy, and impact on the body.18

THE UTILITY OF MAURITIUS FOR RESEARCH ON CLIMATE AND DISEASE

Mauritius, known the world over as the home of the dodo, the quintessential icon of extinction and arguably the first species lost as a consequence of globalization, is an ideal location for studies that aim to contextualize colonial activity and the resulting climatic impacts. The island forms part of the Mascarene biodiversity hotspot, a region recognized as having a high degree of faunal and floral variation. Its lagoons function as a reservoir for its unique marine ecosystem, and prior to colonization, its flora constituted a lush mosaic of microhabitats ranging from heath and forest in the uplands to Pandanus reed swamp in coastal lowlands.19 Mauritius had no indigenous populations; in fact, apart from bats the island had no mammals prior to settlement. Recent research using a variety of paleoecological tools has started to reveal not only a more complete picture of the island’s native flora prior to settlement, but also the magnitude and rate of detrimental outcomes as a consequence of colonization. From 1598, the island witnessed three successive waves of colonialism, with each group bringing its own model of land exploitation. The Dutch (1638–1710) focused on forest resources, the French (1721–1810) introduced large-scale sugar cropping and animal husbandry, and the British (1810–1968) intensified sugar agriculture over the whole island, with the effect that around the 1850s, some 10 percent of global sugar production derived from the island.20
Mauritius serves as an important barometer for the wider region. It is five hundred miles from the nearest major landmass to the west, Madagascar, while eastward there is no land for nearly five thousand miles until one reaches Australia. Thus, its spatial isolation allows us to convincingly tie ecological effects to human agency on the island. Its unique history and rich archival record also provide a rare opportunity to chart temporal change through time using instrumental records (historical archives of rainfall, meteorological activity, and other climate variables) and to observe how these correlate with policy during the various colonial phases.

In addition to the historical backdrop and the ongoing paleoecological work, the team of the MACH project has undertaken excavation on a range of sites that are now providing source materials for further analysis. Of key significance is the Bois Marchand Cemetery, located in Terre Rouge (fig. 11.1), a functional, contemporary cemetery with historic sections ostensibly dedicated to indentured workers. Since 2011, excavations at Bois Marchand have unearthed a unique snapshot of the island’s ancient population, unearthing some thirty human skeletons. In addition to an estimated four hundred to five hundred interred, the cemetery has an extensive and impressive collection of burial records,

FIGURE 11.1. Bois Marchand. (Photo by Yves Pitchen, reproduced here with permission.)
detailing demographic and cause of death data, spanning back to its inception.

At the time it was established in 1867, Bois Marchand covered some four hundred acres, and was created to accommodate the massive death toll resulting from epidemics of malaria and cholera. The smaller cemeteries of the capital, Port Louis, were simply overwhelmed by the numbers of individuals who perished. In 1867, forty-one thousand people, 10 percent of the entire population, died from malaria. The response by the British administration was to expand quarantine and cemetery infrastructure; there was no way the British could have known that mosquitoes were the vector for malaria as these discoveries were not made until Ross’s work some thirty years later.21

While Bois Marchand is under active investigation and has yielded human remains that are currently being analyzed, the site of Flat Island Quarantine Station is also potentially promising. Two brief survey seasons have been undertaken on the island to date, which have revealed rich archaeological potential. The site retains standing archaeological features, such as a hospital block and possible desalination plant. In addition, historic maps indicate zones on the island used as “coolie camps” as well as two cemeteries, one of which may have formed the final resting place for those who fell ill on the voyage to Mauritius and ultimately died while in quarantine. This site thus has the potential to add important information regarding the administration’s response and the actions taken to control the spread of disease. Given the historical reference to a cemetery, it may even prove to be a locus for additional human samples with future excavation.

MAURITIUS, MALARIA, AND THE WIDER INDIAN OCEAN

Having established that from both an ecological and archaeohistoric perspective the island has considerable utility for a better assessment of the environmental consequences of colonization, as well as scope for improving our knowledge of the spread of malaria, the next point is to demonstrate how outcomes from Mauritius may be useful for the wider region. Africa has the highest prevalence of malaria in the world, with approximately 90 percent of cases recorded on this continent. South Asia, and India in particular, has the second highest rate of occurrence.
Mauritius, effectively an African island composed of a plural but predominantly South Asian community, captures the two key elements that underscore malarial transmission: its environment and ecology were, and remain, very well suited to harboring and spreading malaria via mosquitoes. Secondly, the specific demographic that now constitutes the island includes individuals from key high-risk locations; thus, if we can understand how the disease interacts with these groups, we have the opportunity to apply any results to these larger continental landmasses. In addition, the particular history of malaria, its development and impact on the island, is idiosyncratic. No recorded case of the disease was noted during the French period; by 1867 it was epidemic, particularly in urban areas, but was eliminated by 1969 only to reemerge in 1975. The island finally achieved disease-free status in 1998, and is, as of the writing of this chapter, maintaining it. Mauritius is one of only two cases in Africa classed as malaria free by the WHO. Given this singular set of circumstances, what lessons can we learn, especially when we approach the study of ancient malaria transmission from a scientific perspective?

Archaeologically speaking, the role of disease, while figuring strongly in Atlantic research, has remained largely unstudied within an Indian Ocean context, and could prove highly relevant to our understanding of labor provision in the Indian Ocean basin. While this provides immediate outcomes and connects strongly to the themes set out in the introduction to this volume (namely, to find ways to connect historical and archaeological research agendas), it also has bearing on the issue of making archaeohistoric research relevant. This is the case with regard not only to contributions to academic narratives on “environmental crisis,” but also to the very communities with which we work. In an African context, there is an expectation at the governmental level that those individuals who have training and expertise in subjects such as archaeology, and here I emphasize environmental archaeology specifically, will be able to offer solutions to practical issues. The type of archaeohistoric research outlined and expanded on here has considerable potential benefit for contemporary communities, particularly within an African context.

In the remainder of this chapter, I outline the ecological framework currently under development to generate climate proxy data, and explain how this fits into an ongoing investigation of the spread of malaria.
Ecology

The direct measurements of temperature, wind speed, and other climatic data (termed the instrumental record) have only been kept for a relatively short period of time, decades as opposed to centuries in most cases. Therefore, climate scientists face a challenging situation as they have few historically recorded data against which they can compare trends in climate fluctuation, assess change, or test climatic models. There are often major gaps in the archival records, a situation that affects Mauritius as well as being a more general concern. For this reason, additional analytical techniques have been developed to capture “proxy” data, which can be used to infer climatic conditions in the past, often to a high degree of specificity. These proxy data can be assembled from a range of sources, but two particularly profitable records can be derived from analyzing soil and coral core samples. The former provides information on geomorphology, hydrology, and land cover change. For the latter, climatic assessment can be generated from cores extracted from large Porites coral. These are a group of dome-shaped, reef-building corals, with properties that make them highly suitable for climate studies. Cores are drilled (usually at no more than twenty meters below the surface of the sea) using special equipment to extract a precise set of climate proxy data from the skeletons of the corals. As the coral grows, the underlying structure of its skeleton traps particles of minerals and trace metals from the surrounding seawater, acting as a natural reservoir for these elements as they find their way into coastal waters from the land. These large corals form over many decades, with the largest capturing over three hundred years of climate information, although at present the coral from the coastal waters off Mauritius are likely to retain a record of approximately two hundred years as they are generally smaller due to cooler waters.

Coral cores provide evidence of changing sea surface temperatures, sediment runoff, and fertilizer use over time. An additional benefit of using coral is that they form rings during their growth, in much the same way that trees do, and these provide an additional chronological reference point, which can also be carbon-dated to provide an absolute datum. Thus, a suite of ecological proxies forms the basis for the study outlined here, framed within chronological and archaeohistorical datasets. Our principal archaeological, osteological, and molecular
research is being undertaken from human remains, and to date, samples from seventy skeletons—derived from Bois Marchand as well as the earlier slave and postemancipation Le Morne Old Cemetery—have been isolated and are actively under analysis.29

Disease

Geographically speaking, malaria is considered one of the most detrimental diseases on earth in terms of prevalence and mortality, with half of the world’s population at risk from contracting the disease. It is estimated that some 10 percent of those living in high-risk areas will be infected, of which approximately one million will die annually. As mentioned above, Africa bears the brunt of this mortality, with 90 percent of deaths occurring on this continent, primarily in infants under five. Given these rates of mortality and the specific portion of the demographic that is most affected, it is clear why the socioeconomic cost is even greater than this death toll suggests.30 More alarming is that despite decades-long efforts at eradication, malarial prevalence is on the increase. With a warming climate, greater levels of resistance to prophylaxis, and no proven vaccine, malaria poses an increasingly significant global socioeconomic and health challenge, in the context of both shifting zones of infection to new areas and the reemergence in areas formerly under control.31

In light of the fact that malaria is largely preventable, both the widespread socioeconomic ramifications of the disease and its significant cost in human life may seem inexplicable. However, climatic conditions are a critical factor in determining the range of malaria, and are expected to change rapidly in some malaria regions in the future as the climate warms. Thus, while we have good models for assessing how the activity pattern of mosquitoes correlates with changing temperatures for the contemporary setting, these have generally not been contextualized through time, given the paucity of data from the instrumental records. Furthermore, recent research has suggested, in addition to the well-documented effects of temperature, rainfall, and humidity, that geomorphology, hydrology, and land cover change may be crucially important determinants of mosquito distribution and activity.32 With better, more complete correlations between climatic conditions and mosquito activity, it would be possible to provide better advice on how
to avoid periods of peak mosquito activity, and thus reduce the risk of being infected through bites.\textsuperscript{33}

In recent years, evolving resistance to both pesticides and drugs has led to attempts at developing a vaccine. However, vaccines for parasitic disease, as opposed to viral or bacterial illness, are harder to produce because of the greater genetic complexity of the organisms (e.g., the poliovirus has eleven genes while \textit{Plasmodium falciparum}, the most virulent form of the protozoan parasite that causes malaria in humans, has over five thousand). Furthermore, no other vector-borne disease has the capacity to evade the human immune system as effectively as \textit{Plasmodium falciparum}; thus, efforts to aid the immune system through modern medicine have been largely ineffective. Despite the seeming incompatibility between modern medicine and archaeological practice, the following outlines what may be a potentially ground-breaking development in terms of the application of scientific archaeology to modern disease control.\textsuperscript{34} The human skeletal remains that have been (and continue to be) excavated from cemeteries such as Bois Marchand may hold the key to unlocking a path to improved vaccine development, based on a better understanding of how malaria genes have changed over time. Recent advances in DNA analysis using next-generation sequencing (assessing the whole genome) and shotgun techniques allow us to study the genomic basis of virulence, causes of historical outbreaks, and natural selection for drug resistance.\textsuperscript{35} To these molecular techniques, we can add evidence from more traditional osteological assessment of the skeletal remains, which can divulge the extent to which nutrition and other physiological responses triangulate with malaria infection. Osteology also provides an established, though contested, means of recognizing infection from the skull, porotic hyperostosis, and cribera orbitalia (fig. 11.2). The pitting of the cranial vault that typifies these conditions is a skeletal response to anemia and has been linked to malaria.\textsuperscript{36}

**ARCHAEOHISTORIC DATA, \textit{aDNA}, CLIMATE, AND MALARIA**

There is well-established precedent for the extraction of plasmid DNA from ancient remains, in some instances spanning many thousands of years. Indeed, the earliest evidence of malaria was recovered from a mosquito preserved in amber dating to some thirty million years ago in the Dominican Republic. However, research on human malaria has tended
to focus on establishing the origin and early spread of the disease, so the main thrust of this work has not been disease control, although it has certainly been recognized that this may be a future application. More importantly, to my knowledge, no attempts have been made to extract malaria DNA from historic sites, and this is likely a consequence of the fact that strong evidence already exists in the form of archival records for the presence of malaria at that time. However, historical sources detail far more than the mere presence of the disease. Archival records have the potential to provide accounts of daily death rates during spikes in infection, as well as demographic data about those individuals who were dying during periods of malaria epidemics. These data need to be used with caution as they may be subject to inaccuracy, given the lack of scientific mechanisms at the time for establishing malaria per se; thus, general terms such as “fever” were commonly used, which do not necessarily provide evidence for malaria.

By using samples from historically contextualized malarial outbreaks, the aim is to integrate archaeological, climatic, and genetic datasets into a model whereby we know with a high degree of probability when infection occurred, its magnitude in terms of death rate, and the physiological effect that the disease had on individual human bodies through osteological analysis. At a broader level, we also have an account of the sociopolitical response by the administration. The samples from Bois Marchand and the island more generally derive from...
the 1800s, when human migration, a major influence on the spread of the disease, was at a historical peak; however, this is still well before the period of modern prophylaxis. By combining these various datasets and correlating climatic and genetic evidence with information from the archaeohistoric record, we are able to investigate the “evolution” of *Plasmodium falciparum* under environmental and human agency pressures and the responses this triggered in the genomic structure of the malaria virus.

**IMPROVING MALARIA MONITORING AND EARLY WARNING SYSTEMS**

Historical and climate proxy data may allow us to build better models of malaria incidence, incorporating a range of variables: environment, demographics, land use, and public policy (i.e., disease control efforts in the historic past). To this, we add any observed changes that may occur in the genetic structure of the malaria virus itself. The more exciting future prospect lies in combining these data and correlating the historic response to malaria with the way the virus then “reacts” (if at all) to human policy.

In the future, the data generated from the present study could be used to constrain, test, and improve existing mosquito propagation and activity models. Using the recorded incidences and death rates for malarial infection and indications of malaria on the skeletons correlated with the climate record, we can calibrate predictive models in order to assess malaria response to fluctuations in climate. This would allow better forecasting of disease transmission in response to mosquito carrying capacity within the environment. In the local case, although Mauritius has eliminated malaria, it is still actively involved in surveillance measures and maintaining its disease-free status. Furthermore, these types of climate models provide evidence of the activity of mosquitoes, which carry other diseases. A serious outbreak of chikungunya (a viral infection that results in sudden fever and joint pain and is transmitted by mosquitoes) in 2005–6 caused major concerns for both the local population and travellers. Thus, these data would be instrumental in improving management of mosquitoes and therefore have utility for the control of a range of diseases, not just malaria. On a wider regional level, these models can be easily scaled for application to continental landmasses.
This could lead to the development of landscape-based, low-tech, and ecologically sensitive control measures that can be implemented to mitigate spread during periods of increased mosquito activity.42

CONCLUSION

The preceding illustrates the kinds of projects that are open to historical archaeologists in the region, made possible through integrative approaches, and readily applicable to other settings both in the Indian Ocean, but also more widely where diseases such as malaria have had a major impact. The approach outlined here—correlating climate data and osteological analysis with historically documented cases of malaria outbreaks and potentially the impacts that environmental and human agency factors had on the virus’s DNA—could provide a significant body of data for controlling malaria in the future. Recent research has shown that current models, particularly for temperature, need better calibration.43 The data that this project proposes to collect, incorporating temperature, rainfall, and land cover change evidence, in effect mining archaeological and historical sources,44 provide a much more comprehensive assembly of climate proxy data than has been studied, or even attempted, to date. This broad array of climate variables has the potential to be much more informative than current models that aim to predict the spread of mosquitoes or their biting activity (two major factors in determining rates of transmission). Better modeling, and indeed, the possible contributions to vaccine development, become even more urgent when we consider the likelihood that malaria transmission, strongly correlated to temperature, will shift and potentially reemerge in areas where it had been eliminated as temperatures rise with global warming. Thus, beyond the specific benefits for Mauritius, this study has major potential to be applied to other islands in the Indian Ocean basin, Atlantic, and Pacific, as well as scaled up for larger continental landmasses.

History, Archaeology, and Disease

Epidemics are like large signposts from which the statesman of stature can read that a disturbance has occurred in the development of his nation—which not even careless politics can afford to overlook.

—Rudolf Virchow, 184845
Although the significant potential for disease control is tantalizing, the underlying strength of the project outlined here is in the role that archaeology and history can play in helping understand how disease trajectories functioned, as well as making that evidence applicable to a modern global community by improving current modeling or contributing to prophylaxis. History, and specifically political history and the history of science, has been instrumental in explaining the consequences of recent pandemics on demography and socioeconomic life and linking those developments to issues of globalization. Thus, we see the underlying impact that disease actually had on society. In addition to a record of the reduction in population size for a given territory, it is also possible to glean an understanding of the response to disease by administrative powers and of how the specific case nests within a regional zone.46

For archaeologists, this serves as an important theoretical point of departure, principally through analogy, providing the political framing but also chronological backdrop for the expansion of quarantine stations and cemeteries, for example. However, the methodological component is critical and needs to be considered from the ground up. For our case, we have developed new ways of sampling bone: rather than waiting for the osteologist to study the bones prior to sending bone and tooth samples for DNA assay, we extract bone tissue from the skeleton as soon as it is exposed, bagging these and placing them in a freezer as soon as possible after removal from the ground. This not only reduces the risk of contamination, but also potentially increases the likelihood of capturing DNA, which is damaged the longer it is exposed to sunlight and other environmental conditions. Bone tissue is removed from areas of the skeleton that would be highly vascularized during life. This is important, as the traditional skeletal elements favored for recovery of human DNA are the teeth. However, malarial DNA is likely to occur in areas of the body with high red blood cell counts. While it is highly unlikely that we will ever be able to recover cells that contain hemoglobin47 given the rapid rate of osteological deterioration in the tropical climate of Mauritius, by sourcing bone from areas of the skeleton that in life would have had a high blood flow,48 we maximize the likelihood of recovering Plasmodium DNA. Finally, contamination is a serious issue, particularly as we are also interested in and actively studying the demographic origins of those interred. To deal with this, only one individual undertakes sampling following our protocol, and all individuals involved
in excavation can be screened so that their DNA can be cross-referenced with and removed from our ancient human DNA samples. Underlying these new methodological techniques and approaches is a theoretical model that dictates our practice: we are effectively excavating with an underlying premise that we may use recovered material for future analytical procedures not currently being undertaken; in effect, we are future-proofing our sampling strategy.

The new technical approaches, climate data, and molecular techniques are focused on gaining a much better understanding of malaria. The significant potential for understanding how the disease changed in an environment where it was epidemic, then eliminated, is based on the more holistic outlook that archaeohistoric research promotes, an analytical view of the world from an encompassing vantage point.

Disease control and health provision stand to benefit a great deal when we integrate medical perspectives with those from archaeohistory. Particularly for conditions like malaria (and despite the obvious indiscriminate nature of infection), understanding social aspects such as hierarchy is critical as these underpin exposure to the disease, and more importantly, the likelihood of surviving it. More specifically, by correlating osteological evidence with the molecular assessment of the malaria virus, we can explore and gain a better understanding of immune response to the disease in those infected.

At a local level, emphasizing the social context is particularly valid, as this offers fertile ground for integrating the types of data available from archaeology and history. The way in which sexually transmitted diseases, particularly syphilis, were viewed in India during the period of European colonization offers an insightful example of the manner in which social attitude impacted on how populations likely conceptualized certain diseases or, more precisely in this case, types of infections. Syphilis was considered a European import, coming in with the Portuguese; however, a less virulent local form was evidently well established, as noted by the complexions of locals, showing pocks and other skin lesions. In contrast to the European view of syphilis and other sexually transmitted diseases, the local form was not seen as an indicator of a lack of morality. This issue, as well as the role played by Western psychology in attempts to explain sexuality, disease, and morality, is explored in much greater detail within an African context.49

Moving to a wider regional level, it is possible to explore the ways in which disease influenced population, both demographically as well
as who actually travelled to the colonies from European states (i.e., the specific demographic that migrated), and the system that pushed rather than pulled them to these locations. This was true for the elite as well as the soldier, and effectively rests on the way in which diseases created environments that would likely kill someone new to the region, not to mention the likelihood of contracting a disease while shipboard.\textsuperscript{50} It has been estimated that some twenty-five thousand Portuguese soldiers died in Goa during the thirty-year period from 1604–34, mainly from diseases such as cholera, but also from syphilis. Of fifty governors who made it to India, twenty-two died during their term or on the voyage home.\textsuperscript{51} As illustrated in the Caribbean, disease had the power to transform tropical sanctuaries (with disease environs that were similar if not actually better for one’s health than Europe) into epidemic hotspots. This in turn resulted in important economic and political responses, not to mention propaganda, that were replicated in numerous settings. One particularly insightful example of this rests on the connection between African diseases and African “disease resistance,” providing both newly imported slaves and local Creole populations immunity to diseases such as malaria (or at least immunity to the harshest symptoms of such). The recognition of this resulted in the British using Africans in military campaigns, despite fears of arming slaves. This same model was adopted in high-risk malarial regions in Arabian wadis, where African workers were employed on date plantations in complete contrast to the usual system of agricultural slavery in Arabia more generally.\textsuperscript{52} Not only does this background reveal which populations were more likely to fall victim of specific diseases, but it should prompt us to view the skeletal repository from excavations, at least in part, as a record of these political and economic transitions.

Finally, at the global level, the fact that malaria remains a major killer and that the spread of the disease is strongly correlated with temperature and land cover change should alert us to the risks we are potentially exposing ourselves to with a warming climate and the devastating implications that this may have for the poorest members of the world’s community. It is for precisely this reason that we need to better understand cultural and social outcomes, and indeed drivers, for disease transmission. Ultimately, we need to think about disease in new ways, and investigate the way that disease changes as civilization changes, and in response to major society-level transformations in population structure and culture.
NOTES

2. The phrase “climate proxy datasets” refers to a range of evidence that paleoclimatologists gather from natural repositories of past climate variables. These reservoirs include tree rings, ice cores, ocean sediment cores, and, as in this case, coral cores. Coral, which builds its skeleton from calcium carbonate that in turn traps oxygen isotopes, provides a record of sea-surface temperature, along with other parameters.

3. For example, for archaeological research, see: Boivin et al., “East Africa and Madagascar”; Fuller et al., “Across the Indian Ocean”; and Horton, “Artisans, Communities and Commodities.” For historical examples, see: Machado, *Ocean of Trade*; and Sheriff and Ho, *The Indian Ocean*.


10. González-Bernal et al., “Cane Toads on Cowpats.”

11. Murphy et al., “Invasive Feral Pigs.”


13. M. N. Pearson, “First Contacts between Indian and European Medical Systems: Goa in the Sixteenth Century,” in *Warm Climates and
Western Medicines: The Emergence of Tropical Medicine, 1500–1900, ed. David Arnold (Atlanta: Rodopi, 1996), 20–42.


23. For the Atlantic, see A. Pearson et al., *Infernal Traffic*. From the historical perspective, see: Arnold, “Indian Ocean as a Disease Basin,” for a detailed historical overview for the Indian Ocean; and Boodhoo, *Health, Disease and Indian Immigrants*, for Mauritius specifically. See Rohan Deb Roy, “Quinine, Mosquitoes and Empire: Reassembling Malaria in British India, 1890–1910,” *South Asian History and Culture* 4, no. 1 (2013): 65–86, for a detailed study of the way knowledge of malaria was assembled and employed in colonial India.

24. Environmental archaeology is the branch of archaeology dealing specifically with the methods and approaches focused on human-environmental interactions. See Keith Wilkinson and Chris Stevens, *Environmental Archaeology: Approaches, Techniques and Applications* (Gloucester, UK: Tempus, 2003) for an overview, and pp. 45–135 for a discussion on paleoenvironments.


27. Sea surface temperature is investigated using stable isotopic analyses of oxygen, as well as x-ray synchrotron polymorph partitioning, a process that involves analysis of powdered coral under high-energy lasers. Fertilizer use is assessed through analysis of the organic nitrogen isotope found within the coral skeleton. Sediment runoff is traced using barium:calcium ratios, either from within the coral skeleton or by direct measurement of included sediment particles.

28. Erik J. de Boer et al., “Rapid Succession of Plant Associations on the Small Ocean Island of Mauritius at the Onset of the Holocene,” *Quaternary Science Reviews* 68 (2013): 114–25; de Boer et al., “Multi-proxy Reconstruction”; and de Boer et al., “Climate Variability in the SW Indian Ocean from an 8000-Yr Long Multi-proxy Record in the Mauritian Lowlands Shows a Middle to Late Holocene Shift from Negative IOD-State
to ENSO-State,” *Quaternary Science Reviews* 86 (2014): 175–89. See also Lucien F. Montaggioni and Gérard Faure, “Response of Reef Coral Communities to Sea-Level Rise: A Holocene Model from Mauritius (Western Indian Ocean),” *Sedimentology* 44 (1997): 1053–70, for more specific details of the coastal zone.

29. These tests are being undertaken at the GeoGenetics Laboratories in Copenhagen for extraction of *Plasmodium falciparum* DNA. Demographic assessments based on ancient human DNA of the past population are underway in the Bustamante Laboratory, Stanford University. Climate proxy data are also being generated, currently based on core samples previously extracted from Mauritius by Jens Zinke, University of Western Australia, and the Mauritius Oceanographic Institute, with additional samples tentatively scheduled to be cored during the summer of 2016. For our case specifically, instrumental records have been mined from the records of the Mauritius Meteorological Service (which retains climate data, often derived from recording stations established on plantations with the intention of servicing the sugar industry, spanning back to 1862) by Caroline Staub, University of Florida. Supplementary data are available from stations that are maintained by the World Meteorological Organization. Climate proxy data are also available, as various datasets have been published on Mauritius based on terrestrial coring undertaken on volcanic crater sites, which provide a baseline detailing the island’s ecosystem prior to settlement.


38. The presence of periodic fever and other indicators of malaria affecting large numbers of people can be taken as evidence of malaria, at least anecdotally, which should alert us to the possibility that we are dealing with a period in which the disease reached epidemic proportions.


43. Mordecai et al., “Optimal Temperature.”

44. We can consider coral data to be an archaeological dataset in terms of chronological context.


46. Arnold, *Colonizing the Body*.

47. Because of the tropical climate, the bone preservation in Mauritius makes it unlikely that hemozoin (a by-product of blood digestion by parasitic organisms, such as malaria) could be preserved. However, see Setzer, “Malaria Detection,” for a description of the possible detection of this by-product of hematophagous activity in archaeological bone.
48. As opposed to teeth, which are commonly used for capturing human DNA but have only a small amount of blood that travels into them, therefore reducing the likelihood of finding traceable residues of *Plasmodium falciparum* DNA.

49. See M. Pearson, “First Contacts,” 23, for India and Goa specifically; and Vaughan, *Curing Their Ills*, for Africa.

50. For an account of the high death toll of diseases such as smallpox and scurvy on ships, refer to R. Allen, *European Slave Trading*, 80–81.


52. For impacts on different populations that colonized and discussion on the speed with which colonial settings became disease hotspots, see M. Pearson, “First Contacts,” 24–25; and Kiple and Ornelas, “Race, War and Tropical Medicine,” 71. For the use of slaves in the British military, see in Kiple and Ornelas, “Race, War and Tropical Medicine,” 76. For Africans in Arabian wadis, see Benjamin Reilly, “Mutawalladeen and Malaria: African Slavery in Arabian Wadis,” *Journal of Social History* 47, no. 4 (2014): 878–96. For political responses to disease, see: Arnold, *Colonizing the Body*, for India; Schneider, “Smallpox in Africa,” for smallpox in Africa and the use of colonial propaganda; and Watts, “Rapid Change to Stasis,” for an assessment of essential transformations in the methods used for disease prevention and the political underpinnings for these moves. Finally, see Hamoudi and Sachs, “Changing Global Distribution,” 10 (for malaria); and Banthia and Dyson, “Smallpox,” 649, for examples of lessons learned from successful disease control measures.