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Irrigation and Infection: A Bioethnography of Schistosomiasis in Ancient Nubia

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Doctor of Philosophy

Anthropology

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Irrigation and Infection: A Bioethnography of Schistosomiasis in Ancient Nubia

By

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M.A., Emory University, 2008
B.S., Kansas State University, 2005

Advisor: George J. Armelagos, Ph.D.

An abstract of
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James T. Laney School of Graduate Studies of Emory University
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Abstract

Irrigation and Infection: A Bioethnography of Schistosomiasis in Ancient Nubia
By Amber Campbell Hibbs

Irrigation use can significantly influence the epidemiology of schistosomiasis. The infection is transmitted by aquatic snails, and canal irrigation compounds exposure risk by increasing snail habitat and time spent in contact with contaminated water. In modern populations schistosomiasis has been deemed “the most important water-based disease from a global public-health perspective,” yet little is known about the impact of schistosomiasis on populations living in the past.

To better understand the influence of different forms of irrigation on the burden of schistosomiasis disease in ancient populations, an enzyme-linked immunosorbent assay (ELISA) was used to detect antigens specific to *Schistosoma mansoni* in desiccated tissue samples from two Nubian populations, one that used saqia canal irrigation (Wadi Halfa, N=46) and one that used annual flooding (Kulubnarti, N=191). Based on evidence regarding the impact of canal irrigation on schistosomiasis prevalence and transmission in modern populations, the prevalence of infection was predicted to be higher in Wadi Halfa than Kulubnarti, peak infection intensity was predicted to occur at an earlier age and at a higher level within the Wadi Halfa population and the prevalence of schistosomiasis to be higher in males than females in both populations.

The prevalence of *S. mansoni* was greater in the Wadi Halfa population (26.1%) than at Kulubnarti (9.4%)(p=0.002). However, peak prevalence of infection did not occur in a younger age category within the Wadi Halfa population; prevalence of infection peaked at 66.7% in the mature adult age group (46+ years) in the Wadi Halfa population and at16% in the later child age group (6-10 years) in the Kulubnarti population. There were no statistically significant differences in prevalence between males and females of either population.

I also examined the influence of irrigation use and schistosomiasis on the productive capacity of the populations. Using disability estimates from modern populations, the expected reduction in the productive capacity of each population was calculated. The population at Wadi Halfa experienced considerably greater disability of the population due to a higher prevalence of infection; this required a five times greater increase in the productivity of the uninfected population to offset the reduced productivity of infected members.

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John Kingston instilled a sense of confidence that the more you find out the more you will be able to recognize the gaps in your knowledge. Those gaps are areas not shortcomings, but areas for future research. He inspires me to look at my research from a different perspective and has always come through for me when it really mattered.

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Chapter 1: Introduction

Schistosomiasis is an ancient parasite which continues to plague humanity. More than 200 million people are estimated to be currently infected with schistosomiasis (van der Werf et al., 2003; Vennervald and Dunne, 2004); 779 million people are estimated to be at risk of infection (Steinmann et al., 2006). These parasites contribute significantly to morbidity and mortality in endemic regions along the Nile (Vennervald and Dunne, 2004). Archaeological and ethnohistorical data support the presence of schistosomiasis in the Nile Valley throughout the last 5000 years (Contis and David, 1996; David, 2000). Although schistosomiasis has been extensively studied in mummified remains through calcified ova (Ruffer, 1921), immunological testing (Deelder et al., 1990), and ancient DNA extraction incorporated with other techniques (Lambert-Zazulak et al., 2003), these studies have focused attention on the diagnosis of schistosomiasis rather than the cultural, social, and political contexts of infection and transmission.

Although a purely epidemiologic analysis of schistosomiasis in ancient Nubian populations would provide new information, diseases experienced by human populations are not sufficiently explained when studied as "things in themselves" (Brown et al., 1996, p 183). Bioarchaeology as an anthropological field of study must recognize that all aspects of human disease including exposure, transmission, and illness occur within ecological and social contexts. Humans make decisions about the way they interact with the physical environment and have the ability to substantially alter the local ecology. Their actions influence their exposure disease.

As parasitic infection is dependent upon the interaction between the parasite, host, and the environment and the presence of specific parasitic infections can be used to infer information regarding human behavior and the environmental context at archaeological sites (Bouchet et al., 2003). In order for a parasitic infection to be transmitted within a population, the ecological conditions necessary for the survival of definitive as well as intermediate hosts and vector species must occur. Irrigation use leads to fundamental changes in the local ecology that influence the prevalence of schistosomiasis. Canal irrigation compounds the risk of exposure by increasing the available habitat for the aquatic snails necessary for transmission. Studies have shown a clear link between contact with canal waters and exposure to infection in modern Egyptian populations (Abdel-Wahab et al., 2000) and throughout Africa (Steinmann et al., 2006). Meta-analysis of numerous African schistosomiasis studies have produced risk ratios for individuals living in irrigation schemes range as high as 23.0 for schistosomiasis mansoni, the intestinal form of the infection (Steinmann et al., 2006).

Much of the bioarchaeological information produced from the Wadi Halfa and Kulubnarti, two of the most extensively studied populations in bioarchaeology, has been suggestive of schistosomiasis infection, although intensive research into the epidemiology of schistosomiasis in these populations had not, as yet, been conducted. The purpose of this research was to develop a community level epidemiologic profile of schistosomiasis infection within the populations of Wadi Halfa and Kulubnarti and determine how the use of saqia irrigation influenced the risk of exposure to infection within them. I have framed this dissertation within a model of a culturally mediated environment of exposure. Chapter two discusses the need for a bioarchaeoethnographic approach to paleopathology for bioarchaeology to be anthropology. This approach utilizes a general stress perspective and recognizes culture as part of the environment in which past peoples lived and the individuals under study as active agents who both shape and are shaped by their environments. Within this context, disease can be examined in terms of social relations which structure individual exposure to pathogens and access to resources needed to cope with infection. Chapter three provides basic information on the schistosome life cycle, the transmission of infection and pathology associated with schistosomiasis as well as a review of previous paleoparasitological research on the disease. Chapter four provides an overview of political, economic, and climatic conditions in the Ballana and Christian periods at Wadi Halfa and Kulubnarti. These conditions provide the context for the analysis of irrigation use and schistosomiasis exposure within these populations. Chapter five reviews evidence from previous bioarchaeological studies conducted within the Wadi Halfa and Kulubnarti populations and provides general information on the health of the populations. Chapter six outlines the research hypotheses, sample selection criteria, laboratory techniques, and data collection and analysis methods used to test the research hypotheses. Chapter seven provides the basic epidemiological results of the research with possible explanations for epidemiological patterns observed. Chapter eight explores the potential influence of schistosomiasis on the productive capacities of the populations at Wadi Halfa and Kulubnarti and discusses the potential economic impact of schistosomiasis in these populations based on evidence of productivity loss in modern populations. Chapter nine integrates the information provided in other chapters to examine the effectiveness of saqia irrigation as a cultural buffering system in the populations of Wadi Halfa and Kulubnarti.

Chapter 2: Bioarchaeology and Bioethnography

> "Seeing bioarchaeology as anthropology profoundly affects the problems that capture one's interest, the questions that one sees to answer, and the methods one uses to resolve them"(Armelagos, 2003, p 27).

Bioarchaeology grew out of the application of an anthropological perspective to skeletal biology and paleopathology. It combines the scientific principles of the "new physical anthropology" and processual archaeology to examine the biocultural process of adaptation to the environment (Armelagos, 2003). Rather than simply attempting to describe in greater and greater detail the temporal and geographic distribution of human disease, bioarchaeology examines health within cultural contexts from a processual perspective. Armelagos (2003) identified the key advances of bioarchaeology, which distinguish it from paleopathology, as the incorporation of population perspective, the recognition of multiple indicators of stress, the incorporation of a general stress perspective, and the recognition of culture as a component of the environment.

Paleoepidemiology: A Population Perspective on Paleopathology

Traditionally, paleopathology focused on the diagnosis of individual pathologies without regard for their pattern within a population beyond their presence or absence. As a result, research questions commonly focused on the geographic and temporal distribution of disease in the past (Ubelaker, 1996). In contrast, paleoepidemiology applies a population based epidemiological approach to the study of disease in the past. E. A. Hooton's *The Indians of Pecos Pueblo* (1930) is generally acknowledged as the first use of a population perspective in paleopathology and, by extension, as the first evidence of bioarchaeological research (Van Gerven et al., 1990). Hooton introduced paleoepidemiological methodology founded in quantitative analysis combining paleopathological and paleodemographic data and relating this information to the culture and ecology of the population (Goodman and Martin, 2002; Armelagos, 2003). Despite this early recognition of the importance of examining the pattern of disease in a population, the term "paleoepidemiology" was not commonly used until much later (Angel, 1966; Roney, 1966).

The need for population based study of ancient disease is a common theme throughout the paleopathological and bioarchaeological literature and studies incorporating a variety of methodological approaches to the study of pathology within cultural contexts have flourished (Buikstra and Cook, 1980). These analyses have added greatly to our knowledge of the influence of ecological, socio-cultural, and political economic contexts on the health of ancient populations, many of them focusing on the shift from foraging to agricultural production (Cohen and Armelagos, 1984; Clark, 1988; Jurmain, 1990). More recently, large scale investigations of diachronic trends in population health and well being have been undertaken through pathological investigations (Steckel and Rose, 2002; Cohen and Crane-Kramer, 2007).

Paleoepidemiological analyses must be conducted in a manner which recognizes the limitations of working with mortuary collections which are inherently distinct from the living populations from which they are derived (Wood et al., 1992; Mendonça de Souza et al., 2003; Waldron, 2007). The degree to which a skeletal population accurately represents the living population from which it is taken has a direct and significant influence on the usefulness of the bioarchaeological information which can be derived from it. Some aspects of skeletal populations lead to inherent bias. Cemetery populations are collected over an extended period and do not represent a single cohort of once living individuals or even individuals living at the same time (Angel 1969; Larsen 1997); thus the prevalence of a condition may have varied in ways which are unknown and cannot be identified through time. Additional bias resulting from differential mortality, exclusion of some individuals from communal burial locations, and taphonomic processes complicate matters further. Interpretations of epidemiologic data from cemetery collections which are not preserved well enough for demographic data to be obtained or have been procured through less than thorough archaeological excavations are perilous at best (Meindl and Russell 1998). If one cannot be sure the sample population reflects at the very least a representative sample of the complete population of individuals buried at the site, the epidemiologic data obtained from that sample may not be representative of the population buried there and should not be extrapolated to the total burial population nor the population of living individuals from which it was derived. Further, archaeological populations are generally small and often do not achieve statistical significance due to small sample sizes (Mendonça de Souza et al., 2003). While this may make the results of paleoepidemiological research less than conclusive, bioculturally significant explanations for the presence of differences in health between and within populations can help.

While population level analysis is essential, we should not be content to have achieved a general understanding of a population's health without attempting to better understand how individuals within that population lived. In the same way that Boas questioned the ability of the average to represent the "norm" because it is derived from the sum of deviations (Armelagos and van Gerven, 2003, p 55), we recognize that the "health" of the population is only an abstract concept; health and disease are experienced by individuals over a lifetime. Population health cannot represent the biological experience of each member of a population.

General Stress Perspective: Utilizing Multiple Indicators of Stress

Skeletal remains are the cumulative result of biological experience throughout the life history of the individual from conception to death, a "physical history of the individual" (Krogman, 1935, p 103). Individuals experience multiple interacting stressors, sources of physiological disruption, throughout their lives which may cause physiological disruption severe enough to leave discernable evidence on skeletal remains and have real consequences for individuals and populations (Goodman and Martin, 2002). Through thorough examination a bioarchaeologist can retrieve information about diet, disease, and injury over the entire lifespan of an individual. Non-specific skeletal markers of physiologic stress have been utilized to interpret the influence of poor diet, infectious and parasitic disease, and activity in the health of ancient populations. Biochemical (isotopic) investigations of diet have been utilized to contextualize non-specific stress markers (Cook and Powell, 2006).

A multitude of pathological conditions leave evidence on the skeleton. However, bone has a limited number of possible responses to insult and most pathologies leave nonspecific rather than easily diagnosed lesions. As a result, attempting to identify and analyze the impact of a single disease or stressor is difficult, if not impossible, in many cases. Fortunately, the severity, duration, and temporal course of physiological disruptions can tell us a great deal about the lived experience of health of individuals without diagnosis of the etiologic agent (Goodman and Martin, 2002) although identification of the causes of pathology is a valid research goal. These stress indicators can be classified into at least seven major categories: 1) subadult growth and adult stature, 2) linear enamel hypoplasias, 3) porotic hyperostosis and anemia, 4) infectious disease, 5) trauma, 6) osteoarthritis and degenerative joint disease, and 7) dental caries and tooth loss. Goodman and Martin (2002) provide an overview of each. Many of these markers indicate survival of the original physiologic disruption, which Wood and colleagues (1992) argue makes the interpretation of health in past populations from paleopathological evidence less than straightforward (i.e. populations which show little skeletal evidence of pathology may simply have been too frail to survive long enough to accrue skeletal indications of ill health). However, it is possible to differentiate between populations experiencing stress resulting in mortality prior to developing skeletal lesions and those not experiencing stress by examining mortality profiles of those with and without lesions (Goodman, 1993). If members of one of the populations are dying without surviving long enough to develop skeletal indicators of ill health, but another is survives the same stressor long enough to develop these indicators before death, the populations will differ in their mortality profiles with the first population experiencing earlier mortality. The investigation of multiple indicators of health and contextualization of pathological information improves the ability of bioarchaeological studies to adequately manage the concerns raised by Wood and colleagues (Goodman, 1993; Cohen, 1997).

A general stress perspective derived from multiple indicators of stress provides a picture of health over the life course and can allow us to use strong inference to choose between alternate hypotheses that may result from the study of a single health indicator. This improves our ability to identify patterns of stress not readily apparent when studying individual disease diagnoses or single stress indicators (Armelagos, 2003). For example, Van Gerven and colleagues (1995) incorporated data on cribra orbitalia, dental enamel hypoplasia, and mortality to indentify a period of peak physiologic stress and risk of mortality in childhood.

The Western Hemisphere Health Index (Steckel and Rose, 2002) incorporates evidence regarding multiple indicators of stress to facilitate cross cultural and time comparisons of health in past populations. The use of a single index of health, while it may facilitate comparison of health between populations, forces such analyses to consider health in a single dimension despite its obvious multidimensional nature. As there is little correlation between different elements used in the construction of the index (Steckel et al., 2002), populations with the same value for the health index may have been experiencing very different patterns of health and morbidity which are obscured by the use of a single index. Patterns of individual indicators must also be examined within the context of index measures to elucidate the sources of variation or lack thereof in these measures.

Even multidimensional measures which give a greater breadth of information can still only provide a vague understanding of the population if they do not provide a way of analyzing the lived experiences of individuals within those populations. Examining the health of individuals within epidemiological context of their populations can provide insights needed contextualize health at population level. Brothwell (1996) suggests "the degree of life change" associated with physical conditions identified through paleopathology should be examined in order to better understand how the stress indicators we identify translate into the lived experience of the individual in terms of the degree of disability and pain associated with possible causes. When individual assessments are compiled at the population level, the impact of disease "emerges" (Ubelaker, 2003). The impact of the diseases we study on the lives of past peoples is at the heart of bioarchaeology as anthropology. The diagnosis of disease or calculation of its prevalence within a population without examining the influence of human action on the patterns of disease seen or the impact those diseases would have had on the population ignores the humanity of past peoples.

Individual experiences of health can also provide additional information about the ability and willingness of the population to provide support to disabled individuals. At Wadi Halfa, a quadriplegic individual with hydrocephaly lived into their tenth year (Armelagos, 1969). The lifespan of this individual given the impairment the condition would have caused is a clear indication of the ability and willingness of the household and/or community to allocate resources and labor to the care of the individual despite their disablement. This care is even more significant within the context of chronic physiologic stress and poor childhood health most likely resulting from resource scarcity within the population.

Cultural Buffering and Political-Economic Perspectives

The severity and duration of the stress as evidenced by skeletal remains reflects the adequacy of the cultural buffering system and individual resistance resources to cope with environmental constraints and stressors (Goodman and Martin, 2002, p 18). Culture plays a major role in shaping patterns of morbidity and mortality within populations both by shaping how people interact with the environment and shaping the environment in which they live. Archaeological and historical evidence demonstrate the influence, both positive and negative, of environmental changes caused by human behavior on the experience of disease (Brown et al., 1996, p 184). Bioarchaeological analysis can assess the effectiveness of cultural systems as stress buffers, as well as the relative adaptiveness of different cultural systems by identifying instances in which cultural buffering was insufficient as evidenced by skeletal stress (Goodman and Armelagos, 1988).

Goodman and colleagues (1984) developed an etiological model incorporating the causes and consequences of physiological disruption or stress in past populations to examine the adaptive process of interaction between cultural systems and the environment as they relate to health. This model was revised to incorporate the functional implications of stress to the individual and population and feedbacks within the model (Goodman and Armelagos, 1988; Martin et al., 1991; Larsen, 1997). A diagram of the model is provided in Figure 1. In this model, physiological disruption is a product of three factors: environmental constraints, cultural systems, and host resistance. The environment provides material resources needed for food, shelter, and clothing, constrains their availability, and can provide additional stressors such as exposure to harsh physical conditions and disease organisms. Environmental constraints are not entirely natural; they result from an ongoing process of adaptation to the natural environment within a social context. Humans adapt to their environments bioculturally, developing new biological and cultural characteristics in response to stresses imposed. Cultural systems mediate the interaction of individuals with the environment. Through these systems, humans extract resources needed to buffer stress from the environment and allocate those resources through social interactions between individuals and communities. These systems can buffer the stresses imposed by the environment. Even cultural behaviors which are not expressly for disease prevention may serve to prevent disease (Brown et al., 1996). Cultural systems can, however, also generate stressors for populations and individuals within them (Goodman and Armelagos, 1989; Goodman and Martin, 2002). Host resistance factors modulate the physiological disruption experienced by individuals. If this disruption is severe enough, it may result in a skeletal indication of the stress experienced. The cumulative impact of individual physiological stress on the population in turn mediates environmental constraints and the culturally induced stressors.

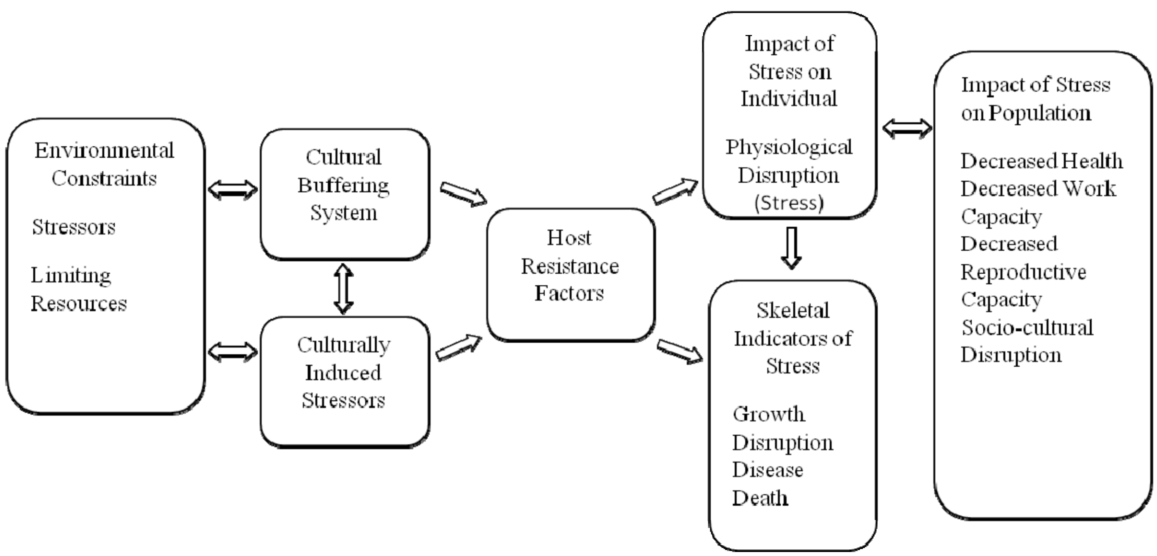

Figure 1: Cultural Buffering System Model based on (Goodman and Armelagos, 1989)

Historical Context: Ecological & Social

This model must be contextualized; the cultural buffering systems available are linked to the historical and political economic context, local social interactions and global processes. Environmental constraints and stressors of both natural and of human original vary over time as well as the context of cultural buffering. An ecological approach to disease must recognize that the environment (including disease organisms) is naturally and culturally constructed, and thus partly the result of human action (Brown et al., 1996; Baer et al., 1997) and that factors such as migration, environmental shifts, changes in land use, socioeconomic factors, technological aspects, medical treatment, demographic factors, population vulnerability, formation of new habitats and microbial evolution influenced the health of populations who lived in the past (Ubelaker, 2003).

Brown and colleagues (1996, p 188) make a distinction between cultural and political ecology relating them to different levels of analysis. They identify cultural ecology as the study of the relationships between individuals and groups interacting with other species in the environment (I would also add relationships directly with the environment) and political ecology as the study of the relationships between humans which influence the environment through "population movements, land use, or differential access to resources." The perspective cultural ecology provides can help to clarify our understanding of not just those aspects of culture which appear directly dependent upon the local ecology like subsistence strategies and migration patterns, but also those which do not seem directly linked to the environment. A political ecological perspective examines interaction between local, ecological determinants and the more distant formulations of fields of power (Goodman et al., 1995, pp 7-8). It should also recognize the importance of human agency in the transformation of the environment (Baer et al., 1997). While these aspects can be studied separately, they are not independent of one another.

Host Resistance

The distribution of any infection or physiological disruption within a population is neither constant nor random and is influenced by host resistance factors including both the inherent physiological characteristics of individuals as well as their position within the cultural system which influences exposure to as well as access to the resources necessary to cope with these disturbances.

Stressors and resources vary to some degree between individuals and between periods within the life of a single individual. Each individual within a population lives within their own "microenvironment" of exposure to stress and resources needed to cope with stress (Goodman, 1998, p 163). The microenvironment is intricately bound up in larger social processes and ecological/political-economic conditions which influence the cultural buffering systems employed and their placement within them. Social relations structure individual access to resources and exposure to pathogens and individuals are active agents who both shape and are shaped by their environments through these social relations. Culture influences behavior which can make transmission more or less likely and thus the exposure risks experienced by individuals and the population; patterns of infection within populations commonly reflect behavioral patterns (Brown et al., 1996). Social pluralism based on ethnic, linguistic, or religious identities can lead to inequality with potential health disparities; analyses of health in the past can help illuminate situations where inequality is most likely to lead to health degradation (Knudson and Stojanowski, 2008).

Previous stress experience may influence the ability of individuals to respond to future stress. For example, linear enamel hypoplasias have repeatedly been shown to be associated with reduced longevity (Armelagos et al., 2009). Goodman and Armelagos

(1988) suggest three mechanisms for the correlation between childhood stress and decreased survival; wear and tear, damaged goods, and differential frailty. The “wear and tear” hypothesis suggests that individuals who experience physiological insult in childhood may continue to experience such insults throughout life leading to reduced survival. In effect, these individuals experience harsher conditions than others in the population and show increased evidence of physiologic perturbation and earlier mortality as a result. The "damaged goods" hypothesis suggests that early physiologic stress directly and negatively influences the ability of the individual to cope with future stress and is supported by evidence from modern populations as well as archaeological ones (Armelagos et al., 2009). The “differential frailty” hypothesis suggests that some individuals within a population are inherently less able to cope with stress than other individuals. A lifelong pattern greater frailty when exposed to physiological perturbations may result in both increased evidence of such disruptions and earlier mortality. Regardless of the manner in which stress negatively influences future health, it is clear that those who experience physiologic distress in childhood fare worse than their counterparts in later health.

Bioarchaeology as Anthropology

Bioarchaeology develops nuanced understandings of lived experience of health and illness in the past under a variety of circumstances. By utilizing a population perspective to study health and disease in the past from physical remains including physiological stress, pathology, consumption and activity patterns, injury and violence, as well as long term trends in population well being researchers can obtain a great deal of information about past societies which is not immediately apparent from other archaeological information and better conceptualize the lives of people living in the past (Larsen, 1997, 2002). The meaning of evidence of physiologic stress and disease in the past “does not lie in the diagnosis of individual cases but, rather, in their pattern by age, sex, and environmental (cultural and natural) setting" (Armelagos and van Gerven, 2003, p 59), yet the health of individuals within a population context can provide important information about the social worlds in which they experienced illness. How the experiences of individuals compare with others in their population can shed light on differential experiences of health in the past.

Bioarchaeology as anthropology must recognize that human biologies are inevitably linked to the local social and political economic circumstances which are in turn linked to more global contexts. We cannot rationally ignore the contexts within which biological realities occur (Goodman and Leatherman, 1998). If we do not recognize the influence of human action, social relations and historical circumstances, bioarchaeology is not anthropology. Rather than simply identifying who is ill or undernourished and then naturalizing the situation, as anthropologists we must to seek to “to go beyond concerns with proximate cause of illness to examination of the broader and underlying social, economic, and political factors that determine patterns of nutrition, health, and mortality" (Goodman and Martin, 2002, p 18) and identify the underlying reasons behind these biological facts (Goodman and Leatherman, 1998).

Bioarchaeologists must be concerned with how resources are allocated when they become constrained, why they are constrained, and what factors of an individual’s social reality put them at greater risk of infection and disease than others? Bioarchaeology can provide insights that are essential for understanding how culture has shaped the natural and social environment in which individuals live and how that shaping influences the experience of health and illness.

Chapter 3: Schistosomiasis

The influence of irrigation use on the epidemiology of schistosomiasis and the health of ancient populations is dependent the schistosome life cycle, the transmission of infection, and the pathology experienced by infected individuals. Kloos and David (2002) suggest the coevolution of schistosome, snail, and hominids in East Africa with endemic infection by the early Neolithic and Paleolithic in some areas. They propose that infection was spread throughout Egypt and the Middle East as people congregated in the Nile Valley and traveled between communities for trading purposes. Populations of Bulinus (intermediate host of *S. haematobium*) and *Biomphalaria* (intermediate host of *S. mansoni*) snails flourished in the warm calm waters of the fresh water lakes and marshes in the Sahara during wet periods and were brought with settlers to the Nile Valley in drier times (Kloos and David, 2002). Increases in human population density as settlers moved into the fertile Nile Valley from the drying lands of the Sahara raised water contamination rates and promoted infection through increased transmission. The implementation of irrigation systems with improved agriculture further exacerbated the problem by bringing with it a further increase in human population (and thus contamination) and augmenting habitats for the schistosomes' snail hosts. *Biomphalaria* and *Bulinus* snails adapted readily to manmade water sources, the former more so than the latter as *Biomphalaria* snails are more capable of tolerating low oxygen and high pollution levels. *Bulinus* generally prefer natural rivers and streams to irrigation canals. As a result, the relative prevalence of *S. mansoni* infection generally increases with the introduction or expansion of irrigation systems.

Lifecycle & Transmission

Adult schistosomes live in the veins of the urinary bladder plexus (*Schistosoma haematobium*) or intestines (*S. mansoni and S. japonicum*). They spend their adult lives as a mated pair. These mated pairs produce hundreds of eggs per day (approximately 400 for *S. mansoni*), some of which are excreted with host wastes (Coon, 2005). When these eggs are excreted in fresh water, miracidia hatch and burrow into a host snail. After asexual replication cercariae are released from the snail and seek out a mammal definitive host, commonly a human. Water contacts such as bathing, washing clothes, collecting water for cooking, getting a drink, fishing, sailing, farming canal irrigated lands, and brick making could put one at risk of infection. After piercing the skin cercariae migrate to the vascular system and eventually the heart and lungs where they form mating pairs and migrate to their final location. Mated pairs have a lifespan of up to 30 years within the host if not treated (Jordan, 1985), but average only three to ten years depending on the species (Gryseels et al., 2006, p 1106). In endemic areas, infections lasting one third to one half of the total lifetime of the host are typical (Satayathum et al., 2006).

Adult schistosomes avoid elimination by the immune system by continually replacing their outer tegument exposing a series of different combinations of surface carbohydrates, host antigens, and host antibodies (Roberts and Janovy, 2005, p 238). In contrast, schistosome eggs induce a pronounced immune response which they rely on to move the eggs from the vascular system to the lumen where they can be excreted by the host (Doenhoff et al., 1985; Damian, 1987). The process is imperfect and less than half of all eggs released are excreted; the rest become trapped within the host (Coon 2005). These eggs induce the pathology associated with schistosomiasis.

The lifecycle of schistosomes and its prerequisite host environments restricts the transmission of schistosomiasis not only to areas with fresh water that provide adequate environments for appropriate snail hosts, but also to areas with waters that have been relatively recently contaminated by mammal host wastes. The prevalence and intensity of schistosomiasis infection is directly related to exposure to contaminated water and therefore (re)infection. Schistosomiasis is generally over dispersed with a few heavily infected individuals carrying the majority of the parasites (Gryseels et al., 2006). As little as one exposure to water containing cercariae per year is sufficient to maintain infection transmission.

The most significant determinants of transmission in modern populations are changes in water contact patterns, improved sanitation and health education, and reduced infection levels through population-based chemotherapy (Brooker, 2007). In an archaeological context, patterns of schistosomiasis would be primarily determined by water contact behavior and the distribution and abundance of intermediate hosts, freshwater snails. Water contact studies identify a correlation of schistosomiasis and exposure patterns associated directly with irrigation, cleaning vegetables in the canals, and washing in irrigation water after farm work (Watts and El Katsha, 1997).

Reduction in the prevalence and severity of disease can be achieved through efforts to reduce exposure to contaminated water and therefore (re)infection and reduce transmission to others after infection by blocking the life cycle of the schistosome. Due to variations in fecal egg presence and count, de Vlas and Gryseels (1992) assert the widespread underestimation of schistosomiasis prevalence. This results in two significantly problematic facts for epidemiologists and public health workers. Because of imperfect parasite detection, the prevalence of schistosomiasis is underestimated and cure rates are overestimated. The error in prevalence estimates is associated with the number of false negatives (individuals who are infected, but whose fecal samples are negative). The number of false negatives is reduced through multiple sample analyses, but they may continue to exist after as many as 30 samples have been taken (de Vlas and Gryseels, 1992, p 275).

Although most infections have deleterious effects, not just those of high intensity, control efforts generally focus on the reduction of the intensity of infection and morbidity rather than elimination of infection (King and Dangerfield-Cha, 2008). Though periodic treatment lessens the burden of severe morbidity (King et al., 2005), complete elimination of infection from endemic areas is rare. Control programs which limit rather than eliminate infections (Gryseels et al., 2006, p 1114) can promote the evolution of these parasites toward resistance to praziquantel, the drug most commonly used to treat schistosomiasis. There is, unfortunately, growing evidence for the resistance of these parasites to praziquantel (Fenwick and Webster, 2006). Despite program efforts, schistosomiasis remains a major concern in many areas (Kloos and David, 2002; van der Werf et al., 2003; Vennervald and Dunne, 2004).

Pathology

Although it has long been suggested that morbidity associated with infection is underestimated, the degree of disability ensuing following schistosome infection is a matter of contention (King et al., 2005; Finkelstein et al., 2008). Symptoms of schistosomal infection vary from mild discomfort to severe disability and pathology is commonly classified as acute or chronic (King et al., 2005). Most of the pathology associated with schistosomiasis is generally attributed to granulomatous response to eggs as opposed to the adult worms (Wynn et al., 2004). Schistosomiasis is significantly associated with chronic pain, diarrhea, fatigue, impaired growth and development, and exercise intolerance (King et al., 2005). All forms of schistosomiasis are "firmly associated" with anemia independent of dietary and co-infection factors and, in general, higher infection intensity is associated with more severe anemia (King and Dangerfield-Cha 2008). Schistosomiasis has been associated with nutritional status, and protein-energy malnutrition possibly due to anorexia, blood loss to parasite consumption, increased physiologic load, and reduced absorption associated with diarrhea (Stephenson, 1993; McGarvey et al., 1996). Even light schistosomiasis infections can cause undernutrition and growth stunting (King and Dangerfield-Cha, 2008). Less prevalent, but severe sequelae include liver fibrosis, portal hypertension, hepatosplenomegaly, urinary tract obstruction (King and Dangerfield-Cha, 2008). Severity of schistosomiasis disease is influenced by host genetics, infection intensity, in utero sensitization to schistosome antigens, and co-infection status (Pearce and MacDonald, 2002).

The initial response to cercarial penetration can manifest as a temporary rash commonly referred to as “swimmers’ itch” or cercarial dermatitis. Acute response to schistosome infection (also known as Katayama fever) induces fever as well as myalgia, malaise, and non-productive cough generally occurring several weeks after infection and is commonly seen in individuals from non-endemic areas concurrent with the onset of egg production. Most cases resolve spontaneously, but some continue with increasing severity. Such a response is rare in *S. haematobium* and *S. mansoni* endemic areas, but occurs more frequently in *S. japonicum* endemic setting even in those who have been previously exposed (Pearce and MacDonald, 2002; Gryseels et al., 2006).

The symptomatology of chronic schistosomiasis varies with the intensity and type of infection although negative impacts are common with all major species (King and Dangerfield-Cha, 2008, pp 66-67). In all chronic schistosome infections eggs elicit an inflammatory granulomatous immune response and microulcerations as they migrate. Eventually, individuals may develop so much scar tissue that they cease to release eggs altogether, thus making their infections invisible to common diagnostic techniques which screen for eggs in excreta (Roberts and Janovy, 2005, p 255). Fibrosis can block circulation to the affected organs including the liver and heart (Coon, 2005). In *S. mansoni* and *S. japonicum* infections blockages can eventually lead to portal hypertension and hepatosplenomegaly in severe cases (Roberts and Janovy, 2005, p 257). Fibrotic hepatic schistosomiasis can lead to potentially fatal gastro-esophageal bleeding (Gryseels et al., 2006). Chronic intestinal schistosomiasis is characterized by abdominal pain, loss of appetite, and diarrhea (Vennervald and Dunne, 2004). Ectopic infection of the female genitals can lead to infertility from scar tissue formation in the ovaries and fallopian tubes (Coon, 2005; Gryseels et al., 2006). In addition to directly resulting in pathology, schistosomiasis can bias immune responses which can reduce the ability to effectively respond to other pathogens and may contribute indirectly to a much wider range of ailments than generally attributed to it (Pearce and MacDonald, 2002; King and Dangerfield-Cha, 2008).

While severe disease is focused in heavily infected individuals, intensity of infection is not always correlated with severity of disease (Pearce and MacDonald, 2002).

The severity of schistosomal disease is modulated by the immune response of the individual to infection (Cheever et al., 2000; Wynn et al., 2004; Gryseels et al., 2006). The nature of this response is modulated by the sex, age, and development of resistance to infection the individual has attained (Dessein et al., 1992; Butterworth, 1993; Khalife et al., 2000; Remoue et al., 2001; Boissier et al., 2003; Klein, 2004; Scott et al., 2004). Individuals seem to be predisposed to a maximum infection intensity and generally reach but do not exceed this limit (Gryseels, 1994). Those living in endemic areas appear to develop resistance to re-infection after years of exposure. This resistance has been assumed to be due to the buildup of immunity after a lifetime of exposure to various schistosomal antigens (Butterworth, 1993; Olds, 2006) but is still contested.

Paleoparasitic Research

A number of different methods have been used to research schistosomiasis in archaeologic populations. Ruffer (1921) identified *Schistosoma haematobium* eggs in the kidney of an Egyptian mummy through histological examination of rehydrated tissues. This was the first recorded diagnosis of a parasitic infection in an archaeological specimen. Since then, a variety of techniques have been utilized in paleoparasitological investigations to identify schistosomiasis infections including rehydration and microscopic examination of coprolite samples and latrine sediments, computer imaging, quantitative parasitological enzyme-linked immunosorbent assays (ELISAs) and DNA testing.

Schistosoma mansoni eggs have been indentified in French latrine samples dating to 1450-1500 CE (Bouchet et al., 2002). As schistosomiasis has never been endemic in Europe, the eggs must have been from an individual who obtained the infection elsewhere either by a European traveler or African emigrant. In an effort to determine whether or not schistosomiasis was present in the America prior to European contact, Araujo and Ferreira (1997) examined 1100 coprolites from South American archaeological sites dating from 30,000 years ago to the colonial era and found no schistosome eggs. They caution, however, against the use of negative data in drawing conclusions regarding parasite dispersion. Several methods have been developed to provide measures of infection intensity based on quantitative analysis of egg counts in coprolite samples (Arguello, 2006) and burial soil sediments (Fugassa et al., 2006). While the usage of such a technique throughout a collection of coprolite samples or burials would allow for the quantitative comparison of parasitic infection between samples, the original volume of the fecal sample is unknown and therefore quantitative measures such as egg per gram (epg) counts can serve only as rough estimates; they should not interpretted as directly equivalent to similar measures in fresh samples.

Radiologic studies of mummified tissues have identified calcified schistosome eggs in several mummified individuals (Contis and David, 1996). The use of non-invasive diagnostic methods such as computed tomography (CT) scanning and scanned electron microscopy (SEM) have made possible the examination of larger, more representative mummy populations (Kloos and David, 2002).

In contrast to microscopy and radiological examination which identify the presence of schistosome eggs as well as their species through visual inspection, immunologic testing can be used to diagnose parasitic infections by identifying parasite antigens or host antibodies. Immunologic testing provides a reliable means diagnosing parasitic infections in archaeological populations in cases in which eggs or cysts cannot be identified microscopically due to taphonomic alteration or absence of identifiable coprolite samples (Goncalves et al., 2002, 2004). Deelder and colleagues (1990) utilized an ELISA to identify schistosomiasis in a naturally mummified individual from predynastic Egypt. Utilizing estimates of 10% blood content in the cheek and a tenfold reduction in tissue weight due to desiccation, they estimated a serum concentration of 25ng/ml of circulating anodic antigen (CAA), a polysaccharide produced in the gut of the schistosome,(from 123 pg/ml of desiccated tissue). Miller and colleagues (1992) utilized this method to test 23 individuals Nubian individuals from the NAX cemetery (350 to 550 CE) for schistosomiasis and found a 65% positivity rate with antigen concentrations ranging from 16 to 1208 pg/mg. By comparison with the antigen concentrations found by Deelder and colleagues (1990) in a New Kingdom weaver known to be heavily infected, these individuals appear to have been moderately to heavily infected. The positivity rate found is within the ranges seen in modern populations in the area.

Extraction of parasite DNA from archaeological samples provides an alternative means of diagnosing parasitic infection. Ancient DNA has been successfully extracted from several ancient samples; however degradation of samples reduces the ability to extract DNA from archaeological samples (Iñiguez et al., 2003). Iñiguez and colleagues (2003) utilized reconstructive polymerization to improve the quality of DNA derived from coprolite samples. In addition to identification of parasitic disease, the extraction of DNA from ancient parasites can produce valuable information regarding the evolution of parasitic organisms through time (Iñiguez et al., 2006).

Relation to Skeletal Stress Indicators

The influence of chronic schistosome infection on numerous indicators of health commonly analyzed in bioarchaeological investigations such as growth and development, nutritional status, and porotic hyperostosis/cribra orbitalia through anemia suggests that the identification of infection within individuals from archaeological contexts may be causal for some of these skeletal indicators within archaeological populations. Infection status data for individuals from archaeological populations may be utilized to calculate prevalence odds ratios for these indicators. This would provide a means of conceptualizing the health burden of schistosomiasis within archaeological populations. However, a correlation between schistosomiasis infection and stress indicators is not necessarily indicative of causation. For schistosomiasis to contribute to stress indicators such as porotic hyperostosis, cribra orbitalia, and dental enamel hypoplasias, the infection must be acquired prior to the end of the period in which the indicator forms. Evidence of cribra orbitalia or porotic hyperostosis and schistosomiasis in an adult are not necessarily linked. The infection may have been acquired years after these skeletal responses were induced. Infections acquired later in life do not contribute to these skeletal responses and because the age of infection cannot be determined correlations between them cannot be considered as evidence of causation. Statistical association between schistosomiasis and these conditions is unlikely and although schistosomiasis exacerbates physiologic stress assumptions about its influence on skeletal indicators of stress without information about the temporal sequence of stress and infection are presumptuous.

Conclusions

The schistosome lifecycle limits the transmission of infection to areas in which exposure to excreta contaminated waters harboring the necessary snail hosts. Alterations of the environment in ways that increase snail habitat or the likelihood of exposure to contaminated water such as the implementation of irrigation systems are prone to increase transmission. Pathology varies throughout the progression of schistosome infection and in relation to the immune response of the host, but consistently results in some level of morbidity. Schistosomiasis contributes to some of the key indicators of health utilized in bioarchaeological research such as growth retardation and anemia. However, the ability to link these indicators with schistosome infection status within archaeological populations is limited by the inability to establish a temporal sequence for infection and the skeletal stress response. Epidemiological patterns from archaeological populations and estimates of morbidity from modern populations may provide a better means of conceptualizing the influence of schistosomiasis on population health in the past.

Chapter 4: Cultural and Ecological Context

Schistosomiasis within the populations of Wadi Halfa and Kulubnarti must be contextualized within the larger cultural, social and ecological history of Nubia during the Ballana and Christian periods. While the majority of documentary sources pertaining to the social history of Nubia come from the writings of outside observers, the high degree of preservation and archaeological interest in the area have resulted in a great deal being known about the history of Nubia despite its lack of written records. The history of Nubia between the fall of the Meroitic Empire (c. 350 BCE) and the Muslim conquering of Nubia (c. 1350 CE) is generally demarcated by archaeologists and Nubian historians into the X Group[1] or Ballana, and Christian cultural periods. At the most basic level, the Ballana period is generally associated with less centralized control and greater autonomy of local populations while the Christian period can be characterized by complex regional political and economic interactions controlled by large state governments and state conflict. For much of history, Nubia provided the only reasonable means of safe passage of people and goods between the Mediterranean and sub-Saharan Africa and experienced cultural influences from each. Throughout these periods, Nubians interacted with both populations as racial, cultural, and economic "middle men" (Adams, 1977).

[1] The "X Group" label was first applied by George A. Reisner during a survey of Nubia conducted prior to the construction of the Aswan Low Dam. Letters rather than more descriptive names were applied because relatively little data was available other than the distinctions in pottery types and burial practices. The X Group was so named because it was chronologically distant and dissimilar to other periods. It has since become recognized as associated with the Ballana culture (Adams 2001: 162).

Nubia and the Nile

Nubia now lies within the boundaries of Egypt and Sudan, but in ancient times it represented a culturally and politically distinct Nile people. The area known as Nubia consists of a thin strip or intermittent patches of fertile, arable land along the edge of the Nile bordered by a harsh, barren landscape. The region is exceptionally arid and has been since 3000 BC (Jackson, 1957). It receives under 5mm of rain per year (Butzer and Hausen, 1968). The summer "drought" lasts from July to September and temperatures are also at their highest during this part of the year (Dafalla 1978). Hot, dry Nubian summers challenge human and plant physiology. Mortality and morbidity have been higher in the summer months since the Ballana period at Wadi Halfa (White, 1991). Even in more moderate seasons, daily temperature extremes vary by 16 to17 C regardless of the time of year (White et al., 2004).

The annual flood of the Nile begins as waters rise in mid-July and reach their peak in mid-September (Dafalla, 1968). The height of the annual Nile flood varies; changes in water height have important ramifications in both seasonal and long term contexts. Low flood levels result in a smaller flood plain, and can reduce harvests, kill livestock and seed stocks, and even cause starvation based upon observations from ancient and modern times (Adams, 1967; Butzer, 1976; White et al., 2004). Excessive flooding is also problematic. Although higher flood levels can increase the extent of the arable floodplain and have positive impacts in the long term, they are often destructive. Settlements, irrigation dykes, food stores, seed stocks and livestock are often lost prior to compensation for higher floods which can take up to 100 years to implement (White et al., 1999).

The Nile was of central importance as a source of water for the production of goods, domestic consumption, and a number of other uses. Perhaps consequently, Nubia is typically defined in relation to the cataracts of the Nile. Each cataract is a region where the fertile, arable land associated with the Nile Valley floodplain is constricted to narrow banks along rapid-filled gorges through granite. Cataracts represent an obstacle to both travel and agricultural production (Adams, 1984, p 38).

Lower Nubia is bounded by the first cataract at Aswan and the second cataract just south of the modern border between Egypt and Sudan. Wadi Halfa is located just north (10km) of the second cataract at the southern extreme of Lower Nubia. Lower Nubia does not offer the uninterrupted flood plain of Egypt, but does provide a good deal of alluvial soil intermittently on either bank which can be productively utilized if sufficient water is available. In addition to being the area of Nubia most proximal to Egypt, it is the region most similar in terms of topography. In this region the Nile is placid and easily navigated, but its banks are higher than in Egypt (Adams, 1977, p 24). The higher banks and narrow valleys of the Nile in Lower Nubia created a rather unique relationship with the Nile River. As opposed to the reasonably predictable flooding of the Nile in the Egyptian Nile Valley and in regions further south, flooding of the valley floor in Lower Nubia is a rare condition (Minoia, 1996).

Kulubnarti is in the Batn el-Hajar, a region of Upper Nubia which includes the lands from the edge of Lower Nubia southwards for roughly 100 miles. Known as the "belly of the rock," Batn el-Hajar is fraught with granite outcroppings and ridges and has served as an "iron curtain" (Adams, 1977: 27) between Egypt and Upper Nubia for most of history. Hundreds of islands break up the flow of the Nile into fast moving rapids which cannot be traversed. Despite its forbidding appearance from the second cataract, Batn el-Hajar is actually less arid than Lower Nubia with a number of alluvial plains interspersed between rocky outcroppings and thus offers a greater opportunity for agricultural production (Carlson, 1979, p 562). It is because of this difference in the ability for agricultural production that the Batn el-Hajar was continuously occupied in throughout Nubia's history while Lower Nubia was abandoned for almost a thousand years.

Wadi Halfa and the Ballana Period (350-550 BCE)

Political and Economic

Prior to the Ballana period, the Meroitic Empire controlled both Lower Nubia and the Batn el Hajar, but the political and economic relations linking them to the wider region were reformulated in the Ballana period (Edwards, 2004). The decline of the Kingdom of Meroe (c. 350 CE) and political instability in Rome's holdings in Egypt led to greater relative autonomy for Nubian peasant communities (Trigger, 1965). Adams describes the Ballana culture as "a decentralized agrarian society, poorer but more self-sufficient than the society of Meroitic times" (1977: 404). The reduction in material wealth did not occur as quickly in Lower Nubia as in the more southern provinces (Adams, 1977). After the fall the of Meroitic kings, a regional power center of Ballana culture arose just north of the second cataract lead by elites of the former Meroitic era and their descents (Edwards, 2004). The middle class formed in the previous period appears to have been eliminated returning the social stratification system to a simple one of the ruling and the ruled.

The Blemmye, thought to represent nomadic cattle herders controlling the region between the Nile and the Red Sea, competed with the Ballana for control of Lower Nubia (Adams, 2001). Eventually the Ballana took control. Three key powers arose in the fifth and sixth centuries: first Nobadia in Lower Nubia and the Batn el Hajar, and later Makuria and Alodia (Alwa) to the south (Edwards, 2004). The core of the developing Nobadian kingdom was likely somewhere between the second cataract and Qasr Ibrim (Wadi Halfa is within this region). Conflict between the Blemmyes and Nobadia appears to have arisen by the 370s and continued until around 450 when Nobadian king Silko asserted control over the Dodekaschoinos, a tract of land along the Nile from the second cataract at Aswan to Maharaqa which had previously formed a buffer zone between the Meroitic Empire and Roman Egypt (Edwards, 2004). Despite hostilities, Blemmyes and Nobadians communally attacked Egyptian forces at Philae within the Dodekaschoinos after a Roman governor attempted to close the Temple of Isis which was sacred to both groups (Adams, 2001).

Political changes were previously thought to have led to a significant decrease in trade with people outside Lower Nubia and increased regional and local exchange (Adams, 1977). There is some debate over whether this change stems from an inability to conduct trade given the dubious political control or a lack of pressure from controlling powers to trade out agricultural products (Martin et al., 1984, p 199). More recent archaeological finds suggests Romano-Egyptian goods as well as native pottery actually became more abundant during this period, at least in some areas, suggesting diminished trade was not universal, but may have occurred in some regions (Edwards, 2004, p 207).

Material and Other Culture

Ballana culture incorporated Byzantine and Meroitic cultural influences. Sites such as Meinarti, just 10km south of Wadi Halfa at the second cataract, provide evidence of continuity of culture and population from Meroitic through Christian periods. Peasant life appears to have continued without much alteration although the more elaborate features of Meroitic civilization and religion were abandoned (Adams, 2001). Adams (1977) explains the apparent rejection of some aspects of Meroitic culture in the Ballana period as the lack of desire by a formerly subjugated population to take on the characteristics of their oppressors once they left. He suggests that the dominant culture of Lower Nubia in this period is that of the peasant populace which moved into Lower Nubia during the Meroitic period. Christian influences in both art and household goods can be seen in the Ballana period in combination with influences of Meroitic, Greek, and Byzantine Egyptian influences (Adams, 1977, 2001; Edwards, 2004).

The Meroitic writing system also fell out of use in this period and was replaced by native Nubian languages. The use of Nubian languages was "a key element in the creation of new Nubian identities, social and political" (Edwards, 2004, p 182). It was also during this period that the first records of individuals self-identifying as Nubian occurs (Edwards, 2004, p 185). Because of this we know very little about the social history of Lower Nubia between the Meroitic and Christian periods and the period has traditionally been known as a “dark age.” However, Adams contends that these people in all likelihood never spoke or wrote in the Meroitic language, keeping their native tongue throughout the Meroitic period. "Their failure to do so [maintain the scribal and artistic establishment] must be interpreted as a reflection of indifference or hostility rather than of incapacity" (Adams, 1977, p 415). Adam's rationale for the lack of reference to these people as a distinct group in earlier periods is their lack of social or political importance to neighboring peoples (i.e. the relatively much greater importance of the Meroitic establishment).

Pottery making during the Ballana period represented a "complete break with the traditions of Meroitic times" (Adams, 1977: 401). Ornate and brightly colored pottery vessels were abundant during the Meroitic period, yet the use of the potter's wheel ceased and pottery making returned to hand constructed utilitarian form in the Ballana period (Adams, 1977). Adams suggests this is due to the manufacture of decorative pottery by males while more utilitarian vessels continued to be constructed by women. Once the demand for decorative pottery decreased so did the production by males and the technology used for this purpose. Utility vessels made by Nubian women show no discontinuity between these periods (Adams, 1977). This pottery reflects strong Roman influence and consists primarily of plain red vessels with little or no decoration. Differences in the decorative motifs of Lower Nubia and the southern Meroitic territories provide additional evidence for cultural distinction between their peoples. What appears to be a pottery factory was found just north of Wadi Halfa and may have produced much of the pottery used in the area.

Burial practices and the structure of tombs exhibit key distinctions between the remains of Ballana and Meroitic periods. Tomb orientation became more varied in the Ballana period (north-south as well as east-west) although this variability declined with the establishment of the Nobadian kingdom (Edwards, 2004). Cemeteries show a pattern in which a few, larger burials of the rich appear to be haphazardly filled in with those of the less well off. Adams interprets this intermingling of social strata in cemeteries as evidence that although stratification existed, "the social distance between the two groups was not great" (Adams, 1977: 375). Ballana period tombs of the elite take the form of rounded earth tumulus as opposed to the Meroitic use of pyramids. Ordinary tombs often did not have tumuli. Royal tombs are the "only monumental structures which the Ballana period ever produced" (Adams, 1977, p 397). The area just north of the second cataract has the most concentrated accumulation of graves from the period. A few sites, including the cemetery at Argin (from which the Wadi Halfa sample is derived) are notable for their large size relative to other Ballana period cemeteries (Adams, 1977). This would suggest that the population was associated with a much more densely populated urban center than was typical in Lower Nubia at the time.

Settlement

Intensification of agricultural production in Lower Nubia resulted in "not quite a land rush...at least the very thorough reoccupation of the long abandoned territory" (Adams, 1977, p 346). The northern reaches of Lower Nubia developed a more dispersed agricultural population than more southerly regions, although much more dense than the region had in previous eras. Even the Batn al-Hajar region, known for its difficult terrain, was utilized by agriculturalists seeking available land (Edwards, 2004).

There was a general expansion of small dispersed settlements in Lower Nubia in the Ballana period in contrast to the few aggregated settlements of the Meroitic period (Edwards, 2004). These settlements lacked the clear evidence of planning and standardized construction practices seen in the Meroitic era. Buildings do not appear to follow any particular pattern or planning in their use of stone or mud brick. In some structures the two are combined in a "highly irregular" manner (Edwards, 2004, p 400). Edwards (2004) interprets changes in the architecture of Nubian settlements between the Meroitic and Ballana periods as the result of a shift to the local construction of agricultural communities from state designed outposts rather than a cultural decline or the encroachment of barbarism.

Ecology & Agriculture

Traditionally, Nubian agriculture along the Nile consisted of planting the main crops following the recession of the Nile's floodwaters. A shaduf, a bucket-lever water lifting mechanism, which is "only practicable in a local horticultural context" (Butzer, 1976, p 47) was used to provide more constant supplies of water to small garden plots. This system of agriculture allows only a single harvest per year from the main fields supplemented with garden crops. Dependence on sufficient Nile floods for water and adequate slack river levels to maintain shaduf access to water would have meant that in low flood years less land was available for cultivation. The land of some individuals or households may not have been cultivatable while others still had sufficient water for cultivation or worse, none of the fields in the area would able

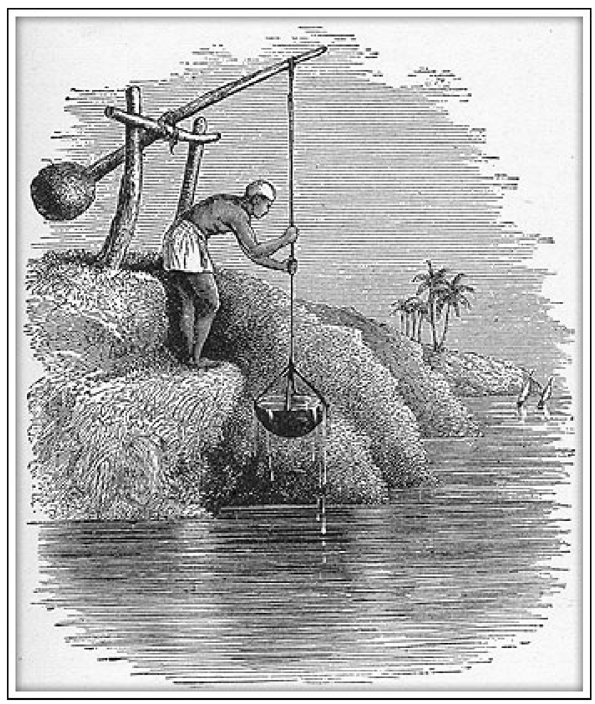

Figure 2: Illustration of a shaduf from, Amelia Ann Blanford: “A Thousand Miles Up The Nile” 1890.

to produce a harvest.

Abundant evidence for the use of the saqia, a waterwheel used to raise water from the Nile to terraces above, in the form of *qadus,* jars used exclusively as part of saqia systems, appears in the fourth and fifth centuries in Lower Nubia, but may have been used in the Dodekaschoinos in the third century. Historical sources and archaeological data indicate abnormally low water levels of the Nile during the Ballana period (White et al., 2004). Artificial saqia irrigation has the advantage of more control over the amount of cultivatable land with varying flood levels as well as extension beyond the floodplain and the production of more than one crop per year (Butzer, 1976). The saqia provided a means of supplying water to areas no longer flooded by the Niles lower waters and made agricultural pursuits in Lower Nubia possible even in the drier conditions of the Ballana period. In contrast to natural flood irrigation, saqia irrigation allowed Nubians to make use of both temperate and tropical crops within a multiple crop cycle (Adams, 1977). However, high and low flood levels would periodically exceed the ability of irrigation systems to compensate and result in harvest loss and potential famine.

By utilizing the saqia, Nubians now had the ability to control to a much greater extent the timing and distribution of water to their fields during the year and increase the number of harvests obtained from a plot of land improving the dependability of the food supply. In addition, a number of new crops were introduced to the area. Sorghum appeared by around 500AD as well as durum wheat, termis beans, peas, bullrush (pearl millet), and sesame (Edwards, 2004, p 204). These crops were incorporated into the crop rotation system in accordance with the appropriate growing conditions. Edwards (2004) suggests the importance of the saqia to the introduction of new cropping regimes was more significant than the increase in arable land area. The production of cotton fabric suggests it was also produced in the region during the Ballana period. The development of cotton industry in northern Nubia may have contributed to continuing prosperity of the region in the post-Meroitic era (Adams, 2001). See Adams (1977: 347) for a diagram of a saqia in use.

The crop rotation system included winter, *shitwi* crops, summer *seifi* crops and flood cultivation or *dameira* crops as well. Following the recession of the Nile, winter *shitwi* crops are planted. These consist primarily of C_3 cereals (wheat and barley), but also include pulses, legumes, onions and other vegetables. These plants grow during the coolest, wettest part of the year (averaging 15.8 C in January with the maximum rainfall occurring between February and July). The main harvest was in April (Dafalla, 1968). Summer *seifi* crops were sown in March and harvested in June, prior the annual Nile flood. They include sorghum and millet, which are C_4 plants. These plants are more drought resistant and thrive in more arid conditions than C_3 plants. *Dameira,* crops were sown in mid-July timed to the rising of the Nile's flood waters and harvested in October. They include additional C_4 *seifi* cultigens as well as a variety of C_3 fruits and vegetables (White et al., 2004). This crop rotation system emphasizing C_3 and C_4 crops to a greater or lesser extent with the season continues to the present and is evidenced by isotopic studies (White, 1993; White and Schwarcz, 1994; Schwarcz and White, 2004; White et al., 2004).

Settlement patterns in ancient Nubia suggest small familial land holdings, the type most well suited to saqia use (Trigger, 1965; Adams, 1977). Rather than the state managing and owning the resources necessary for production as was the case in Egypt and the core of the Meroitic state (Amborn, 1984), control over water in Lower Nubia was held within the village and family (Minoia, 1996). Construction and maintenance of a saqia to provide water access may have determined land ownership (Zarroug, 1991). This has been shown to be the case in other hyper-arid regions (Spooner, 1974). Minoia considers this to be a "historical discontinuity" with other societies in the region.

Schistosomiasis in Context

Utilizing the model set forth in Chapter 2 for examining the interaction of adaptive processes and the environment, this contextual information helps us better understand the implementation of saqia irrigation at Wadi Halfa and its possible influence on the transmission of schistosomiasis. Clearly, the environmental constraints posed by the Nubian context are significant. The dry conditions of the region restrict access to water for direct consumption, agricultural production, and other uses. The heat of Nubian summers and daily extremes of high and low temperatures produce additional physiological stress on individuals living in the region. Adams (1977) notes that Lower Nubia was largely uninhabitable prior to the introduction of the saqia as much of the land lies too high above the Nile to be flood irrigated under normal conditions. The abnormally low flood levels of the Nile during this period would have further reduced access to water and the extent of cultivatable land. The implementation of saqia irrigation was, therefore, not so much a choice as a prerequisite for inhabiting much of Lower Nubia at the time. In addition to increasing the amount of arable land, saqia irrigation increased the productive potential of that land by allowing multiple harvests per year.

The greater autonomy of peasant communities during the Ballana period suggests these communities and the individuals and households within them had more control over the allocation of resources and decisions regarding cultural buffering options than in the preceding period. Although trade continued, it appears that Nubian peasants in the Ballana period focused their efforts on subsistence and the production of useful goods as opposed to more decorative items or surplus production for foreign trade. Martin and colleagues (1984, p 211) identified general improvements in health and nutritional status during the Ballana cultural period which they attribute to localized control and more equitable distribution of resources.

While the use of canal irrigation has advantages, it has been shown to contribute to increased risk of schistosomiasis infection by creating an artificial environment in which vector snails responsible for the transmission of schistosomiasis can flourish (Dougherty and Hall, 1995; Jobin, 1999). As a result, irrigated agriculture can contribute in a significant and negative way to schistosomiasis burden in local populations. However, the extent of the negative health impact of schistosomiasis as a deterrent to irrigation usage must be considered within the context of its relative burden in comparison with the increase in cultivatable land and food insecurity experienced by the population relative to the conditions that would be exist in the absence of irrigation.

The risk of infection to individuals within the population as well as their ability to cope with infection would have varied in accordance with their social position, activities, and resource access. Although social differentiation with the population at Wadi Halfa is minimal, individuals and groups likely varied in their daily activities creating disparities in exposure and infection between members of a population. Those with greater exposure to snail inhabited water would have been at greater risk of exposure to infection than those exposed to other water sources. These individuals likely experienced higher prevalence and intensity of infections.

Kulubnarti and the Christian Period 550-1000 BCE

Kulubnarti is situated at the heart of the Batn el Hajar. In this region pockets of alluvial soil often occur at the base of steep slopes accessible only over rugged terrain. (Kilgore et al., 1997). The harsh and unattractive nature the region has at many times been the saving grace of its people. Many attribute the ability of Christian Nubians to hold out against Islamic conversion and military conquest to the inhospitable nature of its lands (Adams, 1977). Subsistence in the Batn el Hajar has presumably always been marginal at best. Alluvium in the area exists only in protected pockets and coves rather than the extended plains farther to the north (Van Gerven et al., 1995). Edwards (2004), contends that subsistence may not have been possible and that the population in all likelihood depended upon imported food at many points in time. The height of the Nile in the Christian period suggests greater agricultural production in this period.

Like most settlements in the Batn el Hajar, it was a small village of perhaps a dozen households subsisting on their agricultural production (Van Gerven et al., 1995). Due to the building of the Aswan high dam, the Kulubnarti site is now divided into mainland and an island which was not separated from the mainland in ancient times. The island consists primarily of granite outcrops reaching as high as 80m above the Nile's waters. Plains exist between ridges, but are now covered in sand. The lowest lying and most easily flood irrigated land was between the modern island and mainland. For most of the year, the land was made use of for raising legumes and fodder plants (Adams et al., 1999).

As opposed to the distinction between Meroitic and Ballana periods, the beginning of the Christian era does not coincide with any major political change. Instead, the period is marked by a change in the religious affiliation of the ruling powers. The ease and speed attributed to the conversion of Nubia to Christianity as well as Christian influences in art and goods from the preceding period suggest presence of Christian beliefs prior to official missionary action (Adams, 1977; Edwards, 2004). Evidence suggestive of early Christian practices is more common in Lower Nubia than areas further south, but Christian beliefs may have been held by some at Kulubnarti.

The site was previously thought to represent to temporally distinct populations, however, recent carbon dating indicates that both populations date to 500 to 1000 CE.

Political and Economic

While Nubia is generally studied with regard to the influence of Egypt, Edwards (2004) suggests the need to investigate Nubia within a broader context especially during the Christian period in which multiple complex political systems were developing in the region. Three distinct Nubian kingdoms came into existence in the fifth and sixth centuries. Interactions between them shaped the political climate in the Christian era. The first of these was Nobadia in Lower Nubia and the *Batn el Hajar*. Nobadia appears to have had close ties to Egypt throughout the sixth and seventh centuries (Edwards, 2004: 247). Later, Makuria and Alodia (Alwa) formed to the south in Central Sudan (Edwards, 2004; Grzymski, 2004). All three were initiated into Christian faiths although with slightly differing constructions of the young religion. By the early 7th century, Nubia was once again under unified political control, this time by the kingdom of Makuria under a supreme king at Dongola (Edwards, 2004). The royal history of the Nubian kingdoms is "hazy" and the level of conflict which appears to surround succession points to a lack of convention in succession, but there are indications of matrilineal inheritance of royal position. Ibn Khaldun reported Arab seizure of power through marrying Nubian women (Edwards, 2004, p 237).

Islamic invasions from Egypt in 642 and 652 CE eventually resulted in the Baqt treaty which most accounts suggest consisted of an agreement that allowed continued religious and political freedom of Nubia in exchange for annual tribute payments of slaves and protection of Muslims in Nubian lands in return for foodstuffs, wine, and cloth. Alternative versions support Nubian victory and equitable trade of foodstuff for captives and other goods (Edwards, 2004, p 249). There is, however, documentation of additional conflict between Nubian and Arab powers in the seventh century and again in the ninth.

While the center of political power lay to its south, Lower Nubia was a center of economic activity and free trade with Islamic Egypt for which Wadi Halfa served as the southern extreme (Van Gerven et al., 1995). Trade goods from Egypt support the continued access to such items by elites during this period. In contrast, the Batn el Hajar region served as a protective barrier from the expansion of the Islamic world into the center of the Christian kingdom to the south (Adams, 1977; Van Gerven et al., 1995; Edwards, 2004). As conditions worsened, Adams (1977) suggests that the Batn el Hajar served as a sort of Christian refugee resettlement area protected from political conflict by its location off the major trade routes (by this time the routes had shifted to overland across the dessert). The economic isolation of the Batn el Hajar is evidenced by the lack of foreign goods found in archaeological investigations (Adams, 1977).

Material & other Culture

Few "elite goods" have been found in any peasant settlement in Lower Nubia or Batn el Hajar of the Christian period. Pottery was abundant in village contexts and is therefore not considered as an elite good (Adams, 2004). The fact that textile goods were important enough to be included in the terms of Baqt treaty suggests they may have been the elite good of choice during the Christian era explaining the apparent lack of such goods in archaeological remains.

The assumption given the lack of specialized craft and imported goods is that the residents of Kulubnarti and Nubia more generally must have returned to subsistence agriculture to provide for themselves (Van Gerven et al., 1995). However, evidence of mat, basket, and sandal making was found at Kulubnarti (Adams & Adams 1998: 42-44).

There are two distinct cemetery sites at Kulubnarti, 21-S-46 (S cemetery) which lies along the west side of the island in a wadi, a dry riverbed for valley. The other, 21-R-2 (R cemetery) lies along the West Bank of the Nile. There is no typological distinction between burials from the two cemeteries. The burials in the R cemetery are most likely from residents of the archaeological site designated 21-R-3. While the burials excavated are primarily from the Early Christian period, graves in the unexcavated areas of the cemetery are likely from later periods and it appears that the cemetery grew towards the east. The use of the cemetery is likely continuous from the Early Christian though modern times (Adams et al., 1999). The inability to use the direction of the Nile's path as an approximation of north has led to greater variability in the orientation of Christian burials at Kulubnarti than many other Nubian sites dating to the same period (Adams et al., 1999). Christian period graves in Nubia commonly lack of grave goods and those at Kulubnarti are not an exception (Adams, 2004).

The use of written language returned to Nubia in the Christian period and Greek, Coptic and Old Nubian were all used in different contexts. In Lower Nubia the use of Coptic (generally associated with religious contexts and Egyptians) was more widespread than in other areas.

Settlement

Many of the settlements from the Ballana period continued to be used throughout the Christian period and into modern times. Evidence of both pagan and Christian burials within the same cemeteries at Kulubnarti indicate continued habitation. Dispersed settlements became more densely populated and brick structures became widespread. The site of Kulubnarti includes the remnants of several structures including houses, a monastery, a church, a castle and two cemeteries (Kilgore et al., 1997).

In the later medieval period there appears to have been a general shift in the concentration of settlement towards the south with decreasing settlement and construction in Lower Nubia while the population of the Batn el Hajar appears to have expanded. Both Adams (1977) and Edwards (2004) attribute this to political unrest in the north leading to refugee resettlement in the comparatively safe Batn el Hajar. The need for protection is clearly evidenced by defensive nature of architecture in this period. Dwellings are primarily two story structures with entrances on the second floor assessable only by retractable ladders (Adams, 1977; Edwards, 2004). In addition, villages appear to shift in their focus from the churches of the early Christian period to protective castles (Van Gerven et al., 1995).

Although there is little material evidence of religious beliefs among peasants during the Meroitic and Ballana periods (clearly, the willingness to attack Egypt in response to the closure of the Temple of Isis at Phillae implies some religious conviction), churches were built throughout Nubia in the Christian period including relatively poor peasant villages. The number of these churches does not appear to bear any relation to the population of a settlement (Adams, 2004). Many churches appear to have been endowed with lands used to support the needs of the clergy. Historical sources indicate the transfer of plots of land by private parties to churches. Funding church building and enhancement was likely both a sign of piety and status for those able to afford such generosity. However, this evidence stems mostly from Lower Nubia and cannot be assumed to have taken the same form in the Batn el Hajar further south (Edwards, 2004, p 239).

Ecology & Agriculture

In contrast to Wadi Halfa, no evidence of saqia usage has been found within the limits of the excavated portion of the Kulubnarti site dating prior to the Late and Terminal Christian period (1100 - 1500CE) (Adams and Adams, 1998). The lack of evidence for irrigation use at Kulubnarti may simply indicate that such evidence was destroyed prior to archaeological study of the site or missed in the excavation. Given the similarity in preservation of the two sites, the total lack of evidence at Kulubnarti for irrigation prior to the very late Christian period in comparison to the abundance of evidence at Wadi Halfa suggests that if irrigation was being used at Kulubnarti, the land being cultivated utilizing irrigation was less proximate to habitation sites and contact with canal waters was less intensive in those not directly involved with agricultural labor and canal maintenance.

The "rural lifestyles" begun in the Ballana period continued to develop throughout the Christian era. The farming regimes developed in Lower Nubia in the Ballana period spread throughout much of Nubia in the Christian era and use of the Coptic calendar to schedule farming events appears common (Edwards, 2004, p 220). Small scale agricultural production served as the basis for subsistence. Nubians continued to utilize the same crops and agricultural/irrigation techniques of previous periods. Isotopic data from other sites in the area suggests consumption was primarily based on C_3 (barley, legumes, wheat) with some consumption of C_4 (sorghum and millet) and protein with evidence that protein was obtained primarily from plant sources (Sandford and Kissling, 1994). The increase in population suggests that if this is the case, a great deal more land must have been cultivated than in previous epochs.

During the Christian period the Nile rose (with some fluctuation) to one of its greatest recorded heights forcing farmers off lower ground (Adams, 1977: 398). By 1022 AD the rising levels of the Nile floods began to have a negative impact on the productivity of the region as settlements had to be relocated and populations moved (Adams, 1967; Save-Söderberg, 1970; Trigger, 1970). Higher river levels provide an explanation for the lack of evidence for saqia usage at Kulubnarti in the Christian period. Given the limited alluvial soils and the topography of the region, higher flood levels may have provided water to or submerged all of the arable land. This may have increased the productive potential of agricultural pursuits in the area. However, major climatic events including exceedingly cold winters in 829 and 1011AD and unusually low floods in 828-837 and 939-948 likely had a negative impact (Edwards, 2004, p 213).

Schistosomiasis in Context

The harsh climate and rugged topography of the Batn el Hajar placed considerable constraints on the buffering options of the population at Kulubnarti. The aridity of the region makes cultivation almost completely dependent on water from the Nile. During the Christian period, the flood level of the Nile was generally higher than in other periods improving the potential of flood irrigated agriculture, although this was periodically interrupted by lower floods. Increased flood levels which were high enough to provide water to most or all of the alluvial soils in the region, but still low enough to avoid endangering stored harvests or structures would have reduced the need for additional irrigation technologies.

The social/political conditions of the period were less advantageous. Although the remoteness of Kulubnarti preserved the population to some extent, contests for power between states and Islamic invasions clearly presented dangers. The defensive nature of the homes inhabited by the population in the later Christian period is indicative of social context. The danger of time spent outside of such structures may have lead to the utilization of the most time efficient agricultural strategies over the highest yielding practices.

There is no evidence of saqia irrigation usage in the early Christian period at Kulubnarti although it is common in both the modern context and Lower Nubia in the preceding period. The poor general health of the Kulubnarti population (see Chapter 5 for more detail) indicates under nutrition of much of the population. This suggests that food stores were limited and that, at least periodically, resources were not sufficient to provide access to sufficient food for all members of the population. The lack of adequate food resources leads one to question the lack of use of saqia irrigation technology as it had been used in much of Nubia in the preceding era. However, heightened Nile floods may have already been providing water to the entirety of the arable land in the area. Expending additional energy to provide water to sand would be irrational in this context. Alternatively, the relative insecurity experienced while maintaining the saqia, clearing canals to maintain flow, and the cultivating of fodder for the oxen to power them may have been sufficient to deter its use in favor of more time-efficient strategies.

The utilization of flood irrigation would have limited the risk of schistosomiasis within the population. As opposed to canal irrigation systems which maintain a constant supply of water in main canals throughout the year, flood irrigation systems involve periodic flooding followed by a dry period. This dry period reduces vector habitat and the expansion of the vector snail population In addition, the schistosome life cycle requires six to eight weeks between the infection of a snail and the transmission of the infection to a mammal host.

Chapter 5: Health and Well-being at Wadi Halfa and Kulubnarti

Information about the general health derived from their remains provides the context for examining the influence of schistosomiasis on the health of these populations. Because of the high degree of preservation and archaeological interest in the area much is known about the health of Nubia's past inhabitants. Previous bioarchaeological research conducted on the Wadi Halfa and Kulubnarti populations provides an extensive database of health and well being in Lower Nubia and the Batn el Hajar. This chapter provides an overview of the bioarchaeological research completed on the general health of the Wadi Halfa and Kulubnarti populations utilized in this research. This demographic and paleoepidemiological data provides a context for studying schistosomiasis and its impact on health within these populations. The physiological stress experiences described here were shaped by the social, political, and ecological conditions discussed in the previous chapter.

Although the cemetery populations studied are not a direct reflection of the living populations from which they are derived, they provide insight into the health of these populations. It is commonly accepted by bioarchaeologists that the degree to which a skeletal population accurately represents the living population from which it is taken has a direct and significant influence on the usefulness of the bioarchaeological information which can be derived from it. There is some level of inherent bias as these cemetery populations were collected over an extended period and do not represent a single cohort of once living individuals or even individuals living at the same time (Angel, 1969; Larsen, 1997). There may also be additional bias resulting from differential mortality, exclusion of some individuals from communal burial locations, and taphonomic processes. Error results from the fact that skeletal samples do not represent the “normal, healthy, population from which it was drawn" (Johnston, 1962, p 249), they are those individuals who die at a specific age and are not representative of the average individual of that age. Therefore, they are likely to exhibit evidence of higher levels of physiological stress in the form of growth retardation, morbidity, and non-specific indicators of stress than the general population. The inclusion of very young and disabled individuals as well as the high degree of preservation in both the Wadi Halfa and Kulubnarti populations suggest cultural and taphonomic biases are limited.

Demographic Patterns

Demographic patterns provide a context of risk of death throughout the lifecycle in which to interpret other information about the health of archaeological populations (Van Gerven et al., 1990). Formal life table analysis was introduced to many working in skeletal biology and archaeology in the 1970s (Acsadi and Nemeskéri, 1970; Ubelaker, 1974) and soon became the standard means of demographic analysis of past populations (Frankenberg and Konigsberg, 2006). Although there were concerns early on about their use (Angel, 1947, 1969), life table analysis has been and continues to be the predominant means by which bioarchaeologists investigate population dynamics.

Life tables are calculated based on the number of individuals dying in each age group within a population. The number of individuals who die within an age group is influenced both by the relative proportion of the population in the age group and the proportion of individuals within the age group who die rather than surviving to enter the next age group. Many of the statistics derived from standard life table analysis, including life expectancy, are only valid under the assumption of a stationary population, one in which the age distribution is constant and the birth and death rates are equal (Johansson and Horowitz, 1986; Konigsberg and Frankenberg, 1992; Wood et al., 1992). Non-stationarity results in population demographics which are more closely linked to fertility than mortality (Sattenspiel and Harpending, 1983; Johansson and Horowitz, 1986). This is because a population which is growing will have a larger proportion of deaths in younger age groups than a stationary one even though the risk of death in each age group is the same in both populations because the growing population has a larger proportion of individuals in younger age groups. The degree of error introduced by the failure of past populations to meet the assumption of stationarity is proportional to the extent which the population violates the stationary assumption (Gage 1985) and mathematical adjustment for growth can be made (Moore et al. 1975). Thus, failure to meet the stationary assumption is not all that significant when divergence from stationarity is slight or accounted for. Based on an assumption that stochastic variation in growth rates varied around a mean of zero, Johansson and Horowitz (1986) suggest that cemetery populations accumulated over 300-500 year periods may approximate stationarity, but assert that stationarity is unlikely in populations accrued over more common, shorter intervals.

Growth and Development

Childhood is a period of physical growth and interruptions in this process are identifiable in skeletal remains. Rapid growth deceleration in early childhood and early growth cessation suggest developmental stress (Huss-Ashmore, 1981). Evidence of growth interruption can often provide information on the age at which an individual experienced physiologic stress and the type of disruption which caused the interruption. Growth, both in height and weight is a sensitive indicator of nutritional status in modern populations, although catch up growth following growth retardation can reduce sensitivity when studying adult stature attainment (Goodman and Martin, 2002). In skeletal materials both long bone growth and the deposition of cortical bone can provide information about the growth process and disruptions. Fluctuating asymmetry can provide additional information on physiologic stress during growth based on evidence of stress during development resulting in reduced symmetry (Deleon, 2007).

Because teeth are not remodeled evidence of previously experienced stress is retained regardless of the time lapse between the occurrence of physiologic stress and death. The age at which the stress occurred can be estimated as dental formation is well correlated with chronological age. The timing and severity of physiologic stress experiences can be utilized to estimate the magnitude of individual growth disturbances and potential causes. Accentuated striae of Retzius, pronounced incremental growth lines in tooth enamel, and linear enamel hypoplasias (LEH), transverse deficiencies in enamel thickness, both caused by interruption of enamel formation during crown development, provide information on stressed experienced prenatally to seven years of age (Goodman and Martin, 2002).

Porotic hyperostosis and cribra orbitalia are among the most prevalent of all pathological lesions found in archaeological populations (Walker et al., 2009). Porotic hyperostosis, an expansion of the diploe and thinning of the compact bone of the cranium exposing diplodic bone and resulting in a porous appearance of the skull (Stuart-Macadam, 1989), is thought to be a result of marrow hypertrophy to increase red blood cell production in response to anemia and is commonly observed in archaeological populations. Cribra orbitalia, a similar lesion found within the eye orbit, is thought to result from similar processes likely earlier in development than other forms of porotic hyperostosis (Walker, 1985; Stuart-Macadam, 1989). These conditions are commonly associated by bioarchaeologists with iron deficiency anemia, but Walker and colleagues (2009) argue that anemias causing premature red blood cell (RBC) death and increased erythropoiesis such as the megaloblastic and hemolytic anemias, provide a much more likely explanation for porotic hyperostosis than does iron-deficiency anemia in archaeological populations. However, not all cases of cribra orbitalia necessarily indicate anemia and additional causes should be considered. Wapler and colleagues (2003) histologically examined cribra orbitalia in 333 individuals and found no evidence of histological features indicative of anemia in 56.5% of the cases.

The morbidity and mortality information derived from children can provide important information about the health of the population as a whole as well as information about the social dynamics and resource allocation of a community. The increased sensitivity of infants and children to stress and their generally increased vulnerability relative to the rest of the population suggest that they may provide the first evidence of a downward shift in the health of a population (Goodman and Armelagos, 1989).

Diet

Isotopic analysis of archaeological remains provides information on the consumption patterns and resource allocation of past peoples. Analyses of different tissue types provide information on different aspects of diet. Carbon from bone and tooth apatite reflects overall consumption while carbon and nitrogen isotopes from cartilage reflect protein consumed. Differences in measures taken from these sources can be used to estimate the relative importance of animal and vegetable proteins (Turner et al., 2007). Because the isotopic values derived from tissues reflect diet during their formation, tissues vary in the age or time prior to death which isotopic data taken from them represents. Teeth provide information about childhood diet even in adult individuals due to the lack of remodeling. As bone is remodeled older osteons are replaced by newly formed ones reflecting the current diet. This results in an averaging of the diet over time in bone. Hair can provide information about diet shortly before death; longer hair samples provide data of a greater period of time (White, 1993). Utilization of a number of these tissues for isotopic analysis can provide information about consumption over the life course.

Disease and trauma

Evidence of diagnosable diseases and trauma within a population can provide additional insight into the health of ancient populations. The diagnosis of specific pathological conditions can provide information about the severity of the illness associated with the condition and the degree to which it would have influenced the life of the individual. Skeletal responses to infection can provide evidence of differences in exposure and resistance to disease within and between populations.

Trauma resulting in and evidenced by fractures and dislocations are serious injuries often with debilitating effects. Patterns of trauma experienced within a population can provide information about social interaction within and between communities and how the population interacted with their environment. The region and type of fracture may point towards possible etiology and provide information regarding the activity or occupations most likely to result in such injury (Grauer and Roberts, 1996). This can help distinguish between accidental and violence based patterns of injury.

Care provided to ill individuals and treatment of injuries and can provide insight into the social lives of past peoples. The degree to which a person with an illness or injury would have been disabled provides evidence of the amount of support provided by the community in which they lived (Brothwell, 1996). Healing of many fractures indicates immobilization and reduction of injured bones (Grauer and Roberts, 1996).

Bioarchaeology of Wadi Halfa

A total of 218 burials from the Ballana period have been excavated at Wadi Halfa, 54 from site 24I3 and 164 from the North Argin X-Group (NAX). There is no evidence of status differentiation between individuals in the form of differential burial or grave goods (Armelagos et al., 1965). This suggests that status differentiations may not have played a significant role in determining activity patterns or resource access. These populations are among the most extensively studied skeletal populations in the world (Miller et al., 1992).

Demographic Patterns

The mortality pattern of the Wadi Halfa population followed the general agriculturalist pattern of high mortality in small children which leveled off in later years. Women experienced higher mortality in early adulthood while males had greater mortality after age 30 (Armelagos, 1969). Multiple stress markers indicate that those dying in childhood experienced higher levels of stress than those surviving into adulthood (Rudney, 1983a).

Growth and Development

Growth patterns at Wadi Halfa, while not significantly different from modern children, suggest physiologic stress during development. Armelagos and colleagues (1979) found retardation in the growth of cortical thickness (juvenile osteoporosis) in three and four year-old children from the Ballana period at Wadi Halfa. Rudney (1983b) identified a pronounced increase in striae of Retzius occurring between 14 and 22 months of age. Roughly one third of all striae recorded were from this age period. A similar proportion occurred between 23 and 29 months of age. These patterns suggest physiologic stress in early childhood. Rudney (1983b) suggests these patterns may be indicative of weaning "crises," periods of extreme physiological stress associated with weaning. However, the Ballana period population experienced less stress as indicated by striae of Retzius than those in the preceding Meroitic period (Rudney, 1983a).

Forty-three percent of individuals under 21 years of age and 20% of adults examined from Wadi Halfa displayed signs of cribra orbitalia (Carlson et al., 1974). The crude frequency of cribra orbitalia increases from the Meroitic through the Christian period at Wadi (Vagn Neilson, 1970). The prevalence of cribra orbitalia in females decreased from the Ballana to the Christian period (Martin et al., 1984). These prevalences are much lower than those found within the Kulubnarti population which is attributed to the more economically prosperous nature of Lower Nubia as a free trade zone.

Utilizing the health of children as a more sensitive indicator of a populations health as a whole, Goodman and Armelagos (1989) reference high rates of porotic hyperostosis in contrast to very low rates of periostitis in the Wadi Halfa population and attribute the lack of evidence for infection to the consumption of tetracycline (Bassett et al., 1980; Cook, 1998; Stokol and Armelagos, 2002). The link between iron and tetracycline as well as the interactions between them which alter nutrient absorption (iron and calcium both reduce absorption of tetracycline (Leyden, 1985), while tetracycline appears to reduce absorption of iron (Neuvonen et al., 1975) make the interrelationship between these factors intriguing.

Both males and females from Wadi Halfa exhibit evidence of bone resorption with females experiencing bone resorption at earlier ages (Dewey et al., 1969). Histological examination of bone showed rapid resorption of the inner surfaces of subadult bone (Huss-Ashmore, 1981). Between the third and sixth decade of life females lost 10.7% of their cortical area while males lost only 4.9%. Loss of cortical area and cortical thickness in males is modest and steady, but females gain cortical bone between thirty and forty years of age and then exhibit rapid bone loss after 40 years of age (Martin and Armelagos, 1979). Premenopausal women lost 3.8 mm^2 of bone per year while older, likely menopausal women lost only 2.8 mm^2 per year (Van Gerven et al., 1985). This differential pattern of bone resorption is probably associated with increased calcium extraction from females due to gestation and lactation.

Diet

Martin and colleagues (1984: 211) identified general improvements in nutritional status during the Ballana cultural period in comparison to the preceding Meroitic period which they attribute to localized control and more equitable distribution of resources although there is a general pattern of nutritional insufficiency these periods associated with the intensification of agriculture.

Isotopic signatures from Wadi Halfa populations suggest a primary reliance on C_3 plants (wheat, barley, vegetables, and fruits) supplemented by C_4 plants (millet and sorghum); protein was obtained primarily from plant sources (Sandford and Kissling, 1994; White and Schwarcz, 1994). The general pattern of C_3 predominance may reflect the continual availability of C_3 vegetables and fruits from hand watered garden plots while a seasonal shift between C_3 and C_4 consumption with the harvest of wheat/barley and millet/sorghum is apparent in isotopic analyses of hair samples (White, 1993). Consumption of C_4 plants was greatest in the Ballana period (White and Schwarcz, 1994). Using Schwarcz et al.'s (1991) formula White and colleagues (2004) estimate that C_4 plants made up roughly 20% of the carbohydrates consumed in the Ballana period in contrast to 10% in the Christian period. As C_4 plants are more drought resistant this may represent an adaptation of the agricultural scheme in the region to the differing ecological conditions over time. It may also represent a loss of access to imported wheat and barley (White and Schwarcz, 1994).

Schwarcz and White (2004) fit the $\delta^{13}C$ values which indicate the relative concentration of C_3 and C_4 based contributions to the diet representing roughly 60 days of consumption prior to death of 17 individuals from the Ballana and Christian periods to a single plot. They propose a seasonal fluctuation in the consumption of C_3 and C_4 domesticates to explain the sinusoidal curve obtained with a frequency roughly equal to a year in length. However, the actual seasonal pattern cannot be conclusively determined as the season in which the individuals died is unknown. They suggest this pattern results from the consumption of primarily "in season," recently harvested grains. Roughly a quarter of the diet appears to have been derived by “off season” sources which they attribute to the consumption of animals and animal products from animals fed on sorghum and millet which are major fodder crops in the region today and C_3 fruits and vegetables from garden plots in the C_4 season.

Disease and Trauma

In addition to a number of common injuries and pathology including fractures, osteoarthritis, osteophytosis, and dental caries, a number of infrequently reported pathological conditions have been identified in the Wadi Halfa populations including carcinoma, sarcoma, osteochondroma, endochondroma, hydrocephaly, aseptic necrosis of the femur head, and hyperostosis frontalis (Armelagos, 1969, p 256). Several of these conditions including osteoarthritis and trauma increase throughout the Meroitic through Christian periods (Armelagos, 1968).

The populations of Wadi Halfa exhibit low prevalences of infectious and inflammatory disease although the frequency of infectious lesions increased over time (Armelagos, 1968; Martin et al., 1984). Ingestion of tetracycline may help to explain the unusually low levels of infectious lesions at Wadi Halfa (Bassett et al., 1980; Krafeld-Daugherty and Armelagos, 2000; Stokol and Armelagos, 2002). Several parasitic diseases have been identified within the Wadi Halfa samples including schistosomiasis (Miller et al., 1992; Davis, 1996), malaria (Miller et al., 1994), and infestation with lice (Armelagos, 1969).

Only three fractures were identified in 110 individuals (2.7%). All observed fractures were of the forearm (2 left ulnae, 1 right radius). All three fractures were in males. Traumatic cranial injuries were identified in 13.2% of Ballana period individuals (Armelagos, 1969). All of the traumatic injuries were to the crania either to the frontal or left parietal bones. There was no statistically significant difference in the prevalence of fracture or traumatic injuries between males and females (Anderson, 2010).

Bioarchaeology of Kulubnarti

The exceptional preservation at Kulubnarti suggests that paleodemographic reconstructions based on the cemetery populations are less subject to taphonomically induced biases and provides greater information on sex based differences than many other skeletal populations (Adams et al., 1999). There are two distinct cemetery sites at Kulubnarti, 21-S-46 (S cemetery) which lies along the west side of the island. The other, 21-R-2 (R cemetery) lies along the West Bank of the Nile. The S cemetery consists of roughly 300 graves, 215 of which were excavated in 1979. With the exception of two to five Ballana period and eight Islamic period burials, the cemetery has been dated to the Christian period. The lack of grave goods (a common feature of Christian period graves in Nubia) has made more specific dating of the materials problematic. The inclusion of Ballana period burials, fetal burials in Early Christian pottery types, and the use of brick having dimensions common in the Early Christian period in superstructures, and Early Christian textile shrouds on many burials suggest a date of (600-850AD) is appropriate (Adams et al., 1999).

Although the total expanse of the R cemetery includes an estimated 500 to 600 graves, only a small area of the cemetery was excavated in 1979 including 188 graves. The area excavated was the highest in the cemetery and least likely to have damage from flood waters; it is not a representative sample of the cemetery as a whole. The R cemetery was originally interpreted as coming into use about the same time as the S ceased to be utilized, but nearly all the burials excavated at R are now thought to be from the Early Christian period, contemporaneous with the S cemetery (Adams et al., 1999, p 26). Thus, past interpretations which concluded the populations of Kulubnarti experienced the greatest physiological stress during periods of political unification when they were "satellites" to larger outside political powers (Van Gerven et al., 1995) must be re-interpreted within the new chronological scheme.

Demographic Patterns

There is a clear distinction in the demographic patterns of the individuals buried in the two cemeteries from Kulubnarti. The S population exhibits a much higher percentage of individuals dying in infancy and childhood with the mortality patterns of the populations converging later in life (Van Gerven et al., 1990; Adams et al., 1999). The average age at death in the S and R cemeteries was 10.6 and 18.9 years, respectively (Adams et al., 1999, p 47). Only the R cemetery's mortality rate is within the range that can be compensated for by natural fertility (Adams et al., 1999, p 88) assuming a stationary population. The young average age at death in the S cemetery population may indicate that the population was growing and had high fertility or was experiencing very high childhood mortality. As the reduced average age-at-death in the S cemetery is accompanied by increased prevalence and severity of several indicators of poor health, it is unlikely that the distinction between the populations is due entirely to higher fertility in the S cemetery.

Growth and Development

Growth patterns in the children buried in the R and S cemeteries are similar up until the ninth year at which the S cemetery children fall behind (Hummert and Van Gerven, 1982, 1983; Van Gerven et al., 1990). R cemetery children appear to have experienced a later but more sustained adolescent growth spurt (Hummert, 1983). Periods in which children experienced little or no growth on average coincide with peak mortality and peak prevalence of active cribra orbitalia at 11 years of age in the S cemetery population. In contrast, cribra orbitalia peaks at age five in the R cemetery (Van Gerven et al., 1990). In addition, individuals buried in the S cemetery also exhibit greater fluctuating asymmetry, an indicator of increased physiologic stress during growth (Deleon, 2007).

All individuals from Kulubnarti have at least one hypoplasia (Van Gerven et al., 1990). Individuals buried in the S cemetery typically have hypoplasias formed during successive ages providing evidence that these children experienced stress events in rapid succession. Hypoplasias in R cemetery populations tend to be separated by roughly a year. This would suggest annual food stress and could indicate a yearly food shortage. Hypoplasias in the S cemetery population occur more frequently (Van Gerven et al., 1995). Evidence of tetracycline ingestion has been linked to consumption of moldy grain as indicative of diminished food stores (Van Gerven et al., 1995).

One third of all female pelves analyzed from Kulubnarti have pelvic dimensions that would, by modern standards, be diagnoses as contracted (Sibley et al., 1992). Small pelves are most likely related to general retardation of growth associated with nutritional stress during development. Reduced pelvic dimensions can lead to increased natal morbidity and mortality through obstructed labor as well as the reduced survival chances of low birth weight infants. As the modal age at death within the population is birth (i.e. most of individuals in the cemetery population died in the process of being born or shortly after birth), neonatal mortality was significant at Kulubnarti. The presence of female with a breech fetal skeleton within the Kulubnarti cemetery is a testament to perinatal mortality resulting from prolonged obstructed labor (Sibley et al., 1992).

Both cribra orbitalia and porotic hyperostosis are prevalent among the Kulubnarti sample, with the S population experiencing higher rates (94% of S and 82% of R population crania) and greater mortality (Van Gerven et al., 1990). The high prevalence of cribra orbitalia at Kulubnarti is indicative of high rates of anemia which is likely to have contributed to both growth retardation and impaired immune function (Mittler and Van Gerven, 1994). Those with cribra orbitalia had roughly half the iron and magnesium levels of those without such lesions (Sandford and Kissling, 1994). Since magnesium deficiency is almost always the result of digestive dysfunction as opposed to dietary insufficiency, this would indicate that these individuals likely suffered from diarrhea in the period shortly before their deaths (Johnson, 2001). This could indicate that the link between low iron and magnesium levels is modulated by the impact of iron insufficiency on immune system function (i.e. low iron reduces immune function which in turn increases the likelihood and severity of diarrheal disease resulting in individuals with cribra orbitalia and low magnesium levels). Turner and colleagues' (2007) evidence of similar isotopic profiles between the populations suggests that the increase cribra orbitalia rates in the S population is likely due to differences infectious disease and access to sufficient food rather than consumption of different types of food.

The absence of cribra orbitalia in very young infants at Kulubnarti suggests gestational stores were sufficient to prevent deficiency for a period (Adams et al., 1999). All individuals under one year of age with cribra orbitalia have active lesions (Mittler and Van Gerven, 1994). The prevalence of healing lesions increased until at 12 years of age all lesions show signs of healing. This age specific pattern of lesion frequency is in line with clinical evidence of iron deficiency in modern populations and supports Stuart-Macadam's (1989) assertion of cribra orbitalia as a condition of childhood. Cribra orbitalia appears a year earlier is the S cemetery population and active lesions remain longer than in the R cemetery population. In addition Mittler and coworkers (1994) found life expectancies for those with cribra orbitalia in the S cemetery were significantly reduced compared with those with cribra orbitalia in the R population.

Lesion frequencies in adult populations varied by age and sex with males between 16 and 40 years of age having higher lesion frequencies than females while this pattern is reversed in older individuals. Lesions also show significantly less healing in females which has been attributed to a combination of the mineral requirements of gestation and lactation and the general inability to maintain and produce bone in post-menopausal women (Mittler and Van Gerven, 1994; Sheridan and Van Gerven, 1997).

Males and females from Kulubnarti exhibit different patterns of bone growth and resorption. Females lost more cortical bone than males with age. While females tended to have larger osteons than males they exhibited fewer intact osteons (Mulhern and Van Gerven, 1997). Mulhern and Van Gerven (1997) suggest this distinction in male and female responses to stress may be the result of males taking part in heavier labor while females were involved in lighter but more time consuming tasks. A similar pattern was found by Burr and colleagues (1990) among the Pecos Indians. Both larger osteons and a greater number of intact osteons should provide greater resistance to fatigue (Corondan and Haworth, 1986).

Diet

Isotopic values indicate that there was no difference in the makeup of the diet of individuals from the R and S cemetery or between males and females. As numerous previous investigations have shown differential evidence of nutritional stress in the R and S cemetery populations (Van Gerven et al., 1990, 1995), this may indicate differences in the amount of food consumed, parasitic infection, or micronutrient consumption as opposed to the diet's makeup. Differences in the relative micronutrient composition of isotopically similar foods may, however, cause the populations to exhibit similar isotopic patterns and differ in their micronutrient consumption (Turner et al., 2007).

As opposed to the modern practice of weaning infants with millet gruel supplementation, the isotopic values of Kulubnarti infants suggest that weaning foods were C_3 rather than C_4 plants. Stable nitrogen isotopic values suggest a shift to milk from C_3 graving herbivores at weaning. Variation in isotopic signatures from infants suggests that no single weaning strategy was utilized throughout the Kulubnarti populations (Turner et al., 2007).

Turner and colleagues (2007) identified a distinct dietary pattern among Kulubnarti subadults which differed both from that of children and from the adult population. This may have been due to differential food allocation within households. Migration may also account for differences in subadult and adult isotopic rations.

Disease and Trauma

A number of infectious and chronic diseases have been identified through a variety of bioarchaeological means including leishmaniasis (Zink et al., 2006), maxillary sinusitis (Roberts, 2007), and a possible case of rheumatoid arthritis (Kilgore, 1989).

While there is also evidence for tetracycline ingestion at Kulubnarti, the levels consumed do not appear to have been significant enough to produce the ameliorative effects on infectious disease seen at Wadi Halfa. This may be the result of smaller food stores and less time for contamination of grain by tetracycline producing bacteria (Hummert and Van Gerven, 1982).

The Kulubnarti population exhibits a high level of skeletal trauma as evidenced by fractures (Kilgore et al., 1997). Many fractures exhibit angular deformation which suggests no attempt was made to set fractured bones. Sixty seven of 1788 long bones (3.7%) examined by Kilgore and colleagues exhibited healed fractures. The majority of the fractures identified were from the forearm (34 ulnae, 16 radii). The Kulubnarti population exhibits a markedly higher prevalence of arm fractures in comparison to other archaeological populations which Kilgore and colleagues attribute to accidental falls on the rugged terrain, ladder access to dwellings.

Key Distinctions between Wadi Halfa and Kulubnarti

While there are some important distinctions in political economic circumstances and health of the populations of Wadi Halfa and Kulubnarti, it should be remembered that these populations are genetically and culturally similar. Analysis of discrete dental traits and craniometric analysis have not identified significant differences between any of the populations at Wadi Halfa and those at Kulubnarti (Greene, 1982; Van Gerven, 1982).

In general, it appears that the population at Wadi Halfa experienced less stress than the populations of Kulubnarti as evidenced by multiple indicators of health. Individuals experienced lower rates of cribra orbitalia, infectious lesions, as well as less physiological stress as indicated by enamel formation and skeletal growth. This may be the result of the differing political and economic situations of Lower Nubia in the Ballana period (a relatively autonomous agrarian region) and the Batn el Hajar (economic barrier region between Muslim Egypt and the political center of Christian Nubia) during the Christian period. Differential agricultural productive capacity of the regions may also be linked to nutritional differences and their resultant influence on health. One of the most interesting distinctions between the populations at Wadi Halfa and Kulubnarti is the apparent presence of two groups of individuals living simultaneously in the area with very different experiences of health at Kulubnarti. In contrast, there is no archaeological indication of status difference in the three populations from Wadi Halfa (Armelagos 1968).

Conclusions

The health of a population is influenced by the physical and social environment and is evidence of the ability or inability of the cultural buffering systems to limit the physiologic stress experienced by that population. Nubians' relationship with the environment and the larger political combined and interacted to create the circumstances surrounding health and well being at Wadi Halfa and Kulubnarti. Trade and tribute relationships between Nubian peasants and elites of both regional and foreign powers had a significant impact on the health of populations both directly and obliquely. Climatic change and fluctuations in the level of the Nile had direct and immediate impact on the development of and feasibility of agriculture which can be identified historically, archaeologically and isotopically.

The weight of the bioarchaeological evidence from Kulubnarti indicates both more severe and more chronic stress than was experienced at Wadi Halfa. The two populations from Kulubnarti exhibit marked differences in health and well being of their members; those buried in the S cemetery exhibit higher levels of stress than in the R. While differential well being has previously been interpreted as associated with variation in political centralization and economic relationships experienced by the Kulubnarti populations (Van Gerven et al., 1981, 1995), recent recognition of the synchronicity of the burials from the R and S cemeteries (Adams et al., 1999) suggests some other explanation must be found for differences in the relative health of these populations.

At Kulubnarti the level of investment required for agricultural production was much less, yet there is clear evidence of differential access to resources within the population (Adams, et al. 1999). Although the population as a whole exhibits evidence of periodic resource shortages, one group was clearly less able to obtain adequate access to these resources than the other. This cannot, however, be as easily explained in terms of access to land through ownership in a saqia or power held as a result of control over the waters flowing from a saqia as might be done at Wadi Halfa. Adams (1999) suggests the disparity may be indicative of differential well being of a sedentary agricultural population relative to migratory pastoralists based on ethnographic observations made in modern Nubian populations. Additional archaeological evidence may clarify the matter.

Chapter 6: Research Design

The goal of this study was to determine the influence of saqia irrigation on the risk of schistosomiasis infection and its transmission in members of the Wadi Halfa and Kulubnarti populations with sufficiently preserved and recovered skin samples (N=237). Immunologic evidence of schistosomiasis infection was obtained for each individual studied. This data was analyzed in conjunction with existing bioarchaeological data to examine the epidemiological pattern of schistosomiasis mansoni and compare the relative risk of exposure/infection within populations and between the Wadi Halfa and Kulubnarti populations. This study further seeks to examine the impact of schistosomiasis infection and disease within these populations and its impact on the productive capacity of individuals, households, and the population as a whole in order to examine the net increase in productive capacity with the use of saqia irrigation.

Hypotheses

This research was conducted to test three major hypotheses centering on schistosomiasis transmission dynamics and infection within the populations.

Hypothesis 1

Ancient populations utilizing saqia irrigation in proximity to habitation sites such as the population at Wadi Halfa experienced greater risk of exposure and higher rates of transmission of schistosomiasis than less intensive irrigators such as those at Kulubnarti. Equivalent exposure prevalence of individuals from Wadi Halfa and Kulubnarti or a higher prevalence of infection at Kulubnarti would indicate that differences in the intensity of irrigation usage at the two sites were not the predominant factor in variation in schistosomiasis burden.

Hypothesis 2

The age-infection intensity patterns observed in Wadi Halfa and Kulubnarti will differ with the peak infection intensity occurring at an earlier age and at a higher level in Wadi Halfa than Kulubnarti. Empirical evidence from modern populations supports a shift in peak intensity of schistosomiasis infection associated with transmission intensity differences (Woolhouse et al., 1991; Fulford, 1992; Woolhouse, 1998). A peak shift would indicate that as a result of the use of saqia fed irrigation near habitation sites the risk of exposure through contact with canal waters in Wadi Halfa increased. It would also indicate that the transmission of schistosomiasis at Kulubnarti was relatively restricted by less intensive irrigation practices and their limiting effect on snail populations.

Hypothesis 3

The prevalence of schistosomiasis will be higher in males than females of both populations. Males generally experience higher prevalences and intensities of schistosomal infection in modern populations (Klein, 2004, p 249) and a higher prevalence of infection in males was found in previous research schistosomiasis in ancient Nubians from Semma South (Alvrus, 2006). Sex differences in prevalence are thought to result from differential exposure and/or modulation of the immune system by sex specific hormones (Klein, 2004).

Sample

In order to test the hypotheses proposed above, individuals were selected from the overall Wadi Halfa (N=562) and Kulubnarti (N=417) populations based on sufficient preservation and availability of soft tissues. The Wadi Halfa sample consists of 46 individuals excavated from two cemeteries (North Argin X group (NAX) and 24-I-3) near the modern city of Wadi Halfa utilized during the Ballana or X Group period (350-550 CE) and excavated in connection with the UNESCO Campaign to Save the Monuments of Nubia. Both sites are now under the waters of Lake Nubia. The Kulubnarti sample includes 117 individuals from 21-R-2 (R cemetery) and 74 excavated from 21-S-46 (S cemetery) dating to the Christian period (550 -1000 CE) and were disinterred as part joint expedition of the University of Colorado and the University of Kentucky. These sites, both located in Sudanese Nubia are separated by 130km on the Nile River with Wadi Halfa lying just below the second cataract and Kulubnarti just above the third in the region known as the Batn el-Hajar.

Tissue samples consisting of skin, muscle, and/or cranial contents were excised from the remains of each individual for immunologic analysis. The availability of desiccated soft tissue associated with individual burials from Wadi Halfa and Kulubnarti provided the opportunity for diagnosis of parasitic infections through immunodiagnosis and interpretation with reference to information on the age, sex, and health of the individual provided by the skeleton and soft tissues. There is some variation in the completeness of bioarchaeological information available based on the sampling methods used in previous research projects, but all have been examined for dental, cranial, and post-cranial pathologies and general indicators of physiologic stress; additional data on tetracycline consumption, isotopic ratios, as well as a number of specific skeletal pathologies is available for some individuals. Pathological data for both populations is detailed in Chapter Five: Health and Well Being in Wadi Halfa and Kulubnarti.

All individuals with available age data from both samples were placed into age categories following the classification system used by the Museum of London (N. Powers, 2008) and presented in Table 1. The populations have distinct demographic patterns; there is a larger proportion of infants, children, and adolescent individuals in the Kulubnarti population. Figure 3 illustrates the age structures of the Wadi Halfa and Kulubnarti samples.

Table 1: Age Categories Used

Category	Age	Wadi Halfa	Kulubnarti
Early Post-Natal	1-6 months	0	5
Later Post-Natal	7-11 months	0	9
Early Child	1-5 years	2	42
Later Child	6-11 years	3	25
Adolescent	12-17 years	2	15
Young Adult	18-25 years	8	14
Early Middle Adult	26-35 years	13	14
Later Middle Adult	36-45 years	2	33
Mature Adult	46+ years	3	16
Unknown		13	18

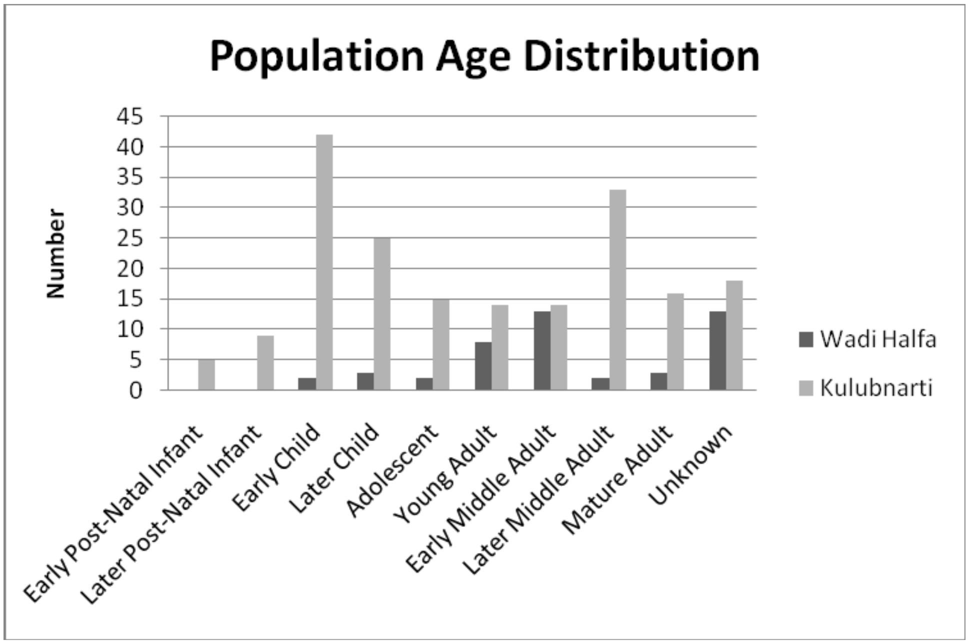

Figure 3: Population Age Distributions for Wadi Halfa and Kulubnarti

Figure 4 provides the distribution of each sample by sex. The large proportion of unknown sex individuals in the Kulubnarti sample is the result of the young age of many of the individuals.

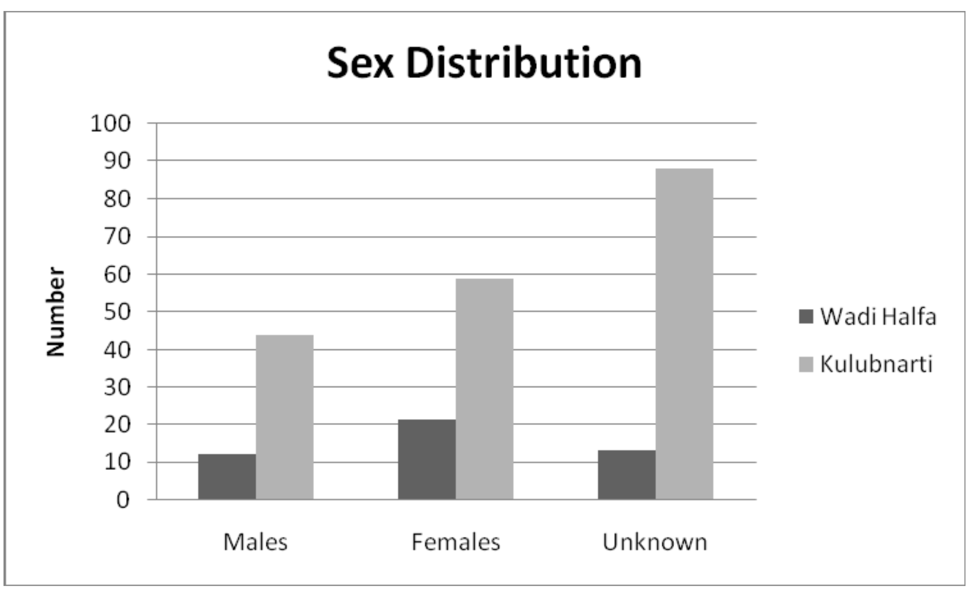

Figure 4: Population Sex Distributions for Wadi Halfa and Kulubnarti

Data Collection: ELISA Diagnosis

Immunological testing provides a more reliable means of differentially diagnosing pathologies in archaeological populations than visual inspection of the skeleton (Miller et al., 1996) and is far less dependent on the length or severity of infection than skeletal diagnosis. Immunodiagnosis also provides a greater opportunity to identify the burden of disease in a population through quantification of antigen levels. Most importantly, immunologic diagnosis provides the ability to identify infections which leave no unique indicators in skeletal morphology, such as schistosomiasis. Additionally, immunological testing may provide the opportunity to diagnose schistosomal infections in cases in which schistosome eggs cannot be identified microscopically in coprolite samples due to taphonomic alteration of the schistosome eggs.

This direct empirical test of schistosomiasis infection provides the opportunity to investigate schistosomiasis infection and its influence on population health in archaeological samples. Previously, researchers have applied immunodiagnostic techniques to a subset of the Wadi Halfa sample (n=23) and found evidence of endemic schistosomiasis (Miller et al., 1992).

Sample Preparation

The preparation of samples was conducted under stringent, diagnostic-quality conditions in the Emory University Anthropology Laboratories to ensure that no cross contamination of samples occurred. All immunologic testing was conducted at the laboratories of the Centers for Disease Control and Prevention's Division of Parasitic Diseases (CDC, DPD) in Chamblee, Georgia.

A number of techniques have been used to extract antigens from mummified remains for ELISA analysis. Prior to preparing the samples to be tested for this research, four methods were tested for antigen yield in sample processing. Skin samples from three individuals whose provenience has been lost were prepared following each sample preparation protocol.

Protocol one followed Deelder and colleagues (Deelder et al., 1990; Miller et al., 1992). One hundred and fifty milligrams of sample tissue was homogenized with 1ml phosphate buffered saline (PBS) on ice in an all glass homogenizer and centrifuged at 16000 g for 35 minutes. The supernatant was mixed with an equal volume 14% trichloroacetic acid (TCA) solution to obtain a 7% solution and spun down at 16000 g for an additional 35 minutes. The supernatant was dialyzed against distilled water through an 8 kDa membrane for 24 hours at 4 C and desiccated. Samples were reconstituted in 250 µl of PBS + 0.05% Tween. *Protocol two* was identical to protocol one with the exception of the use of a steel homogenizer. In *protocol three* 150 mg of tissue was combined with 0.3 ml PBS in a polypropylene tube and subjected to three freeze/thaw cycles consisting of 10 sec in liquid nitrogen followed by 10 sec in boiling water. After three cycles, the samples were sonicated for 15 min in ultrasonic bath. Following sonication, samples underwent an additional freeze/thaw cycle. Suspensions were incubated for 24 h at 4 C warmed to 37 C for 30 min to solubilise remaining antigens and centrifuged at 14000 rpm for 20 minutes. An aliquot of the supernatant was used in the ELISA (Bianucci et al., 2008). *Protocol four* was identical to protocol three except that the length of submersion in liquid nitrogen and boiling water was increased to 30 sec per cycle. After preparation, samples from the three individuals prepared following each protocol were tested in a single assay. After comparison of the antigen yield from each method, it was concluded that protocol two was the most efficient means of sample preparation.

Samples previously tested negative and positive by Miller and colleagues (1992) were utilized as control samples. Negative and positive control samples were prepared in the same manner as other samples.

ELISA

Many immunological tests for schistosomiasis infection focus on the identification of circulating cathodic antigen (CCA) and/or circulating anodic antigen (CAA). Both substances are antigens in the adult worm gut and are released into the host blood stream (Barsoum et al., 1991). However, they are relatively quickly eliminated so that their presence in mummified remains is indicative of infection at the time of death. Because the concentration of antigens in a tissue sample is largely dependent upon the number of schistosomes in the individual (Agnew et al., 1995; Van Lieshout et al., 1995a), antigen concentrations will serve as a biomarker of infection intensity. CCA levels in human serum have been shown to correlate well with egg counts in repeated samplings (Van Lieshout et al. 1995). This suggests CCA levels provide an accurate reflection of current worm burden (Polman et al., 2001). As circulating antigen levels show less day to day variability, they provide a more quantitatively stable measure of infection intensity than egg count (Polman et al., 1998). However, the level of antigens detected in mummified tissues is largely dependent upon the vascularization of the tissues. Hence, measurement of CCA from well vascularized tissue samples would suggest higher intensity infections than less vascularized tissue samples from individuals with similar intensity of infection. Comparison of infection intensity based on antigen concentration between individuals would therefore be dependent upon the ability to obtain tissue samples of known anatomical source and similar vascularization.

An enzyme-linked immunosorbent assay (ELISA) was used to detect biotinylated *S. mansoni* CCA. This technique utilizes an IgM monoclonal antibody (5H11) that binds a carbohydrate epitope that is expressed on *S. mansoni* antigens. 5H11 is specific for *S. mansoni* and not able to detect CCA from *S. haematobium*. The sandwich-linked ELISA is a technique in which the antigen under investigation is "sandwiched" between a pair of antibodies specific to the antigen, one initially attached to the test well and an additional antibody which attaches to the antigens after they have become incorporated in antibody-antigen complexes within the test wells. The presence or absence of the antigen is indicated by a reaction which produces color in proportion to the amount of the antigen in the sample. A positive diagnosis can be made visually by comparing the color of test wells to negative control wells. More quantitatively precise estimates of antigen levels in the sample can be produced by measuring the color change using an optical reader.

The assay was conducted according to Karanja et al. (1997) with the addition of 5% non-fat dried milk as a blocking protein to the assay buffer. Briefly, 50 µl of 5µg/ml solution of 5H11 antibody in 0.05M sodium carbonate buffer (pH 9.6) were added to each well in test plates. Plates were allowed to coat at 4 C overnight. The next morning, the coating solution was discarded and 100 µl of phosphate buffered saline (PBS)+5% non-fat dried milk +0.3% Tween 20 was added to each well. The plates were allowed to block for 1 hour at room temperature. After blocking, plates were washed five times with PBS+.05% Tween 20 and patted dry. A standard curve of schistosome worm antigen preparation (SWAP) was prepared with concentrations of 10, 2.5, 0.625, 0.1562, 0.0390, and 0.0 µg/ml SWAP in 300 µl 0.85% NaCl. To each of the curve preparations 300 µl 4% trichloroacetic acid (TCA) was added to precipitate followed by 600 µl 0.25M, pH 9.6 $NaHCO_3$ for carbonate neutralization. Triplicate wells of prepared test samples, prepared positive and negative controls, and prepared standards were produced by adding 50 µl of the appropriate solution to each well. Blank, biotinylated antibody, and avidin-peroxidase control wells had 50 µl PBS+0.3% Tween 20 added. Plates were then incubated at room temperature for one hour. Plates were again washed five times with PBS+.05% Tween 20 and patted dry. Then 50 µl of a 1:250 solution of biotinylated 5H11 in PBS+0.3% Tween 20 was added to each test well and the avidin peroxidase control; 50 µl PBS+0.3% Tween 20 was added to the biotinylated antibody control and blank wells and the plates were allowed to incubate at room temperature for one hour. Following another wash cycle, 50 µl of a 1:500 solution of avidin peroxidase in PBS+0.3% Tween 20 was added to all but the biotinylated antibody control, avidin peroxidase control and blank wells to which 50µl PBS+0.3% Tween 20 was added. Plates were again allowed to incubate at room temperature for one hour. Plates were again washed five times with PBS+.05% Tween 20 and patted dry. Plates were then developed by adding 50 µl TMB solution to each well and waiting five minutes. The reaction was stopped by adding 50 µl 1:7 H_2SO_4 to each well. Plates were then read at 450 nm by an electronic plate reader. The optical density of each well was measured and recorded.

The optical density measurements for the SWAP standard curve as well as the blank, biotinylated antibody, and avidin-peroxidase control wells were examined to assure the accuracy of antigen concentration readings. If the standard curve values did not produce the expected curve or the control wells varied from zero, the plate was discarded and the samples retested. Antigen concentrations for each sample were calculated by comparison with the SWAP standard curve. The mean of the antigen concentration for the replicates was calculated and those which exceeded the mean of the negative controls by more than two standard deviations were considered positive. Readings from negative and positive control wells were checked and were consistently appropriately categorized.

Epidemiologic Analysis

The pattern of infection within a population as well as the intensity of individual schistosomal infections influence the impact of morbidity associated with schistosomiasis. Investigation of these patterns made it possible to estimate schistosomiasis disease burden in these populations and provided insights into the relationship between prevalence and irrigation usage.

Data obtained through immunodiagnostic testing was utilized to produce the epidemiologic data necessary to test the hypotheses. The total population prevalence of infection and the prevalence of infection within age and sex subgroups were calculated for each population using SPSS. Based on the size of the sample and estimates of prevalence from previous investigations (Miller et al., 1992; Davis, 1996), the minimum prevalence difference between Wadi Halfa and Kulubnarti which would be statistically significant at a 95 percent confidence level was ten percent.

Schistosome infections commonly last for years such that infections acquired in early life are likely to remain in individuals in adulthood. As a result, older populations, with greater cumulative exposure over the life course are likely to exhibit higher prevalence of infection than younger populations with similar transmission dynamics. In order to avoid erroneous conclusions regarding the prevalence of schistosomiasis within these populations resulting from age structure variation between them, the population prevalences were standardized to the age distribution of the combined Kulubnarti population and the age-adjusted prevalence of *S. mansoni* infection calculated. Age adjusted prevalence per 1000 individuals for each group was computed by summing the weighted age-specific prevalences in each age category. While Baker & Pearson (2006) utilized a chi square to test based on the prevalence per 1000 values obtained from the age-adjustment, the chi square values obtained in this manner are artificially inflated. Instead, the chi square test calculations were performed using observed values calculated based on the sample size and age-adjusted prevalence.

Limitations

The information that can be gained from paleoepidemiological studies is inherently limited by the information available from mortuary collections. As this is an archaeological cemetery sample, it does not represent a random sampling of the living populations at Wadi Halfa and Kulubnarti at any point in time. A collection of individuals buried within a cemetery lived and died at various times within the period in which the cemetery was in use. While modern epidemiological investigations are able to utilize point prevalence estimates, bioarchaeologists rarely have the opportunity to work with a group of individuals who lived simultaneously. Period prevalence estimates are the best that can be achieved from a cemetery collection unless the death of each individual can be accurately dated (Mendonça de Souza et al., 2003). Additional bias resulting from differential mortality, exclusion of some individuals from communal burial locations, and taphonomic processes complicate the matter further.

Conditions which influence the risk of mortality are likely to result in prevalence overestimation within cemetery populations. While schistosomiasis is linked to mortality in modern populations, the risk of mortality associated with infection is very low. Estimates of the annual mortality associated with schistosomiasis range from 11,000 (WHO, 2001) to 200,000 (van der Werf and de Vlas, 2001; Hotez et al., 2006) despite a global prevalence of 200 million individuals with schistosomiasis. Because schistosomiasis leads to morbidity rather than mortality in the vast majority of cases, mortality bias is less likely to distort the prevalence in cemetery populations. Therefore, the prevalence of schistosomiasis in the cemetery populations of Wadi Halfa and Kulubnarti should more closely resemble the prevalence in the living populations than for conditions more strongly associated with mortality (Waldron, 1994).

Systematic practices of exclusion of specific members of the population from communal burial (Buikstra, 1981; Gowland and Chamberlain, 2002) and differential preservation, most commonly through under numeration of the very young the elderly (Paine and Harpending, 1988), have significant influence on paleodemographic reconstructions, the paleoepidemiologic data derived from such samples, and the interpretations made about the health and well being of these populations. The presence of the very young in addition to obviously handicapped or deformed may provide evidence of the inclusiveness of burial in a cemetery (Meindl and Russell 1998). The quality of the preservation, the inclusion of remains from a large number of children and infants, and the lack of evidence for differential mortuary practices suggest these samples are a relatively complete sample of the populations buried in these locations, however the low number of young individuals with available skin samples from Wadi Halfa clearly reduces the ability to accurately estimate prevalence in young age groups.

Chapter 7: Immunoepidemiology of Schistosomiasis

This chapter includes text from the pre-peer reviewed version of the following article: Campbell Hibbs A, Secor WE, Van Gerven DP, and Armelagos GJ. Irrigation and Infection: The Immunoepidemiology of Schistosomiasis in Ancient Nubia, which will be published in final form in the American Journal of Physical Anthropology.

Interpopulation Prevalence Difference - Wadi Halfa v. Kulubnarti

Prevalence data for the Wadi Halfa and Kulubnarti populations is presented in Figure 5. The overall prevalence of *Schistosoma mansoni* infection in the Wadi Halfa population was 26.1%. Initially, the R and S cemeteries were considered independently. After a preliminary analysis showed no evidence of any statistically significant differences between the populations, they were grouped for all further analyses. The overall prevalence of schistosomiasis mansoni in the combined Kulubnarti population was 9.4%. The difference in infection prevalence between Wadi Halfa and Kulubnarti is statistically significant (Pearson Chi Square p=0.002). Further, age specific analysis showed this difference is only significant (Fisher's Exact Test p=.018) in the mature adult age group when comparisons are made within each age category. There is a statistically significant difference in the prevalence of infection between Wadi Halfa and Kulubnarti females (Fisher's Exact Test p=0.011). In age specific analysis, this difference is only significant in the mature adult category (Fisher's Exact Test p=0.029). There is not a statistically significant difference in the prevalence of *S. mansoni* infection between males in Wadi Halfa and Kulubnarti samples for the overall population or in any age category.

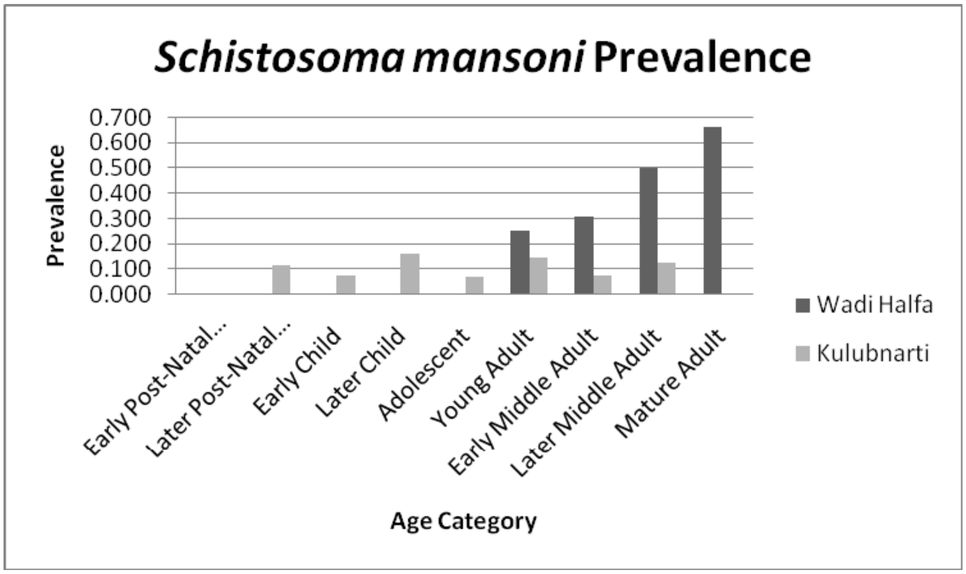

Figure 5: Prevalence data for Wadi Halfa and Kulubnarti Populations

Given the discrepancy in age distributions of the Wadi Halfa and Kulubnarti populations, age-adjusted prevalence values were calculated to ensure that the prevalence difference between populations was not due to the difference in age of the populations (Baker and Pearson, 2006).The prevalence estimates for each population were standardized to the age-distribution of the Kulubnarti population over one year of age. Only individuals one year of age or older (early child and older age groups) were included in the age-adjusted prevalence analysis as there were no individuals in younger age categories in the Wadi Halfa population. I calculated age adjusted prevalence per 1000 individuals for each group by summing the weighted age-specific prevalences in age category. Age-adjusted prevalence calculations are presented in Table 2 and Table 3. Age-adjusted comparisons produce similar results to the analysis of raw prevalence data with an age-adjusted prevalence of 221.063 per 1000 or 22.1% for the Wadi Halfa population and 96.043 per 1000 or 9.6% for the Kulubnarti population. This is statistically significant (p=0.021).

Table 2: Age Adjusted Prevalence - Wadi Halfa

	N	% of Population	Cases	Prevalence per 1000	% of Kulubnarti Population	Age Specific Prevalence
Early Child	2	0.043	0	0.000	0.237	0.000
Later Child	3	0.065	0	0.000	0.141	0.000
Adolescent	2	0.043	0	0.000	0.085	0.000
Young Adult	8	0.174	2	250.000	0.079	19.774
Early Middle Adult	13	0.283	4	307.692	0.079	24.337
Later Middle Adult	2	0.043	1	500.000	0.186	93.220
Mature Adult	3	0.065	2	666.667	0.090	60.264
Unknown	13	0.283	3	230.769	0.102	23.468
	46		12			
		Wadi Halfa age-adjusted prev.				221.063

Table 3: Age Adjusted Prevalence – Kulubnarti

	N	% of Population	Cases	Prevalence per 1000	% of Kulubnarti Population	Age Specific Prevalence
Early Child	42	0.237	3	71.429	0.237	16.949

Later Child	25	0.141	4	160.000	0.141	22.599
Adolescent	15	0.085	1	66.667	0.085	5.650
Young Adult	14	0.079	2	142.857	0.079	11.299
Early Middle Adult	14	0.079	1	71.429	0.079	5.650
Later Middle Adult	33	0.186	4	121.212	0.186	22.599
Mature Adult	16	0.090	0	0.000	0.090	0.000
Unknown	18	0.102	2	111.111	0.102	11.299
	177		17	96.045		
			Kulubnarti age-adjusted prev.			96.045

Age at Peak Infection Prevalence

There is no evidence of *S. mansoni* infection in sub adults (n=7) within the Wadi Halfa population. This is likely the result of a small number of young individuals and low prevalence rather than a complete absence of infection. The prevalence of infection increased in each age category with the highest prevalence occurring in the mature adult category (66.7%). Infection was detected in individuals from all age categories except early post-natal infants and mature adults at Kulubnarti. The youngest positive individual was 9 months old and the oldest was greater than 40 years of age. Prevalence of infection detected within age categories fluctuates erratically and did not follow any pattern with age. This is most likely the result of a relatively small sample size and very low prevalence. The highest prevalence (16.0%) was found in the later child category (6-10 years) followed by the young adult category (18-25 years) (14.3%). Contrary to our prediction, peak infection prevalence did not occur in a younger age category at Wadi Halfa than in Kulubnarti.

Sex differences in prevalence

The prevalence of infection in females at Wadi Halfa (33.3%) was slightly higher than in males (25.0%), however, this was not statistically significant (Fisher's Exact Test p=0.710). There were no statistically significant differences in prevalence between males and females in any age category. However, there does appear to be a difference in the pattern of prevalence with age. As shown in Figure 6, prevalence increases with each age category following early middle adult in females, while male prevalence peaks in young adults and decreases thereafter.

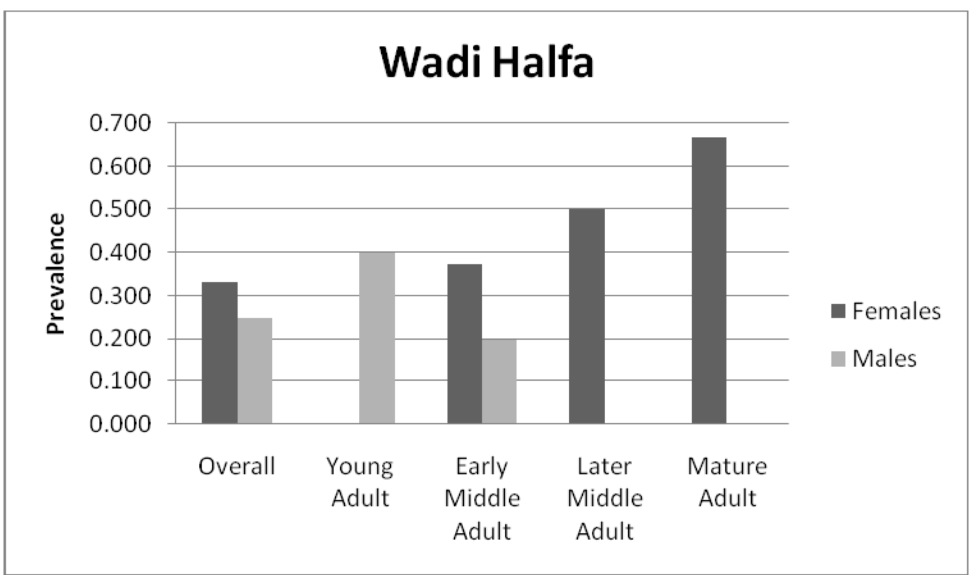

Figure 6: Prevalence data by sex for Wadi Halfa

The prevalence of infection in females at Kulubnarti (8.5%) was similar to that of males (9.3%) (Fisher's Exact Test p=1.00). As seen in Figure 7, the same pattern of fluctuating prevalence by age category exists within sex subgroups as in the total population. This is most likely the result of a small sample size and low prevalence. Only four males and five females were infected in the population and subdividing into age categories results in prevalence variation. Within age categories where infections were identified, the prevalence of schistosomiasis among males was higher than females in the early middle adult and later middle adult categories, but lower in the young adult category. As in the Wadi Halfa population, none of these differences were statistically significant. The highest prevalence occurred in the young adult age category in females (28.6%) and the later child category in males (33.3%) although only 3 individuals are included in this category likely resulting in an inflated prevalence value.

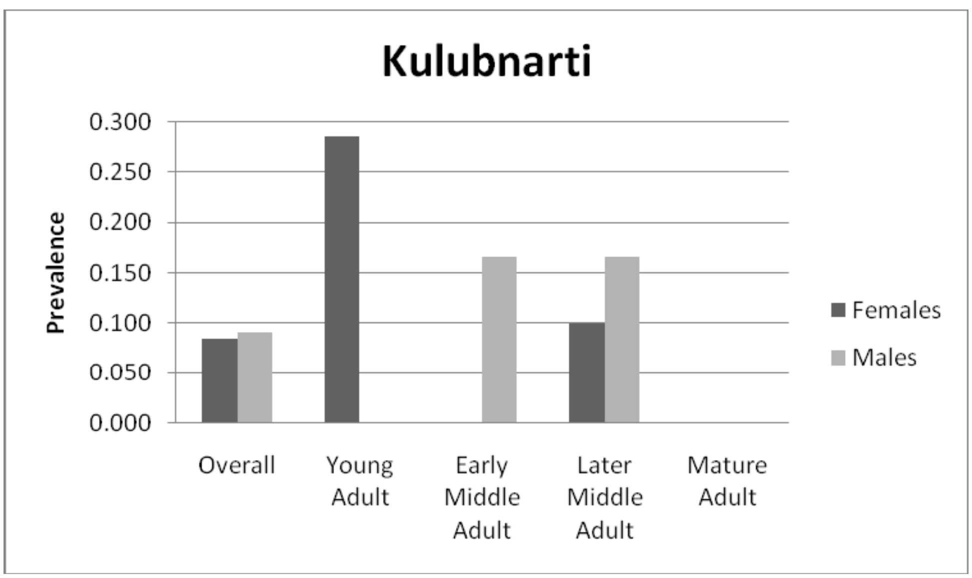

Figure 7: Prevalence data by sex for Kulubnarti

Although neither population exhibits a statistically significance difference in prevalence between males and females, the peak prevalence for males occurs in a younger age category than for females in both populations.

Discussion

Variation in the prevalence of schistosomiasis mansoni within and these populations can be better understood within the cultural context of exposure and transmission (i.e. social constructions of activity patterns associated with exposure to contaminated water that may vary between individuals of different ages and genders). We were interested in seeing if the socioecolgoical model would help us understand differences in schistosomiasis experienced at Wadi Half and Kulubnarti. Based on archaeological evidence for saqia irrigation, which is associated with additional snail habitat and known to facilitate transmission in modern populations, at Wadi Halfa and the lack of evidence thereof at Kulubnarti, we hypothesized that the Wadi Halfa population would have a higher prevalence of schistosomiasis, younger age at peak prevalence and a greater disparity between prevalence in males and females due to gendered water contact behavior.

In modern populations, the prevalence and intensity of *S. mansoni* infection varies widely between communities. Schistosomiasis mansoni in Egypt is highest near the Nile Delta region and decreases upstream. Infections are rarely found in modern populations living along the Nile in Upper Egypt and Northern Sudan; only in the Fayoom governate did prevalence reach 4.3% (Abdel-Wahab et al., 2000). However, prevalence estimates between 40 to 50 percent have been made for populations living near recently implemented irrigation schemes in the region (El-Sayed et al., 1995). The prevalence of schistosomiasis is generally underestimated due to variations in fecal egg presence and count (the most commonly used technique for infection diagnosis) (de Vlas and Gryseels, 1992).

As previously noted, patterns of schistosomiasis transmission and infection prevalence in archaeological populations such as Wadi Halfa and Kulubnarti were likely primarily determined by the distribution of appropriate habitats for intermediate aquatic snails hosts and water contact patterns (Brooker, 2007). Habitat distribution is influenced by local geography and climate as well as human alteration of the environment while water contact patterns will be shaped by more general activity patterns relating to water. As expected, the Wadi Halfa population had a higher prevalence than the Kulubnarti population. This follows the pattern of higher prevalence in populations living near irrigation schemes in modern populations (Kloos et al., 1983; Abdel-Wahab et al., 2000; Steinmann et al., 2006).

Both populations differ from the pattern typically seen in modern populations of peak infection prevalence in adolescence or early adulthood with declining prevalence thereafter (Jordan and Webbe, 1982; Woolhouse et al., 1991; Fulford, 1992; Pearce and MacDonald, 2002). In the Wadi Halfa population, peak prevalence occurred within the mature adult age category much later than generally seen in modern endemic populations. This is not, however, entirely unheard-of in modern populations. Van Lieshout and colleagues (1995b) found a similar epidemiologic pattern with a peak level of prevalence and infection intensity occurring between 40 and 49 years of age in a modern low transmission endemic area. They suggest that infection intensities did not reach a level needed to induce an immunity producing response thought to result in decreased prevalence and intensity of infection with age. If the prevalence and intensity of infection within these ancient populations followed a similar pattern to that shown by Katabereine and colleagues (2004), it would suggest the delay in peak prevalence may be explained by a relatively low average intensity of infection. Low prevalence peaks occurring at older ages are generally associated with low rates of infection transmission (Woolhouse, 1998). The pattern of fluctuating prevalence with age seen at Kulubnarti is the result of small sample sizes within age categories relative to that needed to accurately estimate prevalence in a population with very low prevalence (Jovani and Tella, 2006) rather than a true pattern of random fluctuations in prevalence between age categories. However, insignificant differences in prevalence and intensity of infection with age have been noted (Birrie et al., 1998).

There was no statistically significant difference in prevalence between males and females within either the Wadi Halfa or Kulubnarti collections for the total sample or within age categories. The lack of statistical significance may be due to lack of power due to small sample size. Given the current sample size, a difference in prevalence less than 46.8% in the Wadi Halfa sample and 21.1% in the Kulubnarti sample would not be statistically significant (alpha =0.05, power = 0.20). Smaller sample sizes within age categories require even greater differences in prevalence to be identified as statistically significant. However, the peak prevalence occurred at a later age in females than males at both Wadi Halfa and Kulubnarti. If this is interpreted as evidence of lower transmission rates for females, this would be consistent with our predictions of age associated gendered differences in activity leading to differential exposure patterns.

Alvrus (2006) utilized an ELISA which was only specific to the genus level (i.e. identifies both *Schistosoma mansoni* and *S. haematobium* infections, but cannot distinguish between the two) within a population of individuals living in Semma South in the Batn el Hajar in the preceding Meroitic period (350 BC-350CE). In that study 69% of the total population was infected by at least one species of schistosome, with prevalence reaching 100% in young adult males. Prevalence of infection in both males and females decreased with age after early adulthood. Since Alvrus' study includes both *S. mansoni* and *S. haematobium* infections, it is difficult to know how the prevalence of *S. mansoni* infections compares to those found here.

Several limitations of the data presented must be acknowledged. As discussed previously, variation in antigen presence due to tissue vascularization cannot be controlled for in this sample. As a result, individual samples may not contain detectable schistosome antigens due to low vascularization despite being taken from infected individuals. Such false negatives result in underestimation of prevalence; the true prevalence of schistosomiasis within the population was likely higher than presented here. Conducting tests on multiple tissue samples from the same individual would reduce this, but the benefit of the potential increase in the accuracy of prevalence estimates was deemed insufficient to justify the repetitive use of a destructive technique. Doenhoff and colleagues (1993) suggest the sensitivity and specificity of ELISA diagnosis is comparable to microscopic diagnostic techniques. Estimates of true prevalence have been made based on a single diagnostic test per individual and the average intensity of infections (as measured by egg count) diagnosed within a population (de Vlas et al., 1993, 1997) and antigen concentrations have been shown to be correlated with egg count

(Van Lieshout et al., 1995a). However, the influence of tissue vascularization also confounds comparisons of antigen concentrations.

In addition to the specific limitations of the sample, the data are inherently limited in the same manner as all epidemiological data derived from archaeological populations by the information available from archaeological populations/mortuary collections. As a cemetery collection is not a single cohort of once living individuals or even a group of people living simultaneously. They are thus inherently distinct from the living populations from which they are derived. As a result, a period prevalence over the duration of the cemetery's use is the best that can be achieved (Mendonça de Souza et al., 2003). Exposure to schistosomiasis and infection prevalence may have varied over the period in which individuals were buried within these cemeteries in ways that cannot be known. Additional bias resulting from differential mortality, exclusion of some individuals from these burial locations, and taphonomic processes complicate the matter further. These data only represent those buried within these cemeteries, excavated, and from whom tissue samples were obtainable. Because schistosomiasis leads to morbidity rather than mortality in the vast majority of cases, mortality bias is less likely to distort the prevalence of this infection within archaeological populations. Hence, the prevalence of schistosomiasis in the cemetery populations of Wadi Halfa and Kulubnarti may better reflect the prevalence of schistosomiasis in the living populations than diseases more closely associated with mortality (Waldron, 1994).

Conclusions

Understanding the health impact of disease in the past is dependent on our understanding of the same conditions that influence human impact of disease in modern populations (Ubelaker, 2003). While some aspects of social determinants of schistosomiasis exposure cannot be known, the impact of human alteration of the environment in the distribution of aquatic snail habitat and transmission of schistosomiasis is clearly shown in these populations. Just as in modern contexts, irrigated agriculture contributed in a significant and negative way to schistosomiasis burden (Dougherty and Hall, 1995; Jobin, 1999).

These results are also interesting with regard to the Nile Shift, a change in the predominant species of infection in the Nile Valley from *Schistosoma haematobium* to *S. mansoni* (Jobin, 1999). It has generally been assumed that in ancient populations schistosomiasis was primarily caused by *S. haematobium* (Contis and David, 1996; David, 2000; Kloos and David, 2002) and that *S. mansoni* gained predominance over *S. haematobium* due to the intensification of irrigation practices in the 20th century. The increased relative importance of *S. mansoni* over *S. haematobium* in later periods has been linked to the greater ability of *Biomphalaria* snails, the host of *S. mansoni,* to survive in less oxygenated and polluted waters such as those commonly created within irrigation schemes in comparison to the *Bulinus* snails which serve as the host of *S. haematobium* (Jobin, 1999; Kloos and David, 2002). As *S. haematobium* infections were not diagnosed, it is unclear which species predominates or how the epidemiology of these infections differ. However, the inclusion of *S. haematobium* infections would likely result in an increase the prevalence of schistosome infection as both infections almost undoubtedly existed within these populations. In modern contexts, the relative prevalence of *S. mansoni* increases in populations with increased exposure to water more hospitable to *S. mansoni*'s intermediate snail host. This shift may have occurred even in early, less extensive irrigation schemes intermittently throughout the history of the Nile Valley. Further testing to *S. haematobium* should clarify the issue.

How would this have impacted the health of these populations? Infected individuals may have experienced anemia, fatigue and chronic pain. Those with higher infection intensity likely experienced more severe symptoms of anemia, and possibly liver fibrosis, portal hypertension, hepatosplenomegaly likely to cause significant disability (King and Dangerfield-Cha 2008). The symptoms of schistosomiasis detailed in Chapter 3 suggest infected individuals The data presented here along with information from previous research on a number of other indicators of health including non-specific stress indicators and growth will be incorporated into an analysis of the impact of schistosomiasis on general health within these populations in order to develop a more complete picture of schistosomiasis in the past.

Chapter 8: Parasitism and Productivity

The Economic Impact of Irrigation and Schistosomiasis at Wadi Halfa and Kulubnarti

Cultural buffering systems mediate the impact of environmental constraints on human health (through reduction of physiologic stress). The types of buffering systems needed within any environment are dependent upon both environmental stressors and limiting resources. Environmental stressors include extremes of heat and cold, humidity and aridity, etc. The accessibility of limiting resources such as land, labor, and water constrain cultural buffering options. These limitations may exclude the implementation or limit the effectiveness of buffering systems. As a result, there is significant variation in the implementation of buffering systems within and between communities. Attempts to buffer constraints can also unintentionally induce stress by creating new environmental stressors or by limiting the availability of resources for other uses.

Nubia is a “hot barren land of few resources" (Adams, 1977, p 19) and the extreme aridity of the region is a considerable environmental constraint on subsistence. Irrigation provides a means of culturally mediating these environmental constraints on water availability. Irrigation can compensate for insufficient or excessive water for agricultural production which can stabilize and increase yields, making it possible to feed a larger number of people and increase population density, but this does not imply that irrigation must be utilized to sustain a population or will be utilized by all households for their holdings. Availability of land and labor are also important influences on the use of irrigation. The accessibility of arable land is constrained by population density and the existence and location of alluvial soils. Irrigation is unlikely to be implemented if enough land is available to support the population with techniques which have a lower yield per area but a greater return in terms of yield per labor hour than the available irrigation methods or all the arable land in the area receives sufficient water for cultivation without additional irrigation. The labor needed to support irrigation agriculture is also a constraint as the use of irrigation necessitates additional labor inputs which may or may not be available. If sufficient labor is not available, more intensive techniques cannot be implemented.

While the implementation of canal irrigation systems can effectively buffer water access constraints on production, it can also increase the habitat available for and promote the growth of vector snail populations which spread schistosomiasis infection. Those taking part in agricultural activities, such as canal maintenance and water regulation, which result in extended contact with canal waters experience the greatest risk of infection. However, the use of canal irrigation near residential areas increases the risk of exposure to schistosomiasis of the entire population coming into contact with canal water regardless of if they, as individuals or households, make use of irrigation. As schistosomiasis is associated with chronic pain, diarrhea, fatigue, impaired growth and development, and exercise intolerance (King et al., 2005), the stress induced in the form of schistosomiasis disease would limit the net benefit resulting from the implementation of saqia irrigation. Research has demonstrated a strong link between economic development strategies, where irrigation has been introduced to boost agricultural production, and the increased transmission of schistosomiasis infection in modern populations (Huang and Manderson, 1992; King and Dangerfield-Cha, 2008). The detrimental effects of increased parasitic infection following the implementation of irrigation schemes can be considerable; Wolstenholme (1962) even argued the reduction in health and productivity associated with the increase in schistosomiasis prevalence due to irrigation usage outweighed the increase in wealth from agricultural development.

Modern populations are well aware of the risk of schistosomiasis associated with irrigation water contact but often feel they have no alternative to irrigation practices which put them at risk of infection (Watts and El Katsha, 1997). It is possible that ancient Nubians experienced a similar knowledge of the risk of schistosomiasis disease associated with the use of canal irrigation agriculture, but found the benefits sufficient to warrant its use.

A number of different forms of irrigation were implemented throughout Nubian history to supplement agricultural production. The extent to which each irrigation method and their associated cultivation practices increases the productive potential of agriculture varies as does the extent to which they encouraged the transmission of schistosomiasis. In comparison to the population at Kulubnarti which appears to have subsisted with only basin irrigation or shaduf supplementation for the majority of its history, the population at Wadi Halfa utilized saqia irrigation and experienced a greater prevalence of schistosomiasis infection as a result. The difference in irrigation utilization is most likely the result of a combination of ecological, demographic, and social factors.

Productivity gains associated with the use of irrigation depend upon the increase in arable land associated with irrigation implementation, increased yield, and/or the ability to increase the number of harvests (i.e. how many times one can plant and harvest in a year) from that area. The use of irrigation increases the productive capacity of land but reduces the efficiency of that production (i.e. more labor needed to achieve that productivity). Not only is the original construction of an irrigation system often time and energy intensive, the continued maintenance of irrigation systems necessitates a great deal of annual labor. Thus, irrigation may improve the productive capacity of land, but may have a less advantageous impact on production per unit of labor. At both the household and population level the implementation of more complex irrigation practices is unlikely if subsistence needs can be met without them. Thus, the use of irrigation should not be seen as automatically more productive than agriculture without irrigation. The increase in productive capacity as a result of irrigation should be measured both in total productivity (or yield) and in relative efficiency (yield per hour of labor). The productivity lost due to schistosomiasis in these populations can be extrapolated from data on schistosome infection epidemiology and modern measures of reduced productive capacity associated with similar levels of infection. Based on these estimates, the net gain and loss of productivity associated with the implementation of irrigation in these populations can be estimated. However, a simple estimate that does not take into account the ways in which buffering options are constrained or the ability of the population to cope with reduced productivity of infected members does not give the whole picture.

Irrigation and Productivity in the Nile Valley

In ancient times as today, the majority of Nubia's population was involved in subsistence agriculture. Nubian households needed to produce a harvest sufficient for subsistence as well as a surplus for the purchase of pottery, textiles, and iron goods they could not make themselves. The height of the annual Nile flood is highly variable in the short term, often dramatically increasing or decreasing the flooded area that could be cultivated after the flood's recession (Butzer, 1976, p 30). Thus, the ability of a saqia irrigation system to compensate for variation in flood levels from year to year would have been as important as expanding flood plain.

Historical irrigation practices in the Nile valley can be delineated as basin irrigation, shaduf supplementation, and saqia canal systems. A range of irrigation practices were likely utilized at Wadi Halfa and Kulubnarti in particular circumstances, but as information about the use of irrigation by field or even household is unavailable, the central tendencies of each will be discussed.

Basin irrigation is the earliest form of artificial irrigation known in the Nile valley. The Nile's summer flood waters were directed by canals into natural or artificially created basins and allowed to soak into the soil. Low flood levels or short flood periods could be mediated by retaining water within basins, minimizing their detrimental effects. Remaining water would be drained after some period of time and a single crop was planted after the waters receded in the same manner as in natural flood plains (Butzer, 1976; Watts and El Katsha, 1997). The amount of land that can be cultivated by this method is dependent upon the height of the Nile and the topography of the area.

The shaduf (or shadoof), a bucket-lever water lifting device pictured in Figure 2 can supplement water supply in basin irrigation systems by lifting additional water from the Nile into basins in low floods and as floodwaters recede. The shaduf can also compensate to some extent for variability in flood levels from year to year to maintain a more consistent area of cultivatable land and extend the harvest by providing water for small permanent gardens near the river. The amount of land that can be irrigated by shaduf is limited by the height the water must be lifted and the amount of labor required to lift it. Postel (1999) estimates an average increase of 10 to 15 percent in arable land with the incorporation of shaduf supplementation over exclusively flood supplied basin irrigation.

The efficiency of the system is reduced as the height the water must be raised increases (i.e. there is a greater effort needed per unit of height for each unit the water is lifted) with a maximum lift of well over a meter (Butzer, 1976, p 46). This limits efficient use of shadufs to relatively low lying fields; higher fields may be irrigated by a series of shadufs and canals, but this becomes prohibitively inefficient. The infeasibility of the shaduf system following a significant drop in the level of the Nile and its annual floods led to the abandonment of Lower Nubia around 1000 BCE. Agriculture in Lower Nubia was made possible again by the introduction of the saqia (Edwards, 2004, p 109).

The saqia (alternative spellings include sakia, saqiya and sakiyeh), an oxen powered water wheel came into widespread use near the end of the Meroitic period in fourth century, shortly before the Ballana period began in Lower Nubia (Edwards, 2004). Archaeological evidence of kilns which appear to have produced only saqia pots in numerous locations point to the importance of saqia irrigation throughout Nubia (Adams, 1977).

In comparison to the shaduf, the saqia loses very little efficiency as the height water must be raised increases. The area which can be feasibly irrigated by a single saqia varies with its dimensions and the number of oxen employed in powering it (Adams, 1977). The saqia has a maximum lift of approximately 3.5 meters (Butzer, 1976: 46) and the area which can be feasibly irrigated is between 1.6 to 2 ha per saqia at high Nile and 0.61 to 1 ha per saqia at low Nile (Allan and Smith, 1948, p 268) Postel (1999) estimates an additional average increase of 10 to 15 percent in arable land with the use of a saqia over shaduf supplemented basin irrigation or a 21 to 32 percent increase over basin irrigation. The use of the saqia also allows the substitution of animal labor (oxen) for human labor (Adams, 1977) although a rather sizeable proportion of the production must be used to feed the oxen powering the saqia (Trigger, 1965, p 69).

The use of the saqia expanded opportunities for irrigated agriculture, but more importantly contributed to the development of new agricultural production regimes. By increasing the period of possible irrigation, the saqia contributed to the ability to expand the range of crops produced as well as continual production through a multi-crop yearly rotation. This allowed Nubians to grow both temperate wheat and barley crops and other tropical varieties. A number of new crops were introduced to Nubia along with the saqia including sorghum, termis beans, peas, and sesame (Edwards, 2004: 203-204). The production of multiple crops throughout the year increased the dependability of the food supply.

Schistosomiasis and Productivity

Disease affects families and larger social groupings beyond the individual (Goodman and Armelagos, 1989, p 239). The reduction in productivity due to schistosomiasis, or any disease, must be examined at the individual, household, and population level.

At the individual level, symptoms of schistosomal infection vary from mild discomfort to severe disability and include chronic pain, diarrhea, fatigue, anemia, exercise intolerance and reduced work capacity (King et al., 2005; King and Dangerfield-Cha, 2008). The association of schistosomiasis infection with exercise intolerance and reduced work capacity of an individual suggest infection has a negative impact on productivity and there is a negative correlation between helminth infections, such as schistosomiasis, and income level both within and between countries (de Silva et al., 2003). Fenwick and Figenschou (1972) found a three to five percent reduction in the productivity of schistosomiasis mansoni infected sugar cane workers in comparison to uninfected workers on an irrigated sugar estate in Tanzania. Productivity is further reduced in individuals with severe symptoms of schistosomiasis infection than those with less severe forms of disease. Barbosa and Costa (1981) found a 35.1% reduction in the productivity of sugar cane workers with severe hepatosplenic symptoms of schistosomiasis mansoni infection versus the average productivity of other infected individuals.

While not a direct measure of lost productivity, the disablement of individuals due to infection is a proxy for productivity reduction. The World Health Organization (WHO) assigns disability weights, measures of the relative severity of disease or disablement to many medical conditions on a scale of zero (perfect health) to one (equivalent to complete disablement or death). The official WHO disability weight of schistosomiasis infection regardless of species is 0.005; for cases with severe renal or hepatic disease the disability weight is .104 (WHO, 2004). The use of these sequelae as the only criteria for determining morbidity estimates has come under criticism (Michaud et al., 2003; van der Werf et al., 2003; King et al., 2005). Schistosomiasis disease is much less prevalent than schistosomiasis infection, but can have much more significant morbidity. The prevalence of schistosomiasis infection as compared to schistosomiasis disease can explain the relatively low disability weight attributed to schistosomiasis. In contrast, other helminth infections such as hookworm have disability weights for cognitive impairment (.024) and anemia (.024) as well as high intensity infection; both sequelae are also associated with schistosomiasis infection but are not given a disability weight for schistosomiasis disease. As different symptoms of schistosomiasis are not necessarily well correlated in their manifestation and have differing impacts on the physical and mental capabilities of hosts; it has been argued that each should be accorded a distinct disability weight (Michaud et al., 2003). King and Dickman (2005) suggest 0.02 to 0.15 as a more reasonable estimate for the disability weight that should be attributed to schistosomiasis infection based on the epidemiology of infection, morbidity, and logically linked disability, including diarrhea, pain, fatigue, hemoglobin deficit, undernutrition, and reduced exercise tolerance (or tolerance for laborious activity).

Although economic studies generally focus on the influence of schistosomiasis infection on the working capacity of individuals and extrapolate these findings to make generalizations about the impact of schistosomiasis on productivity of populations (Huang and Manderson, 1992), reduced productive capacity of an individual does not necessarily imply reduced productivity of the group. Research has shown that the total productivity of households with infected members does not suffer, but the relative productivity level (in terms of yield per person-hour) was higher in uninfected households (Audibert and Etard, 1998). Households with infected members worked longer hours in order to compensate for the reduced productivity of infected members, achieving total yields similar to households without infected members. Thus, at the household level, reductions in productivity due to schistosomiasis are relative rather than absolute. If all the infected individuals within a population are members of a household sufficiently large enough to adequately compensate for their lowered productivity, the total productivity of the population should not decrease. However, not all individuals will be members of such households.

Ecological/social Context

I have provided a summarization of the ecological and cultural context of irrigation use and its influence on schistosomiasis transmission and health at Wadi Halfa and Kulubnarti below. For more detailed information on the ecological and cultural context of irrigation use and schistosomiasis see Chapter 4: Cultural and Ecological Context.

Wadi Halfa – Ballana Period (350-550 CE)

Environmental conditions during the Ballana period are likely to have increased the potential for physiological stress experienced by individuals living at Wadi Halfa through reduction of resource availability. Both historical and archaeological evidence exist for low Nile floods during the Ballana period. Low flood levels reduce the extent of the flood plain resulting in less land suitable for planting, reduced harvest yields, loss of livestock and seed stocks, and starvation in extreme cases (Adams, 1967; Butzer, 1976). Use of the saqia became widespread throughout Lower Nubia including the area of Wadi Halfa shortly before the beginning of this period. Isotopic evidence from populations at Wadi Halfa suggests the continual availability of C_3 vegetables and fruits from hand watered garden plots and a seasonal shift between C_3 (wheat/barley) and C_4 (millet/sorghum) plant consumption following the harvest cycle (White and Schwarcz, 1994). Consumption of more drought resistant C_4 plants was greatest in the Ballana period. These crops may have been utilized in areas which could not be irrigated even with saqia and may represent an adaptation of the agricultural scheme in the region to the differing ecological conditions over time. It may, however, also represent a loss of access to wheat and barley imported from Egypt (White and Schwarcz, 1994; Edwards, 2004).

While the majority of Lower Nubia had a low population density in the Ballana period and small, dispersed archaeological sites are the norm, a few sites, including the cemetery at Argin from which the Wadi Halfa sample is derived are notable for their large size relative to other Ballana period cemeteries (Adams, 1977, p 393). This would suggest that the population was associated with a much more densely populated urban center than was typical in Lower Nubia at the time. Pressures based on population density and land shortage have been credited with obliging the adoption of more intensive agricultural techniques in other contexts (Boserup, 1965; Netting, 1993) and the dense population at Wadi Halfa would have required a higher yield even if that must be achieved as lower efficiency.

The use of saqia irrigation maintains aquatic habitat for vector snails throughout the year in canals. Repairing and maintaining canals create additional opportunities for transmission. The higher population density of Wadi Halfa relative to Kulubnarti may also have contributed to the prevalence of schistosomiasis mansoni through higher fecal contamination of surface water. The increase in time spent in fields near canals necessary to produce sufficient yields would in turn increase the potential for contamination of canal waters.

Kulubnarti – Christian Period (550-1000 CE)

Small scale agricultural production served as the basis for subsistence in medieval Nubia. The lack of specialized craft and imported goods at Kulubnarti has been interpreted as evidence that the residents of Kulubnarti, and Nubia more generally, returned to a focus on subsistence agriculture to provide for themselves (Van Gerven et al., 1995).

Relatively high Nile floods prevailed during the Christian period expanding the flood plain in many areas (Edwards, 2004). The Batn el Hajar is characterized by granite ridges and limited alluvial soils. Because Kulubnarti was situated near a pocket of alluvial flood plain, it was possible to cultivate a number of crops including wheat, barley, legumes and fodder plants using only basin irrigation and there is no evidence for the use of additional irrigation technologies at Kulubnarti until very late in the Christian period (Adams, 1977, p 51). Van Gerven and colleagues (1995) note the presence of retaining walls which may have served as dykes to hold in flood waters as the river resided and preserve alluvial soils from erosion. The use of basin irrigation extends the period of inundation and provides habitat for aquatic snails such as those which transmit schistosomiasis, but the draining of basin fields prior to planting eliminates this habitat and discourages large snail populations. Due to the high flood levels of the Christian period it is possible that all of the alluvial soils appropriate for cultivation received sufficient water during flood periods. If this was the case, there would be little incentive to implement additional irrigation technologies as they could not increase the amount of land suitable for farming. Additional grains having greater resistance of heat and aridity such as millet and sorghum could have been produced beyond the limits of the floodplain, however the topography of the area would make opportunities for such cultivation limited. The herding of goats and other animals which feed on these arid grasses provided additional sources of subsistence (Adams, 1977).

Political unrest in the north lead the population of Nubia made a general shift towards the south in the Christian period with decreasing settlement and construction in Lower Nubia and refugee resettlement in the comparatively safe Batn el Hajar (Adams, 1977; Edwards, 2004). In addition, higher floods may have caused the population to move south (Van Gerven et al., 1995). While population density increased over previous periods, it was still relatively low with only a dozen or so households at Kulubnarti throughout the Christian period (Van Gerven et al., 1995). The low population density of the Batn el Hajar limited the risk of contamination of these waters by the excrement of infected individuals.

Islamic invasions from Egypt in 642 and 652 CE eventually resulted in the Baqt treaty which most accounts suggest consisted of an agreement which allowed continued religious and political freedom of Nubia in exchange for annual tribute payments of slaves and protection of Muslims in Nubian lands in return for foodstuffs, wine, and cloth. Alternative versions support Nubian victory and equitable trade of foodstuff for captives (Edwards, 2004, p 249). Both versions suggest a reduction in available labor as a result of conflict with Egypt. Without sufficient labor, the population at Kulubnarti could not have made use of more complex forms of irrigation. Even with sufficient labor, it would not make sense to implement more complex irrigation systems until production greater than that possible with basin and shaduf irrigation was necessitated.

Analytic Methods

In order to estimate the increase in agricultural productivity associated with the implementation of saqia or shaduf irrigation over basin irrigation, all land was assumed to be of equal fertility. Based on this assumption, the increase in agricultural productive capacity using shaduf irrigation is ten to fifteen percent greater than basin irrigation and saqia irrigation is an additional ten to fifteen percent greater than shaduf supplied systems or a 21 to 32 percent increase over basin irrigation. However, these are estimates and in circumstances in which agriculture was infeasible without the saqia, its use would represent a much greater increase in productive capacity. If all available cultivatable land was sufficiently supplied with water prior to the implementation of additional irrigation, there would be no increase in productive potential. The productive increase in terms of yield would also depend upon cropping regime utilized and the types of crops planted/harvested. Two harvest systems would result in greater productivity increases.

The reduction in productivity associated with schistosomiasis infection within the populations was estimated using a modified form the WHO Disability Adjusted Life Year (DALY). DALYs are calculated by summing the years of life lost to premature mortality (YLL) and the number of years lost to disability (YLD)

$$DALY = YLL + YLD$$

Years of life lost are calculated using the number of deaths (N) and the life expectancy at time of death (L).

$$YLL = N \times L$$

Estimates of the mortality rate of schistosomiasis infection vary, but are consistently very low. In an endemic community in Sudan the fatality rate per year for schistosomiasis mansoni was 1/1,000 infected persons/year, but was as high as 11/100 infected patients with bleeding varices (Kheir et al., 1999). The productivity lost due to death as a result of schistosomiasis disease in most circumstances can be assumed to be negligible.

Years lost to disability is calculated using the number of incident cases (I) , the average duration of the disease (L) and the disability weight for the condition (DW).

$$YLD = I \times L \times DW$$

Estimates of both the incidence of schistosomiasis infection and the duration of infection to before remission or death are lacking; even in populations considered in epidemiologic studies, the incidence rate for schistosomiasis is unknown as infection is commonly asymptomatic (Michaud et al., 2003). Global Burden of Disease (GBD) estimates are based on a simplified disease model in which the duration of infection is assumed to be one year so that the prevalence of infection can be substituted for incidence (Michaud et al., 2003).

In modern populations receiving annual praziquantel treatments, the assumption of the duration of schistosomiasis infection as one year may be valid. However, it is unlikely that this assumption is equally applicable to archaeological populations. The duration of infection in archaeological populations without effective treatment would more closely resemble untreated populations. While the average lifespan of a schistosome within a human host is only three to five years (Gryseels et al., 2006, p 1106), infections commonly last one third to one half of the total lifetime on average in endemic populations (Satayathum et al., 2006) and mated schistosome pairs can have a lifespan of up to 30 years within the host if not treated (Jordan, 1985; Gryseels et al., 2006).

Results

Based on Postel's (1999) estimates, the cultivatable area at Wadi Halfa may have increased by as much as 21 to 32 percent as a result of the introduction of saqia irrigation. Given that the population was also making use of a multiple harvest system, even greater gains in agricultural productivity are likely, possibly doubling the productive capacity of the land (a total increase of 142 to 164 percent). Although some of the excess production would have been needed to sustain animals for labor, this clearly represents a significant increase in the amount of food that could be produced for human consumption. As the Nile was exceptionally low during the Ballana period and some even suggest that agriculture was not possible in Lower Nubia until the introduction of the saqia this is an underestimate of the productivity increase.

In contrast to the population at Wadi Halfa, the population at Kulubnarti did not implement saqia irrigation.

Figure 8 presents the disability due to schistosomiasis within the Wadi Halfa and Kulubnarti populations. Using the WHO disability weight of .005, the morbidity associated with schistosomiasis in the Wadi Halfa population was estimated at 0.130 and 0.047 percent of total productivity at Kulubnarti. King and Dickman's (2005) estimate suggests the disability due to schistosomiasis within the populations would be three and a half to twenty-five times greater. King and colleagues estimates suggest a morbidity of 0.5 to 3.9 percent at Wadi Halfa and 0.2 to 1.4 percent in the Kulubnarti population.

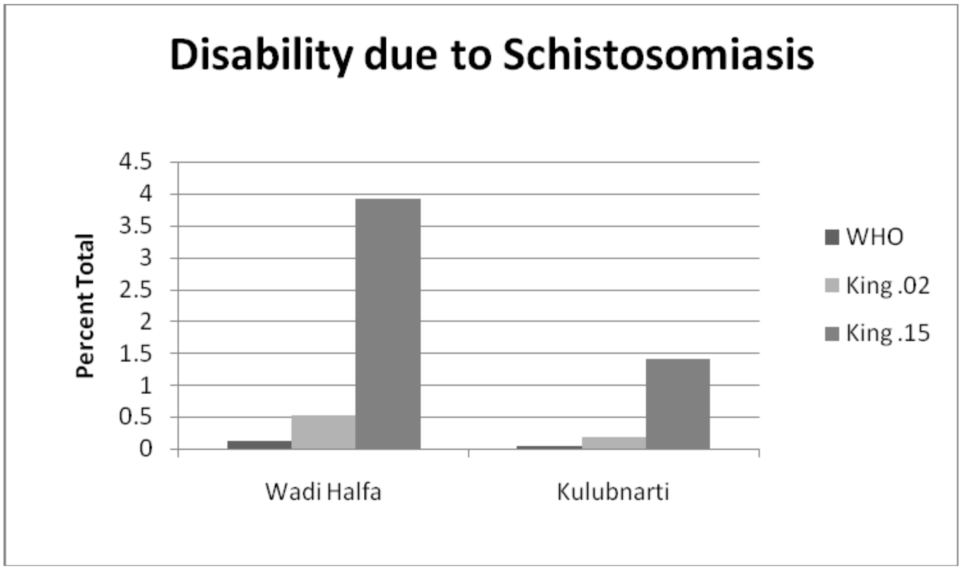

Figure 8: Disability due to Schistosomiasis

The disability experienced as a result of schistosomiasis infection occurs over of period of time. Given that individuals are likely to be infected for up to half of their lifespan this can result in a substantial loss of productive life. The total productive life lost to schistosomiasis disability (assuming infection duration of one half the lifespan and 15% disability) was roughly two and a half years per case at Wadi Halfa and 1.4 years at Kulubnarti based on the prevalence of infection and the age of death of infected individuals.

These numbers only represent the loss of production from infected individuals; to offset the reduction in productivity other members of their households will have to work longer hours. Numerous studies have found that households cope with reduction in the productivity of infected members by increasing the number of hours worked (Huang and Manderson, 1992; Audibert and Etard, 1998). The uninfected population of Wadi Halfa would have to increase their productivity by five percent on average if they were to compensate for the reduced productivity of infected members based on King's (2005)

15% estimate of schistosomiasis disability. Only a one percent average increase in production would be required of the uninfected population at Kulubnarti to retain the total productivity expected without schistosomiasis infection in the population. Of course, coping with reduced productivity would occur within households and some households would be obliged to provide much more additional labor than others depending upon the distribution of infection within and between households.

Discussion

If the assertion made by Edwards (2004) that agriculture would have been impossible at Wadi Halfa without the use of saqia irrigation is correct, the increase in the productive capacity of agriculture following the introduction of the saqia greatly exceeds the reduction in productivity resulting from increased schistosomiasis infection in the population at Wadi Halfa Large urban centers such as Wadi Halfa would have also required great quantities of agricultural produce to sustain the farming population and meet the needs of nonagricultural populations (Edwards, 2004: 148). Health and nutritional status improved during the Ballana period due to localized control and more equitable distribution of resources (Martin et al., 1984, p 211).

Although the population at Kulubnarti was certainly aware of saqia irrigation as it had been utilized in other parts of Nubia for centuries, the practice was not implemented until very late in the Christian period. Bioarchaeological evidence of the health of the population at Kulubnarti suggests the population was less able to buffer environmental stresses than the population at Wadi Halfa. Every individual from Kulubnarti exhibits at least one hypoplasia, many of them occurring in a yearly cycle in those from the R cemetery, but more often in those from the S cemetery (Van Gerven et al., 1995). This would suggest some annual or semi-annual source of physiologic stress and could indicate periodic food shortages. The question is then “why would a population not implement a technology they were aware of if they did not have sufficient food supply and knew the technology could increase overall production?” The answer most likely involves limiting resources. Implementing saqia irrigation only increases productive capacity if water is the limiting resource. If water is not the limiting resource, the use of a may not increase productive capacity. Other resources such as land and labor maybe have been the limiting factor. In that case, production will still be limited by other factors and additional water will not result in any gain in production. This may have been the case for the population at Kulubnarti. If they were able to utilize all of the available alluvial soil without additional irrigation, providing water to granite and sand would not have decreased food stress and would have required additional labor. If all of the available labor was needed for flood basin irrigation production, saqia irrigation may have been infeasible. There is also the possibility that labor was available, but the risk associated with time spent in fields was too risky to warrant the additional time spent away from habitation sites required by the implementation of saqia irrigation.

Conclusions

While total production can be maximized by achieving the greatest efficiency in the use of the resource which limits productive capacity, the process of adaptation to the environment through cultural buffering is much more complex. The decisions which can be made regarding irrigation and agricultural production are constrained and shaped by the natural and social environment and the constraints on resources such as the availability of water, land, and labor.

Wadi Halfa implemented perennial saqia irrigation greatly increasing the cultivatable area. They also had greater disability due to schistosomiasis infection both in percent and years lost per case, but were able to do more coping and appear to have been more successful in buffering stress.

Kulubnarti has lower prevalence of schistosomiasis, less disability, and required less additional labor from uninfected individuals to compensate for the decreased productivity of infected members, but skeletal indicators of health suggest the population at Kulubnarti was less able to mediate physiologic stress than the population at Wadi Halfa. As the population of Kulubnarti would have been aware of saqia irrigation, other factors must have constrained agricultural buffering options. Ecological as well as socio-political factors were likely involved.

Limited alluvial soils and high Nile flood levels during the Christian period may have meant that all cultivatable land had sufficient water without saqia irrigation. However, physiological stress experienced by the population suggests this was not the case, or that the production capabilities of this amount of land was insufficient to meet the needs of the population. Conflict between Muslim Egypt and the Christian Kingdom of Nubia during the Christian period should also be considered. The restriction of trade due to the use of the Batn el Hajar as a buffer region would have limited access to outside resources when local supplies were insufficient. Military conflict and the limited safety of individuals working away from habitation sites likely influenced agricultural decision making and exacerbated resource shortages. Individuals and households may have been willing to forego additional food in order to retain a level of personal safety. All of these factors would have been involved in the decision making processes of the Kulubnarti population and the importance of these factors would have varied between households as well as the decisions they made as a result. In general, this resulted in greater stress to the Kulubnarti population.

Chapter 9: Conclusions

The use of saqia irrigation as a form of cultural buffering can provide greater water access and increase crop yields. However, if one were to judge saqia irrigation usage solely in terms of the risk of schistosomiasis within a population, it would not be an adaptive behavior; increasing vector habitat increases the risk of infection and the prevalence of schistosomiasis. Coping with the consequences of increased schistosomiasis transmission and infection prevalence in terms of lost productivity is part of the on going process of biocultural adaptation to environment. The adaptiveness of any form of cultural buffering is relative and best understood within the constraints posed by the context.

Climatic change and fluctuations in the level of the Nile had direct and immediate impact on the development and feasibility of agriculture in Nubia during the Ballana and Christian periods. During the Ballana period low Nile floods reduced water access. Lower Nubia was, in fact, near uninhabitable without the implementation of saqia irrigation. Thus, the implementation of saqia irrigation was not simply a means of obtaining higher yields, it was a necessary prerequisite for inhabiting the region. As water availability was the limiting factor in agricultural pursuits, increased effort was directed at the elaboration and maintenance of saqia irrigation systems. In contrast, Nile levels were at their greatest recorded height in the Christian period. More land was naturally irrigated by Nile floods. However, in the Batn el Hajar alluvial soils are limited and the benefit of higher Nile levels would only extend as far as the cultivatable soil. In this context, alluvial soil was likely the limiting resource in agricultural production.

Based on evidence regarding the impact of canal irrigation on schistosomiasis prevalence and transmission in modern populations, I predicted that the prevalence of *Schistosoma mansoni* infection would be higher in Wadi Halfa than Kulubnarti, peak infection intensity would occur at an earlier age and at a higher level within the Wadi Halfa population than the population from Kulubnarti, and the prevalence of schistosomiasis to be higher in males than females of both populations. As expected, the prevalence of *S. mansoni* infection was greater in the Wadi Halfa population than at Kulubnarti.

However, the peak prevalence of infection occurred much later at Wadi Halfa than at Kulubnarti although the very low prevalence of schistosomiasis within the Kulubnarti population made the sample size insufficient to provide a clear picture of prevalence change with age. As the entire population with available skin samples has already been tested, the pattern of infection with age in the population will remain inconclusive. The late age of peak infection in the Wadi Halfa population has been seen in modern populations with low rates of transmission and has been suggested to be due to an inability to develop immunity at the low infection intensities experienced.

There were no statistically significant differences in prevalence between males and females of either population, although the pattern of prevalence with age does suggest some difference in exposure patterns over the life course between males and females at Wadi Halfa. While the prevalence of infection decreased within the male sample after the young adult (18-25 year) age category, the prevalence in the female sample increased with age reaching a peak in the mature (55+ years) age category. This suggests that while a similar proportion of males and females became infected during their lifetime, their exposure varied over the life course. The low prevalence and relatively small sample size make conclusions regarding the exposure of males and females within the Kulubnarti population untenable.

The schistosomal infections diagnosed in this research had negative health consequences and decreased the productive capacity of infected individuals. The inability to determine the chronology of infection and skeletal evidence of growth retardation and anemia precludes assertions regarding the impact of infection on these conditions within the populations. However, the extent of bioarchaeological research conducted on the Wadi Halfa and Kulubnarti populations makes it possible to look at the detrimental impact of schistosomiasis in terms of the overall health of the populations. The Ballana period Wadi Halfa population clearly experienced physiologic stress, but the majority of skeletal indicators suggest they were healthier than the population at Kulubnarti. Given that the prevalence of schistosomiasis is higher in this population, one must conclude that the amount of physiologic stress caused by schistosomiasis infection was less significant than that resulting from other conditions. Saqia irrigation may have been buffering this stress.

In comparison to the population at Kulubnarti, the population at Wadi Halfa had a greater experienced a two and a half times greater reduction in the productive capacity of the population. The differences in lost productivity and the prevalence of infection would have resulted in an even greater difference in the compensation required by uninfected members of the populations to offset the reduced productivity of infected members. While the uninfected population would have had to increase their productivity by five percent on average within the Wadi Halfa population, an increase of only one percent would have been required of the infected population at Kulubnarti to compensate for the reduced productivity of infected members. In this context, not implementing saqia irrigation prevented the Kulubnarti population from being required to cope with additional stress associated with reduced productivity resulting from increased schistosomiasis transmission.

The population at Kulubnarti did not implement saqia irrigation until very late in the Christian period although they would have been aware of the technology. It is possible that the lack of evidence for earlier saqia usage is simply the result of destruction of the archaeological evidence, but the prevalence of schistosomiasis with the population relative to Wadi Halfa suggests they had significantly less exposure to schistosomiasis. Had they been making use of saqia irrigation, some additional source of variation in exposure to contaminated water must have existed. Testing a sample population from a period of known saqia usage at Kulubnarti for schistosomiasis would provide a better understanding of the extent to which schistosomiasis transmission increased following saqia implementation. If the population at Kulubnarti was not making use of a known technology they probably had a good reason not to. Populations commonly do not implement "more advanced" technologies which can produce greater yields at lower labor efficiency until it becomes necessary (Boserup, 1965). The reduced labor efficiency of saqia irrigation in comparison to basin irrigation may partially explain the choice not to implement it.

The fact that evidence of physiological stress is so prevalent in the Kulubnarti population and appears to fit a pattern indicative of periodic food shortage suggests there would have been an incentive to produce as much food as possible even if its production was less labor efficient. This suggests water access was not the limiting factor in food production, or at least that other constraints made saqia irrigation less attractive. Saqia irrigation requires a greater amount of time spent maintaining the saqia and canals. The defensive nature of structures suggests that this would have placed workers at risk during periods of conflict. Further, implementing saqia irrigation would not result in any increase in yield if all the cultivatable land was provided sufficient water using basin irrigation or shaduf supplementation. In this context, implementing saqia irrigation would have meant adopting a technology which required significant additional labor without also providing a significant increase in productive potential.

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