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Enslaved Labor In The Gang and Task Systems: A Case Study In Comparative Bioarchaeology Of Commingled Remains

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ABSTRACT

This study designs and tests an approach intended to confront one of the major problems faced within biological anthropology, the commingling or mixing of human skeletal remains. The first goal of the study is to implement an approach to sorting mixed human remains in order that they can be made amenable to comparative study. Bioarchaeologists depend on an array of measures, preserved in the human skeleton, to assess the lifestyles and identity of past human groups. As many of these measures are preserved within the morphology of different bones, it is imperative that the association and context of remains are known for purposes of study. Frequently, the effects of nature, human activity, recovery by untrained personnel, and long-term storage or curation, cause commingling among samples of skeletal remains, meaning that they often remain unstudied. Many of these skeletal samples have the potential to provide valuable information about past human biology and culture within our recent evolution. This study implements a combined method approach using traditional morphological and osteological methods for sorting mixed assemblages of remains, combined with elemental analysis of bones using portable X-ray Fluorescence (pXRF) in order to test its efficacy in sorting a sample of human remains that were mixed and damaged by modern construction. Elemental analysis with pXRF has shown potential in recent studies, but has not yet been employed within bioarchaeology for the purpose of facilitating comparative studies.

The remains under study, the skeletons of enslaved African Americans who labored in the tidal rice fields of lowcountry South Carolina during the mid-nineteenth century, offer new insight into our understanding of the lifestyles and health of the enslaved in South Carolina. Following the implementation of an approach to sort these damaged remains into discrete individuals, this study then includes them in a comparative biocultural study designed to contribute to the growing body of temporal and regional studies of diasporic experiences of African, European, and Native American populations within the historic and formative periods of North America and the Caribbean. This study uses a biomechanical approach based on CT-scan derived images of human bone cross sections, in order to test historical questions using the sorted sample of human remains from a South Carolina rice plantation (Hagley Plantation) in a comparative framework with remains from a Barbadian sugar plantation (Newton Plantation). These two historical contexts involved characteristically-different labor regimes and social and economic arrangements according to historical sources. The current study tests questions based on the historical narrative using skeletal measures of functional adaptation designed to assess the effects of lifestyle and forced labor on these two groups within a comparative biohistorical framework.

PREFACE

This dissertation assesses the comparative biological impact of enslaved labor imposed upon African, Barbadian, and African American bondsmen and bondswomen within the context of plantation slavery. In order to assess the biological and historical evidence for these comparisons of lived experience, the study employs primary and secondary documentary evidence which contains racist and derogatory terminology common to the colonial and antebellum periods. These terms are unaltered in quotations from these sources and meant to convey their original meaning within contexts of social control and forced servitude.

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CHAPTER 1

INTRODUCTION

Slave labor and plantation systems formed the basis for the American South and the Caribbean economies from the seventeenth to nineteenth centuries, but despite more than a century of scholarly investigation, we still do not fully understand the relationships between labor and the health of enslaved populations. From the evidence, historians of slavery, economic historians, demographers, and anthropologists have created a picture of great variability in the impacts of slavery on populations and differential life experiences by economy and geography (Higman 1984; Young 1993). Bioarchaeology is uniquely situated to investigate the social and biological effects of subjugation and social control in the past, especially through examination of evidence for violence and forced labor associated with slavery (Harrod and Martin 2015). While historians have examined and compared economies of slavery for decades (Fogel 1989; Fogel and Engerman 1974; Genovese 1967; Stampp 1972; Sutch 1975), the biological effects of enslaved labor have yet to be quantified and compared between economies by means of direct biological evidence.

Ample bioarchaeological and historical evidence exists to suggest slave labor was stressful and even fatal. What remains unclear, and stands to be augmented by biological evidence, is the degree to which the relative variables of mode of labor, type of crop produced or the culture, social organization, and environment of cultivation are to blame for these population impacts (Dusinberre 2000; Handler and Corruccini 1983; Higman 1984; Morgan 1982; Rathbun and Steckel 2002). The skeletal signatures of New World slavery, including evidence for malnutrition, tropical diseases, and reduced lifespan, are widely reported (Hodge 2010; Owsley et al. 1987; Rathbun and Scurry 1983; Rathbun 1987; Rathbun and Steckel 2002; Shuler 2005; 2011; Wilczak et al. 2004) but biomechanical comparisons between samples have never been attempted. Thus studies of the biological consequences of labor stand to critically address and augment the archival and archaeological evidence for enslaved labor.

Project Goals and Design

The goal of this project is to examine and compare the life and labor stresses experienced by enslaved Africans and African Americans between two New World crop systems (rice and sugar) using a biomechanical method in conjunction with historical and archival evidence, considered from a biohistorical and biocultural perspective. Biomechanical studies within bioarchaeology provide a direct means of examining the specific stresses placed on the human body that are preserved in the morphology of the skeleton, permitting inference into the types and intensity of habitual activity of past populations. My study is the first to assess and compare evidence for upper and lower limb strength differences between enslaved populations and therefore provides a unique chance to measure differential labor stress endured in different contexts of New World slavery.

I also develop and test a model approach for the comparative bioarchaeological study of skeletal populations which consist of commingled human remains. The populations under study, Hagley Plantation (38GE81), a South Carolina rice plantation, and Newton Plantation, a Barbadian sugar plantation, are, respectively, completely commingled and partly commingled. In order to resolve this, I adopt two methods commonly used within biological anthropology: systematic approaches designed for the reassociation of commingled human remains including elemental analysis by portable X-ray fluorescence (pXRF), and comparative biomechanical analysis based on computed tomography (CT) scan derived measures of the cross-sectional geometry of long bones. My goal is to apply and test a novel multiple method technique for resolving a commingled sample of skeletal remains into discrete individuals, and thereafter, to use the derived sample within a comparative study to test hypotheses about the effects of enslaved labor within these two contexts of slavery.

Commingling of human remains is a common impediment to the analysis and comparative study of past human biology and lifestyles. Commingled contexts result from varied processes, including cultural practices (i.e. ossuaries, mass graves, disposal during conflict and warfare, charnel houses, surface burial, and cremation), disturbance of cemeteries and burial grounds by human activity (i.e. construction and development), disturbance of buried remains by natural processes (i.e. erosion and natural disasters), and, in many cases, due to careless excavation and poor record-keeping on the part of archaeologists and museum personnel. Recent research incorporates novel approaches based on new method and theory to address all aspects of the context of commingled remains, greatly amplifying their potential to contribute to the understanding of past social behavior, identity, and lifestyles (Osterholtz et al. 2014) and additionally, to improve and standardize the scientific methods involved in recovery and analysis of commingled remains in the forensic context (Adams and Byrd 2014). My study situates itself within the framework of current research and methods by testing a multiple method approach to the resolution of commingling among the Hagley Plantation population. This approach stands to demonstrate both the potentials and the limitations of commingling methods and their success within archaeological contexts involving long-term burial of human remains.

In the next phase of this study, I undertake a comparative biomechanical study of the derived skeletal sample from Hagley Plantation with remains from Newton Plantation, Barbados, an eighteenth and nineteenth century sugar plantation. The two populations are compared by upper and lower limb measures of strength which represent, in part, skeletal functional adaptation to labor and activity, using cross-sectional geometric (CSG) properties of bone derived from CT imaging of long bones. The use of evidence for functional adaptation for testing and inference of past human behavior is, like commingling studies, also in an active phase of research and critical evaluation. At stake are issues of comparability, analytical standardization, and understanding of environmental and evolutionary determinants and their role in bone structure (Carlson and Marchi 2014). This study compares CSG properties within two skeletal series in order to test hypotheses about the effects of labor within the two economies, population demography, population mobility, and disease and nutrition. To generate testable hypotheses, I query the historical and documentary evidence for labor and lifestyle between the contexts of rice plantation and sugar plantation slavery. The conclusion considers the results of both components of this project within a biocultural framework.

The two contexts under study present not only different production crops, but differing structures of labor and social control within plantation slavery. Gang labor systems characterize New World colonial sugar plantations while the "Task System" of enslaved labor is unique to the southern rice plantation economy. The task system has been viewed as a more benign labor system which afforded more autonomy and self sufficiency to the enslaved and created a "proto-peasant" society (Carney 1993; Joyner 1984; Morgan 1982; Fogel 1989). The sugar system is considered to be one of the harshest labor regimes within New World slavery based on historical demography and archival evidence (Dunn 1973; Eltis and Engerman 1993; Fogel 1989; Higman 1976; 1984; Kiple 1984).

Few studies have compared the effects of enslaved labor on populations by economy. The current study presents the opportunity to test the historical record for accuracy in that the skeletal remains from Hagley Plantation are the remains of those enslaved by a planter whose historical legacy suggests he was among the kindest and humane of slaveholders (Collins 1864; Devereux 1973, Joyner 1984; Whitten 1977). Given that the rice economy and task system of labor supposedly afforded among the highest degrees of independence for the enslaved among economies of slavery, this may mean that Hagley's slaves labored under less extreme conditions than those of other systems, such as Barbadian sugar production.

Theoretical Perspective and Intellectual Merit

My study follows in the tradition of a biohistory approach in that I attempt to synthesize skeletal findings (in this case primarily biomechanical measures of bone strength) with the historical record for health and labor conditions within my study samples. Biohistorical approaches are the foundation of African Diaspora bioarchaeological studies and have a lengthy and productive scholarly history which I review in Chapter 2 (Blakey 2001; Rankin-Hill 1997). The reason that these methods are fundamental to studies of health within the African Diaspora is that they consider multiple lines of evidence, especially social factors, and provide a means to model the stresses faced by past populations in many dimensions: biological, cultural, political, and psychological. Health, disease, labor, and lifestyle must be examined with respect to changing social variables and historical contingencies. Biohistorical frameworks continue to provide the most effective means for linking political-economic process to health and biology worldwide, and are particularly relevant to African Diasporic studies since they consider the effects of subjugation, deprivation, forced migration, social control, poverty, and inequality on population biology.

My study interprets the results of skeletal comparisons designed to assess the effects of enslaved labor in historical, temporal, and geographic context between two enslaved groups: Barbadian sugar producers and South Carolina rice producers, within a framework which considers environmental and sociopolitical stressors and their impact upon these populations (see Chapter 8). This project will contribute to some of the most interesting and perplexing questions within African Diaspora studies and North American plantation slavery studies, namely the reasons for different health outcomes within differing regimes of slave labor and the true nature of the biological impact of slavery. In constructing a study of this nature, comparing the mechanical and chemical aspects of bone, it is important to avoid typological or deterministic lines of thought. Saying that the bones of enslaved Africans and African Americans reflect the stresses of their forced participation in an oppressive and dehumanizing labor system is accurate but far too simplistic. Slaves were not simply passive victims. Their biology reflects not only their role in the system of slavery, but their resistance to it, their individual experience within a diasporic experience of bondage and forced migration, and their shared experience of New World labor, health, and disease with European and Native American populations during the creation of the first truly global economy.

Admittedly, since rice and sugar plantation economies stand apart from other slave crop economies such as cotton due to the intensity of their seasonal round of agriculture (Dunn 1973; Morgan 1982; Stewart 1991; Whitten 1977), the question may be raised as to what justifies the comparison. Rathbun and Steckel (2002) argued that South Carolina slaves rank among the least healthy of North American slaves, while Higman (1991a) argued that Barbadian slaves ranked among the most “healthy” or at least uniquely self-sustaining groups of West Indian slaves. Skeletal evidence from Newton Plantation does not support good health (Shuler 2011), and my study has the potential to provide significant biological evidence for health within South Carolina slavery, as previous findings have been based on very limited data sets. I hope that this study of comparative labor strain considered by context may be effective in addressing the typicality of both of these plantations in terms of labor structure. I believe a comparison of South Carolina and Barbadian evidence will add to our understanding of what sets these crop systems apart from other regions, and permit further investigation of the myriad factors involved in determining health and stability of enslaved African populations.

Biological anthropologists are becoming more involved in collaborative, cross-disciplinary studies and, as a result, they are becoming more successful at integrating archival research methods with studies of skeletal samples to broaden our understanding of recent human history (Herring and Swedlund 2003). Additionally, efforts are being made to improve the means of assessing health patterns both regionally and diachronically through standardization and integration of data sets derived from skeletal remains (Steckel and Rose 2002). Within these frameworks, the new data derived from this study will contribute to a growing comparative framework built on archival studies, skeletal evidence, and archaeological and ethnographic data as well as to the growing body of knowledge about the diversity of the African Diasporic experience in the New World.

Finally, this study will employ a biocultural, political-economic perspective in order to address the comparative study of enslaved labor proposed here. Goodman and Leatherman (1998:4) have developed integrative political-economic and ecological perspectives for the study of human health and biology which emphasize the need to understand “local realities in global contexts”. Their framework emphasizes the need to trace inequalities from their local to global origins in order to understand human biology. This type of theoretical approach is increasingly being applied within bioarchaeology (Goodman 1998). Bioarchaeological studies add a “dimension of history and context” to health studies which can serve to “link past processes of poor health with present conditions" (Martin 1998:176). Recent research demonstrates that the global economic relationships that originated from colonialism continue to affect human health, creating unique and often compromised "biologies" (Goodman and Leatherman 1998:5). Economic development continues to foster unequal social relations, oppressive labor regimes, and adverse health outcomes in the present day (Leatherman and Goodman 2005). My study offers the chance to conduct an analog to this type of study, linking regional, political and social factors to population health.

Expectations and Questions

This study will contribute to several lines of scholarly argument. A comparative biohistorical and biocultural approach will allow the study to consider the contributions of factors like political economy, ecology, seasonality, local historical context, infectious disease, and nutrition in the assessment of labor stress and comparative health. Diversity of occupation is documented within both of these contexts of slavery and it may prove difficult to disentangle the effects of specific stresses on the human skeleton. Likewise, it is recognized that many of the contexts in which biomechanical studies have been employed are prehistoric, preagricultural, and preindustrial and are thus quite different from contexts of slavery in terms of labor differentials, subsistence, and specialization, having implications for activities and behavior. There are many variables involved in assessing lower limb and especially upper limb stresses but this study stands to contribute particularly to questions surrounding the differences in degree and intensity of labor endured by slaves within "gang" labor, characterized by sugar agriculture and "task" labor, characterized by rice.

Gang vs. Task Labor

History suggests that rice slaves engaged in intensive labor, but that the highly desirable skills possessed by West African slaves may have translated into greater autonomy. Rice was grown in a daily 'task' labor system, wherein laborers were 'free' after completion of the daily task. The study of Hagley's enslaved African Americans presents the chance to test the historic reputation of their owner Plowden C. J. Weston as a more humane planter. If his "Rules and Management for the Plantation" were followed to the letter, they suggest measures of paternalism, encouragement for expediency of task in order for slaves to tend to their own family and domestic affairs, concern for the adequacy and variety of rations and adherence to holiday schedules, as well as notes on the means of enforcement of regulations with prescribed punishments (Weston cited in Collins 1865) (Appendix A). The regulations put forth by Weston do not seem to describe a system as harsh as those described for sugar production (Dunn 1973; Higman 1984; Tadman 2000). From the harshness conveyed by the preceding historical research, the conception is that slaves were often literally "worked to death" in the gang labor system of sugar production. The primary question that this study can ask through the comparative biomechanical analysis is which context displays evidence for greater labor stress and what types of stress are suggested by the biomechanical evidence?

Although the picture is complex, historical conceptions regarding the life experiences of the enslaved within different labor regimes permit the development of research questions that can be addressed through bioarchaeological investigation. The following hypotheses will be tested within the biomechanical CSG-based component of my study, following the sorting of commingled remains.

Hypothesis 1.

Based on historical narratives, demography, and slave import records, and the possibility of African birth within the group, Newton Plantation's enslaved may reveal a sample of individuals who were possibly selected for their body size and musculature within the context of planter preference for sugar laborers (Handler 1978). They may be larger than Hagley rice plantation's enslaved in measures of body size, cortical area of bone, and relative measures of bone strength. The archival and skeletal evidence for reduced height and possibly small body size of South Carolina bondsmen contributes to this hypothesis (Rathbun and Steckel 2002).

Hypothesis 2.

2A. Relative to body size, I expect, despite the notion of more benign work conditions for rice task agriculture, that both of these groups will exhibit relatively strong bones compared to a base line and be similar in bone strength measures to each other. Both groups were faced with heavy disease burdens and possible nutritional inadequacy, however, which may have placed limiting factors on their expression of bone functional adaptation, placing them in similar biocultural contexts.

2B. Alternatively, the fact that Hagley Plantation's enslaved appear to have lived longer on average, may mean that they show greater expression of labor-related bone strength increase. Implicit to this hypothesis is the possibility that Newton's individuals may be more compromised by nutritional and health insults, corroborating the conception of being "worked to death". Questions that will be addressed under Hypothesis 2 are as follows:

1) Do the skeletal remains between the two samples reflect any population differences in upper or lower limb strength that suggest that one form of labor placed greater demand on the individuals than the other as suggested by historical perceptions of the labor regimes (gang system vs. task system)?

2) What do CSG data suggest about the role of health and nutrition in determining bone quantity and strength within these two economies? Does one context appear to be more compromised in health than the other?

3) Do the skeletal remains between the two samples reflect differences in lower limb CSG properties that suggest differences in degree of mobility or the effects of terrain or labor? How do these factors possibly relate to the geography of the environment of enslavement and the historical narrative surrounding the labor regime and negotiated and permitted freedom of travel and interaction experienced by the enslaved?

Hypothesis 3.

Due to the fact that both of these groups were involved in heavy but diverse labor in terms of occupations within each economy, variations in relative strength and shape of the skeletal elements under study within and between these samples should be present and indicative to some degree of differential labor strains. The following questions will be addressed within Hypothesis 3:

1) Does the skeletal evidence correlate with documented tasks and divisions of labor? If not, how do we account for the discrepancies?

2) Studies of slave skeletal remains in urban and industrial contexts such as Catoctin Furnace (Kelley and Angel 1983), and Cape Town, South Africa (Ledger et al. 2000) suggest evidence for a considerable degree of sexual dimorphism in limb strength, suggesting clear sexual divisions of labor. Do the skeletal remains within the Rice and Sugar Plantation economies reflect differences in CSG properties that reflect differential labor patterns and sexual division of labor?

Structure of the Dissertation

The present chapter has introduced the goals of the study and the methods that will be used. It has also introduced the context of the skeletal samples and the questions that will be addressed in order to compare the samples. Chapter 2 provides an overview of biohistorical investigation of slavery focusing on the two regions under study while briefly reviewing previous contributions of the bioarchaeology of slavery. Chapter 3 is a literature review of forensic and archaeological approaches to the sorting of commingled skeletal remains which informs Chapter 4, wherein the approach to commingling for the current study is devised and tested. Chapter 5 is a literature review of current understandings of the functional adaptation of the human skeleton which provide the basis for anthropological study of human skeletal within activity reconstruction and study of past lifestyles. Chapter 6 employs the skeletal data set derived by the commingling approach in a comparative study of cross-sectional geometry (CSG) between the two samples and presents the results of comparative CSG measures.

Chapter 7 interprets the results derived from both Chapters 4 and 6 within a biocultural framework informed by archival evidence from the two plantation contexts. Chapter 8 provides a brief conclusion to the study.

CHAPTER 2

HISTORICAL AND BIOARCHAEOLOGICAL CONTEXT

The bioarchaeology of slavery has emerged from the intersection of African Diasporic studies, publicly-engaged research agendas, and biocultural approaches to become a dynamic area of study as it serves to link population biology and cultural connections over wide temporal and geographical spans (Blakey 2001). Scholaship has matured amidst political controversy stemming from debates surrounding the legitimacy and purpose of research agendas and ethical concerns for descendant communities. As a result, the current state of the field is one based upon a broad and multidisciplinary theoretical base, able to engage a wide range of historical questions (Blakey 2001).

Biocultural and biohistorical approaches to past human health underlie and tie together studies of African American and Diasporic bioarchaeology. These perspectives are rooted in early efforts to understand the role of social constructs, such as inequality and racism, in determining aspects of population biology in the critique of race-based and typological "scientific" agendas. William Montague Cobb (1904-1990), the first African American physical anthropologist, made these first efforts, informed his background as a physician and anatomist, and in conjunction with his training and scholarship under T. Wingate Todd, one of the first physical anthropologists to actively confront racialized and deterministic biology (Rankin-Hill and Blakey 1994). Cobb's work with the Hamman-Todd Skeletal Collection was the first study to consider skeletal evidence for demography and health in relation to social and cultural phenomena, i.e. the Great Migration and the Great Depression (de la Cova 2008). Since Cobb's time, his work has profoundly influenced the goals and research agendas of the scholars who have studied the largest samples of enslaved and free African Americans. These studies include bioarchaeology of cemetery groups as well as the investigation of intriguing new questions through the study of extant museum collections (Blakey et al. 2004; de la Cova 2008; Rankin-Hill 1997; Watkins 2003).

Ted Rathbun and Jerome Rose organized the highly influential symposium: *Afro-American Biohistory: the Physical Evidence* for the fifty fourth annual meeting of the American Association of Physical Anthropologists in 1985. The publications that stemmed from the symposium marked a point of departure for the continuing investigation of the life stresses of African Americans in the nineteenth century (Angel et al. 1987; Kelley and Angel 1987; Martin et al. 1987; Owsley et al. 1987; Rathbun 1987; Rose and Rathbun 1987). Over recent decades, skeletal samples from many contexts have been studied, providing insight into differentials in life experience of the enslaved by region and economy of slavery. The field has benefitted from the abundance of historical documentary evidence pertaining to slavery, and with the recognition of the biased viewpoints inherent to records produced by the dominant class or those who enslaved others, achieved effective means of querying and testing historical viewpoints with direct biological evidence for health and disease (Kelley and Angel 1987; Lambert 2006; Hutchinson 1987; Rathbun and Steckel 2002).

Urban contexts have been particularly informative about health and resource access. These studieshave revealed evidence for labor differentials as indicated by different types of physical and environmental stress experienced by urban slaves in comparison to rural agricultural slaves (Owsley et al. 1987; Owsley et al. 1990). By far the largest sample of enslaved Africans, and a model for interdisciplinary biohistorical research, the New York African Burial Ground project, permitted the analysis of 419 enslaved individuals dating from the late seventeenth through the eighteenth century. These individuals were of African or Caribbean birth, as corroborated by documentary, isotopic, and DNA evidence (Blakey and Rankin-Hill 2004; Goodman et al. 2004; Jackson et al. 2004; Medford 2004).

Many of New York's enslaved during the period would likely have spent time in the Caribbean involved in sugar plantation labor (Barrett and Blakey 2011). Blakey, Rankin-Hill (2004) and their co-investigators used multiple lines of historical, biological, and archaeological evidence to provide deep insight into the life histories of enslaved men, women, and children in colonial New York, including signs of childhood stress, nutritional deficiency, and heavy manual labor evidenced through patterns of degenerative change. Their demonstration of the biological impacts of forced migration and enslavement on the young and old over a century's span as well as the material and historical insight they provide into the maintenance of African identity during enslavement are particularly salient aspects of the project.

The bioarchaeological comparison of health and demography of free African Americans at Philadelphia's First African Baptist Church Cemeteries provided a framework for biocultural comparison to other contexts of slavery. It also revealed commonalities such as the experience of severe childhood stress across contexts and differential sex patterns in mortality for the enslaved over the colonial, antebellum, and reconstruction eras (Rankin-Hill 1997). Skeletal samples encompassing the emancipation period and reconstruction era also demonstrate health differentials presumed to be due to discrimination and lack of resource access (Braser and Nystrom 2010; de la Cova 2008, Moramarco 2010). Rankin-Hill's (1997) study also provided insight into the role of social constructions and organizations and their role as stress buffers in biocultural consideration of population health outcomes. Recent work in the bioarchaeology of slavery emphasizes political-economic perspectives and the role of global connections and labor structures in population histories. Slavery contexts are viewed as the roots and underpinnings of the emergence of modern inequality and poverty (Cox et al. 2001).

Biocultural Theory and Political-Economic Perspectives

African Diaspora bioarchaeology has become firmly situated in biocultural and political-economic theoretical perspectives. This is primarily due to the unique ability that these frameworks offer to questioning and understanding of the role of modes of social control, inequality, and power relations and their impact upon populations and their health and lifestyles. The field is also inextricably tied to the development of modern capitalism, commoditization, production, and its present day social, cultural, and biological manifestations (Luke et al. 2001; Roseberry 1998).

The biocultural approach arose within anthropology from a merger of perspectives from processual ecology, human adaptability, and political economy. Biocultural viewpoints were considered central to the earliest bioarchaeological research goals (Buikstra 1977). This paradigm emerged primarily in response to critiques of strict adaptationist and functionalist viewpoints which failed to consider the reciprocal relationship between culture and biology (Goodman et al. 1998; Goodman and Leatherman 1998; Goodman et al. 1995; Goodman et al. 1988). A deepening split between biological and cultural anthropology resulting from a clash between empirical and materialist viewpoints and interpretive approaches, with epicenters in arguments over "race" and biology, fueled vibrant debate but threatened the four-field, holistic nature of anthropology (Calcagno 2003; Goodman and Leatherman 1998; Goodman et al. 1988). The increasing isolation of subfields served to perpetuate simplistic views of culture and biology as closed systems (Goodman and Leatherman 1998). Biocultural theory was thus seen by many as a means toward renewing holism and creating a unified approach to the study of human variation, adaptation, and evolution. The biocultural paradigm addresses the complexities and dynamism of human behavior past and present in a dialectical manner, emphasizing the relationships between human biology and larger social and cultural processes which serve to "mediate and produce each other" (Zuckerman and Armelagos 2011).

Goodman and co-authors (Goodman et al. 1988) voiced initial critiques of the adaptationist perspective by describing them as unrealistic and reductionist, even implying that their tendency to view human adaptation in light of purely positive outcomes and adjustments was damaging and dangerous. The "small but healthy" concept and debate permeated many disciplines and is exemplary of the type of intense arguments fostered by divergent viewpoints between functional adaptationist and biocultural viewpoints (Cook and Powell 2006). Goodman and others proposed a means of studying human adaptation that borrowed elements from adaptation studies, physiology, and processual ecology but went beyond proximate conditions such as the environment to a consideration of the linkages between culture and biology. Their main argument is that culture shapes biology and the reverse, both past and present. They proposed that a general stress model derived from the Selyean model of stress (a means of assessing and measuring physiological stress reactions in organisms brought on by environmental change via increased catecholamine and corticosteroid output) could be modified to create a framework for the examination of human adaptation within contemporary and past contexts. The idea that stressors are multi-component and synergistic (e.g. poverty) is central to the concept of modeling stress. Cultural systems within this framework are viewed as buffers to stress. The models are designed to delineate causation, impact, response, and consequence of the impact of stress on human biology and culture (Armelagos and Goodman 1991; Goodman et al. 1988).

Implementation of Biocultural Models

The central appeal and utility of the biocultural perspective is its ability to model stress within different domains using overlapping methods, each having their own interpretive strengths and weaknesses, thus linking levels of analysis and creating interpretive potential. Prehistoric studies employ skeletal evidence of stress reflective of proximate conditions, and, when coupled with archaeological investigation, can be used to link health consequences to broader social and economic factors. Bioarchaeologists and paleopathologists use a suite of non-specific skeletal stress indicators to do this, including dental enamel defects, signs of growth disruption, cortical bone maintenance data, periostits, and porotic hyperostosis among others. Consideration of the pattern and prevalence of skeletal stress markers in this manner permit the researcher to link the individual to the population level and address broader questions of health and adaptation (Goodman et al. 1988).

Historic studies are advantaged over prehistoric foci since they permit the diachronic assessment of stressors via generational, familial, and class divisions. For historic populations, it is often possible to explore demographic records, manifests, health and disease records, and vital records as lucrative data sets. This is especially relevant for enslaved populations and institutional and almshouse settings. Patterns of the spread of disease are also often accessible through historical demography. The study of mortality, morbidity, birth, and infant mortality rates especially provide a means of examining stress and adaptation and linking contexts from the local to the regional and above (Goodman et al. 1988)

There are varying levels of analysis and interpretive challenges to consider in disentangling aspects of the impact, response, and consequence of population stress. Historic studies are best suited for examining biological consequences (e.g. changing demographic patterns and mortality). Contemporary studies are able to both track and assess impact, response, and consequences. They are also the realm in which the relationship among stress indicators will hopefully be unraveled. The goal of linking levels of analysis and domains may be achieved by employing common methods (e.g. methods that overlap these domains or levels such as mortality and life table phenomena, anthropometric methods and enamel defects, visible in prehistoric, historic, and modern samples (Goodman et al. 1988).

Political-Economic Perspectives on Human Biology

Political-economic perspectives were adopted by biocultural theorists for many reasons but perhaps the most important is their ability to address complexity in past and present social behavior. Goodman's (1998) view is that if ideology, power, and politics affect health and human relations in the present, they must surely have done so in the past. The means of broadening the scope of study of human adaptation should thus involve analysis of pattern and testing of competing hypotheses and alternate explanations to explain past behavior, viewed through the lens of power relations. The complex and changing nature of social aspects such as status and the often unclear relationship between status and health, are key points raised by Goodman in developing the approach. Goodman and others believed these perspectives would be best applied to large-scale regional and inter- and intra-population studies, emphasizing the historical contingencies of power relations (Goodman 1998; Saitta 1999; Steckel et al. 2002; Zuckerman and Armelagos 2011).

Saitta (1999) proposed a critical Marxist perspective as the best theoretical approach to biocultural studies of health by political economy. His main reasoning was that Marxist theory provides the best means of tracing and confronting complexity and ambiguity of social and biological relationships. In his assessment of complexities within the archaeological and skeletal record of North American prehistory, he demonstrated that health disparities do not always correlate with class or social disparities. By tracing flow of surplus labor and class relationships, Marxist theoretical views permit examinations of the historical context and particulars of relationships both synchronically and diachronically. The need for more "fine-grained" analysis of contexts of human health that Saitta called for is concurrent with the thinking that underlay the creation of the “Backbone of History” a health index designed to assess health in the western hemisphere based on collaboration between economic historians and physical anthropologists (Steckel and Rose 2002).

New avenues of inquiry within the biocultural framework include reconsideration and more critical examination of the complexities of social relationships among power relations, gender, ideology, labor structures, inequality, and violence and control. The political-economic perspective permits the exploration of these domains from the local level to that of larger historical and political process (Zuckerman and Armelagos 2011). In Armelagos’ view, questions that explore the linkages of human health and nutrition to class and gender relationships, past and present from an evolutionary perspective are areas of inquiry that make bioarchaeology in general more relevant and accessible to contemporary society (Armelagos 2003). My study clearly addresses these goals by addressing the biological costs of enslavement within the formation of a global economy.

Historical Background of the Skeletal Samples

The following section provides brief historical context for the skeletal remains studied in this project and reviews previous and related studies of these samples. Hagley Plantation, SC is introduced first, followed by a synopsis of bioarchaeological studies of similar South Carolina contexts.

Historical Context for Hagley Plantation, SC

Hagley Plantation, located in Georgetown County, SC was typical of the large rice plantations that lined the Waccamaw River. This area of the Waccamaw Neck was used in tidal rice agriculture from the latter eighteenth century forward by the wealthy Allston and Weston families. Hagley Plantation is one of four adjoining plantations purchased by Francis Marion Weston and bequeathed to his son Plowden C.J. Weston in the early 1830s. Based on 1860 census data for all four plantations, Plowden Weston had 334 slaves (196 males and 138 females) and 2,171 acres (900 of which were cultivated in rice). In 1860, Weston produced 1,253,000 lbs of rice: roughly 1,400 lbs per acre or 3,751 pounds per slave (Joyner 1984;20).

Plowden Weston was among the wealthiest men in America during the period and he is conceived of historically as one of the most benevolent of the wealthy rice planters in terms of treatment of his slaves (Devereux 1973; Joyner 1984; Dusinberre 2000; Whitten 1977). Significantly, Plowden Weston's estate is named by former slave Ben Horry in WPA interviews, as among only four plantations where the enslaved were decently as opposed to cruelly treated (Rawick 1972). Weston was born in Warwickshire, England, while his parents were visiting their ancestral home. He lived a life of letters, social discourse, and politics, although it was cut short by tuberculosis when he died in 1864 at age 44 (Devereux 1973). Weston's wife Emily Francis Weston also led a life of letters and art, illustrating aspects of nature, landscape and architecture, and the environment of the Waccamaw area through drawings and watercolor paintings which survive in private collections today. Weston was elected to the South Carolina House of Representatives in 1860 and was elected Lieutenant Governor in 1862 by the state legislature in consideration of his feeble health and in order to curtail his participation in military campaigns in the Georgetown area (Devereux 1973).

Archival Research

My study will use primary sources pertaining directly to Hagley Plantation, Plowden Weston, his enslaved workers, and secondary sources which record evidence of rice plantation culture and labor for Hagley Plantation and the surrounding rice coast. The existence of plantation rules, slave inventories, food rationing records, and meteorological documentation pertaining directly to Hagley Plantation as well as published demographies of Georgetown County rice slaves provide the unique opportunity to compare and test historical records and questions using the skeletal evidence. The primary sources used in my study are the Weston Family Papers (Weston 1764-1855), Plowden Weston's "Rules and Management for the Plantation" (Weston, cited in Collins 1865), and the Allston Family Papers, containing PCJ Weston's will (Weston 1864), which lists his bondsmen and women by occupation. Additionally, a demographic study of Georgetown County rice slaves is also available (Ricards and Blackburn 1975).

Bioarchaeology of Slavery in South Carolina and Rice Plantation Contexts

Bioarchaeological studies of enslaved African Americans in South Carolina are characterized by small sample size and varied temporal context. Rathbun's (1987) study of the remains from Remley Plantation (38CH778) provided a glimpse of health and lifestyle at a smaller scale plantation involved in rice and other mixed agriculture in the antebellum and peribellum period. Thirty-six slave burials dated roughly from 1840 to 1870 were removed and studied during the project. Material culture in terms of grave goods was scarce, but coffin and shroud-only burial styles were represented. Mean adult age at death was 35 for males and 40 for females, comparable to other enslaved groups from the colonial and antebellum periods.

Rathbun suggested that the slightly higher ratio of female to male slaves represented at the site is consistent with historical records from coastal South Carolina that indicate higher populations of females, possibly due to impaired survival of males, cultural practices, occupational requirements, or a suggested comparative advantage of female workers in rice plantations. The presence of healed cribra orbitalia and diplotic expansion at Remley suggested childhood anemia (43% and roughly 31% resp.) and possible adult iron deficiency and sickle cell anemia. Rathbun cited modern Charleston, SC data from hemoglobin studies that indicates Charleston area blacks still possess an elevated rate of sickling (15.5% to national norm of 9.6%) comparable to that of West Africans. The presence of non-specific evidence for infection or inflammatory response in the form of periostitis was also high among the remains from Remley Plantation, congruent with historical sources indicating the high prevalence of treponemal diseases, and respiratory, parasitic, and gastrointestinal ailments among enslaved workers in the south. In terms of occupational and degenerative changes, Rathbun attributed differential distribution of arthritic changes between the sexes as indicators of occupational differences and corresponding heavy lifting requirements.

Harris and Rathbun (1989) studied the dentitions from Remley Plantation (38CH778) and found unusually small tooth crown diameters within the sample. They demonstrated consistency of this historic sample in relative apportionment of tooth size with other sub-Saharan African groups and contrasted these populations with Caucasians, proposing that Remley's slaves' overall small tooth size may reflect either kin-based divergence from other historic samples, or perhaps demonstrate normal variation among African derived populations, suggesting differing geographic sources of enslaved Africans.

Crist (1990; 1995) performed a multi-element bone chemistry analysis of 26 individuals fromRemley Plantation. He tested historical questions surrounding the variability of the slave diet, such as central kitchen versus home cooking, rationing, and supplementation. His analysis revealed differences by age and sex in consumption patterns which suggested that young males may have eaten more meat, and older individuals probably relied more upon a vegetable-based diet. Young females were more exposed to lead, presumably from use of lead-glazed vessels in domestic chores. He concluded that the findings served to bolster the more current archaeological and historical interpretations of the variation and complexity of the slave diet in the lowcountry. His later publication of the study (Crist 1995) was concurrent with criticisms and reevaluation of bone chemistry and trace element studies within anthropology and he acknowledged that the findings may be subject to diagenesis or may in fact be useful in future reinterpretation of the data as bone chemistry techniques improve.

Rathbun and Steckel (2002) included the data from Remley Plantation within the framework of the "Health Index", noting that they ranked among the least healthy in most aspects (on par with highly stressed pre-Columbian populations) of those samples included in the analysis. Notably, the Remley group had the highest incidence of cribra orbitalia, extremely high rates of wrist and hand arthritis, and stand out as among the most heavily stressed of all populations during childhood based on evidence such as LEH defects and archival records for South Carolina slaves indicating compromised stature and growth disruption.

Rathbun and Scurry (1991) examined health and status among a group of white planters and enslaved African Americans from the colonial period at Belleview Plantation (38CH434). The study provided interesting comparative data on lead and comparative evidence for equally poor health regardless of status for the planter and enslaved. Belleview does not appear to have been involved in rice agriculture and was instead used for shipbuilding and mixed agriculture. Rathbun and Scurry emphasized the contribution of childhood diseases such as mumps, measles, chicken pox and whooping cough to mortality rates in plantation contexts in South Carolina.

Davis and colleagues (2010) conducted a study of the prevalence and distribution of degenerative joint disease (DJD) among skeletal remains from Hunter Army Air Field, Chatham County, Georgia (9CH875) during removal and relocation of the cemetery. The emancipation era African American cemetery was probably used from the 1870's to 1930's by freed African Americans without land who had come to Savannah, Georgia from South Carolina and Florida for the possibility of employment in the port city. It is likely, according to the authors, that the burial group (n=356) contained former rice plantation slaves. DJD was present in approximately 70 percent of their adult male and female sample and showed patterns of age-related increase, with females showing more extensive joint damage, suggesting they may have participated in the labor force until advanced age. The knees, back, and elbows were most frequently affected. Graham (2014) conducted an oral pathology study in which she compared the 9CH875 remains to other Georgia free African American cemetery samples. She demonstrated differentials in oral health presumably related to varying post-slavery resource access and dietary challenges associated with emancipation.

Historical Background for Newton Plantation

Newton Plantation is a former sugar plantation located in southern Christ Church Parish, Barbados (Shuler 2005). It was typical of a large Barbadian sugar plantation of the seventeenth through nineteenth centuries, averaging roughly 420 acres in size, with a slave population of nearly 200 at its height (Handler and Lange 1978). Newton Plantation was initially chosen for archaeological investigation in the early 1970's during the Barbados Archaeological Project, which was designed specifically to yield information on sugar plantation slave life that was not available in the written record (Handler et al. 1989). Their stated goals were to confront and assess planter bias in the written records, and to assess cultural change in Barbados through a combined critical view of the written and material records (Handler et al. 1989). Newton was selected for study due to the existence of extensive archival manuscripts pertaining to its early history and due to its large size and typicality in terms of social and demographic structure (Handler 1976; Handler and Lange 1978). Initial archaeological testing at Newton focused on the presumed slave village site with the goal of investigating the domestic and community life of the enslaved. These efforts at Newton did not prove nearly as productive as those on other plantations, presumably due to the effects of the tropical climate and modern agriculture limiting the recovery of material culture at the site.

Ethnographic and archaeological investigation, however, soon permitted the determination of the location of an undocumented slave cemetery at Newton, which quickly yielded a wealth of material, cultural, and biological information and became the impetus for decades of research. During the first field seasons, researchers recovered the remains of 104 individuals buried between approximately 1660 and 1820 (Handler et al. 1989).

The initial studies of these skeletons by Robert Corruccini, Jerome Handler, and colleagues generated a wealth of cranial and dental data on Caribbean slave health (Corruccini et al. 1982; Handler and Corruccini 1983) but the postcranial material was reinterred without study. Since this time, the skeletal and archaeological remains from Newton Plantation have been studied extensively, providing a picture of the harsh lifestyles endured by enslaved sugar workers at Newton Plantation, as well as their origins, occupations, mortuary practices, and other important inferences. Specific studies have examined weaning stress, enamel hypoplasia, and other dental defects (Corruccini et al. 1985; Corruccini et al. 1987b), skeletal lead content (Corruccini et al. 1987a; Handler et al. 1986), demographic estimates of fertility (Corruccini et al. 1989), and determination of African birth from skeletal remains (Handler 1994; Handler 1995; Handler 1996; Handler 1997; Handler et al. 1982).

In 1997-1998, excavations resumed at the site, conducted by Kristrina Shuler and Ray Pasquariello under the direction of Corruccini to address new research questions on health and demography. The recovery of complete skeletons as well as portions of commingled remains has since permitted further examination of health at Newton. Recent work includes the bioarchaeological assessment of health, nutrition, labor stress, and demography for previously unreported segments of Newton Plantation's burials (Shuler 2005a; Shuler 2005b; Shuler 2011; Shuler and Corruccini 2009), isotopic evidence for migration and African birth (Schroeder and Shuler 2006; Schroeder et al. 2009), and reevaluation of the initial lead studies and consideration of the impact of lead poisoning and alcohol consumption on this population (Schroeder et al. 2013).

The Rice Industry and Slavery in South Carolina

The rice plantation economy of South Carolina generated some of the greatest wealth in the world during the eighteenth and nineteenth centuries. The legacy of the now defunct rice industry is readily apparent throughout coastal South Carolina and Georgia, visable from land or air as the remnants of a landscape modified to an incredible extent by enslaved laborers for the production of rice. Equally important are the cultural and social legacy of the descendants of the enslaved African Americans of the coastal south and their identity within Gullah-Geechee heritage. The historical roots and global connections of South Carolina's rice economy are the subject of a lineage of wide-reaching scholarly investigation which continues to evolve in scope within the fields of history, historical archaeology, and the African Diaspora.

English Colonial South Carolina was established in 1670 by Barbadian planters in settlements near the confluence of the Ashley and Cooper Rivers (Greene 1987:192) and has been dubbed the "colony of a colony" (Edgar 1998). Dedication of the majority of

Barbados' land to sugar cane agriculture meant that Barbadian planters had to seek the establishment of colonial extensions in order to provide provisions for Barbados. The early coastal province engaged in ranching, deerskin trading, and pitch and tar production for naval stores (Carney 1996). Indigo and cotton were also successful crops throughout the colonial period. As the colony grew, it provided a number of supplies and naval stores to the West Indies, including staples of beef and pork, peas, and building materials such as lumber and shingles, receiving sugar, cocoa, coffee, and rum in return (Greene 1987; Eltis 1995). Flows of people and goods between South Carolina and the English Caribbean would be maintained for decades to come (Greene 1987).

By the late eighteenth century, rice production was fully established on the South Carolina coast. Evidence suggests it took some time and experimentation for rice to become successful in the colonies. Clifton (1981) illustrates the numerous environmental and technological challenges to rice becoming successful, reviewing the documentary evidence for rice sources and period records of experimental attempts with rice from the late seventeenth century. Throughout the period, South Carolina plantations supported themselves with slaves from local populations, from throughout the American South and the Caribbean, and—in the tens of thousands—from Africa and West Africa. Planters preferentially imported slaves from the rice growing regions of West Africa, the 'Rice Coast', because of their highly specialized knowledge and skills, which were critical to the success of rice in South Carolina (Littlefield 1981; Otto 1989; Wood 1974).

Carney (1998) has built upon the preceding scholarship to develop a convincing argument based on botanical, environmental, and historical evidence that African slaves who brought African rice (*Oryza glaberrima*) may have been the driving force in the establishment of rice agriculture in the New World. The techniques of rice production were "vested in the knowledge carried by… African peoples to the Americas" (Carney1993:1). The micro-environmental contexts and constraints in the tidal and inland swamp regions of West Africa were almost identical to those that would be found in the rice producing areas of South Carolina, and thus, with the knowledge and tutorship of enslaved Africans, coupled with their own ingenuity, European planters were able to achieve one of the most lucrative economies in the world by using "duplicate" technologies. The absence of any archival or documentary evidence that African slaves played a tutorial role in the development of the rice economy can be explained by racism and denial of intellectual capacity of enslaved Africans in addition to general lack of colonial period documentation according to Carney (Carney 1996a:7).

On lowcountry rice plantations, a unique arrangement known as "task" labor developed (Morgan 1982). Labor was organized by white overseers and black drivers who assigned and enforced daily tasks. Within task labor, work began at sunrise, and only after completion of daily tasks, could slaves engage in family work. Field tasks involved hoeing ¾ acres per day, or sowing ½ acre per day, and slaves were designated as "full-", "three-quarter", "half-hands", or other, by age, gender, and fitness. Men dug ditches and produced earthworks, but both sexes planted, sowed, and harvested. Seasonal labor, however, permitted some autonomy for the enslaved (Morgan 1982). Carney (1993) argues that task system was likely the direct result of a complex social and technological negotiation between European planters and enslaved Africans which fostered the development of a unique labor system under which the enslaved had more agency in the determination of their labor schedule. Negotiations and constructions of labor in the rice fields may have permitted the enslaved to duplicate the conditions many of them were familiar with in Africa or to “redefine the nature of…servitude so as to improve their conditions of existence” (Carney 1993:4). The seasonal round of rice processing, however, on top of cultivation and other yearly demands, required intense and arduous labor (Dethloff 2000).

The task system generated great wealth for elite planters and thus persisted along the coast beyond the Civil War (Joyner 1984; Morgan 1982). Eighteenth century rice grain milling and processing is thought to have been primarily a gendered task performed by women which was done daily, prior to shifts in technology and increasing mechanization in the nineteenth century which led to intensification of field labor for both sexes in a seasonal cycle (Carney 1996b). The 1730’s marked the shift from inland swamp production to more productive and labor-intensive tidal floodplain rice production (Carney 1996b:113). South Carolina tidal rice plantations, such as those along the Waccamaw River, exploited tidal estuaries where the interaction of brackish, fresh and saltwater bodies could be employed for irrigation purposes. Georgetown, South Carolina was a particularly good area for this as freshwater, pushed by tides, could be harnessed to flood the fields (Chaplin 1992; Morgan 1982).

Tidal rice cultivation in this area employed a complex system of banks, dams, canals and ditches with water flow controlled by wooden floodgates called trunks (Morgan 1982). Flooding was prevented by the construction of five foot high embankments with internal ditches. The enclosed areas were further subdivided into half-acre plots with trenches for sowing. The trunks were opened and closed to maintain water levels in the fields (Chaplin 1992). The hydraulic system required constant maintenance, as did weeding the fields, and landscape manipulation was as demanding as the harvesting and processing of rice (Chaplain 1992). Ferguson (1992) provides an intriguing discussion of the cultural and technological melding of African and European ingenuity involved in forming the colony of South Carolina, especially the earth moving feats and quantification and organization of the human labor involved in tidal rice transformation.

The skill and intimate relationship with the landscape, hydraulic machinery, and the crop harbored by rice slaves is hard to appreciate from archival sources and probably involved push and pull dynamics between planters and the enslaved in the determination of labor schedules and lifestyle constructs (Stewart 1991). The hydrodynamics and architecture of the built landscape characterizing tidal rice agriculture were not only instruments of production and profit, but can also be seen as instruments of social control. Considering the seasonal patterns of rice production and the uncertainties of weather, epidemics of illness, and planter absenteeism (especially during unhealthful seasons), the rice planters maintained a delicate equilibrium requiring "firm managerial authority"(Stewart 1991:54).

The Sugar Economy and Slavery in the Caribbean

Barbados was established as a British colony in 1627, and initially focused on small-scale farming of tobacco, indigo, and cotton using indentured European labor. Tobacco was quickly abandoned as the major staple crop in light of the rapidly increasing market value of sugar (Dunn 1973:19; Handler 1978:15). The English planters, under the tutelage of Dutch planters from Suriname, learned how to grow and manage sugar cane in the 1640's. They began using indentured white servitude, but quickly developed an effective enterprise manned by African slaves. Concerns about the dependability of white servants, the reputation for cruelty in the sugar economy, as well as the example of labor success employing African slave labor in Brazil, were determining factors in this change to enslaved labor (Dunn 1973:72-73). At the onset, the majority of the slaves imported to Barbados were from the Gold Coast and the Bight of Benin, brought by British and Dutch slave traders. During the 18th century, creole slaves became preferred over African slaves according to period accounts (Handler 1978:25). Barbadian planters also made efforts towards maintaining equal sex ratios (Beckles 1996).

The majority of the island was cleared and planted in cane, and enslaved Africans were brought in as the demand for sugar increased. Sidney Mintz' (1985) details how sugar began as a luxury commodity for the English nobility, but by 1750, had become a staple for even the English poor. Sugar cane continued to be the basis of Barbados' economy well into the latter half of the twentieth century (Handler 1965). The sugar planters' proclivity for secrecy regarding their attainment of wealth is one of the reasons that limited documentary evidence of the sugar plantations remains (Dunn 1973:xv-xvi). Ethnohistory and archaeology, however, have been particularly informative about sugar production, especially on Barbados (Handler 1978).

Barbados has high land elevations but is not mountainous, with a sizable ratio of arable land to total land mass (Dunn 1973:27-28; Stinchcombe 1995:32) It is small and fairly isolated, which made it ideal strategically, as the British were under constant threat of Spanish and French attack during the colonial period (Dunn 1973:15-17). Political strife and conflict characterized the period as the nations skirmished over resources and wealth, imposing navigation acts and tariffs on trade (Dunn 1973:20). Health hazards, overcrowding, and concerns about agriculture and food supply on Barbados eventually led Barbadian planters to emigrate and play a crucial role in the founding of South Carolina and its slave economies (Dunn 1973:113-116; Greene 1987:197).

Labor roles were diverse in Barbados, and slaves worked as drivers and managers, boiler and crusher operators, domestics, and in specialized labor (Handler and Lange 1978). However, most of the work was carried out in the fields. Using 18th century archival data for 450 enslaved laborers from St. Christopher, Dunn (1973:198) identified 64% of slaves as field hands, 10% as factory workers, 14% as domestics, and 12% as specialized labor. Field labor was structured through gangs, with as many as three to four gangs on large plantations. Men, women, and adolescents worked most intensively on the Great Gang. Lesser gangs were filled with the less able-bodied, including children. In the fields, slaves hoed without the use of draught animals, digging small holes by hand into which they planted clippings from the previous year's sugar crops. Dunn (1973) estimates that approximately 30 slaves could prepare two acres for planting in a day. Sugar production required strenuous labor under close supervision. Since sugar cane requires 14 to 18 months to ripen, the seasonal round of planting and harvesting was staggered in terms of planned ripening times between January and May. Thus, intense labor took place almost year round. As the norm, English sugar planters partitioned sugar fields in to ten acre parcels with varied planting times. Sugar fields required large amounts of animal dung for fertilizer, requiring planters to have ample cattle and sheep on hand (Dunn 1973:190-191).

Plantation size varied across Barbados, but the average number of slaves was one per two acres of land. Sixty plus slaves and one hundred acres or more characterized the larger plantations, with 200 acres being the optimal size for large scale production. Most plantations had their own sugar mill (Dunn 1973:92-96). Sugar cane was harvested by slaves using curved knives called 'bills'. Stalks were bundled and carried to a mill for grinding. Sugar mills typically were enclosed or covered machinery with three rollers for the extraction of cane juice. The mills were powered by wind, water, or cattle, depending on local conditions. Extracted cane juice was then transferred to a boiling house where it had to be boiled for evaporation into crystallized sugar. Boiling achieved granulation of the sugar and permitted separation of molasses during the process, which was then fermented and distilled to make rum. Muscovedo (golden brown) and white sugars were made for export. Sugar plantation labor also required specialized tasks and skilled labor to operate and maintain machinery as well as to build barrels and pots. Many planters required year-round heavy and degrading labor of the enslaved for reasons of social control, rather than purely for the timing of the crop (Dunn 1973:192-196).

The work day for the enslaved lasted 10 to 11 hours with a meal break. A six day work week was the norm (Dunn 1973:248). The constant labor schedule of sugar production is described as a "factory in the field" (Fogel and Engerman 1974). Handler's (1965) ethnographic study reveals much about the dynamics and diversity of task involved in the sugar industry in the post-slavery society. He describes male, female, and child labor including planting, digging, weeding, maintenance of drainage ditches, and cutting and harvest activities, little-changed since the slavery period. Planters imposed strict slave codes which included brutal corporal punishment for crimes such as theft, and even imposed death for major infractions. Slaves lived in rows of huts or similar arrangements and were allotted a monotonous starchy diet consisting of beans, yams, corn, and plantains. They were provided with rum rations for the weekends (Dunn 1973:248-249). Alcohol abuse was rampant, especially among the planters. Nearly everyone experienced the effects of lead poisoning due to lead-lined drinking vessels, lead-contaminated rum, and occupational exposure. Planter and enslaved alike suffered from the disease environment which fostered malaria, yellow fever, dysentery, dropsy, yaws, tuberculosis and venereal disease. Parasitism and geophagy were widespread due to parasites such as hookworm and guinea worm, likely brought to Barbados during the transatlantic passage (Dunn 1973:302-307).

Shepherd (2002) and other scholars (Bush 1990; Morrissey 1989) critiqued early historical viewpoints that viewed the Caribbean, during sugar slavery, in terms of a strict dichotomy between planter and enslaved. The reality was one of complex variation in social stratification, gender roles, occupation, and identity among planters and enslaved and freed classes alike. The picture of Caribbean slavery varied temporally and geographically throughout the slavery period (Stinchcombe 1995:130-133), with those islands most deeply tied to sugar production being the most rigid slave societies.

Biomechanical Studies in Biological Anthropology

Measurement of the robusticity and strength of human long bone diaphyses provides valuable information about past human habitual behavior (Larsen 1997). The cross-sectional geometry of long bone diaphyses is particularly sensitive to the mechanical loading of body mass (Ruff 2000; Trinkaus et al. 1994). The fact that bone cross-sectional geometry is also extremely sensitive to behavioral use of the limbs is a key consideration for reconstructions of past behavior.

The morphological variables most frequently used by anthropologists in these studies are the strength of the diaphysis relative to body size, asymmetry of the limbs, shape of the diaphysis, and sexually dimorphic mechanical properties (Stock and Pfieffer 2004). The concept that bone shape and structure reflect the stresses that are placed upon them is derived from Wolff's Law (Wolff 1892), which states that bone is added where it is needed and removed where it is not. Modern understandings of skeletal biology reveal much more about the dynamics of remodeling, but aspects such as its change in rate throughout the human lifespan remain poorly understood. What is clear is that the plastic nature of long bone diaphyses reflects more about stress and structural adaptation than do the joints, whose architecture remains more or less stable throughout life, aside from degenerative and pathological change (Ruff and Runestad 1992).

Several means of assessing of the effects of behavior from size and shape of bones have been proposed but cross-sectional geometry studies are thought to be the most informative (Pearson 2000; Pietrusewsky 2000) since they permit the observation of the distribution of bone mass (Larsen 2002). Other means primarily rely on external metric indices (Stock and Shaw 2007). Studies within bioarchaeology often assess these measures within and between groups in order to assess relative levels of workload and type of labor, as well as sexual division of labor and sexual dimorphism (Pomeroy and Zakrzewski 2009; Ruff 1987).

Biomechanical Studies of Nineteenth Century Groups

Bioarchaeological studies of enslaved and historic period African American groups have traditionally examined prevalence and patterning of musculoskeletal stress markers, entheses, and osteoarthritis for inference into labor patterns within groups (Kelly and Angel 1983; Owsley et al. 1987; Rankin-Hill 1997; Rathbun 1987; Shuler 2005; Wilczak et al. 2004). Few studies have adopted a biomechanical approach to compare enslaved groups. Phillips (2001) was among the first to consider comparative measures of labor for nineteenth century groups. He tested historical questions surrounding the biological impact of nineteenth century “labor therapy” imposed as a means of therapeutic control of mentally-ill patients from the Upstate New York Oneida Asylum by incorporating archival records of work regimes with skeletal evidence of labor stress. His measures included vertebral burst fractures, metric skeletal robusticity indicators, and maintenance of cortical area derived from sectioned long bones. He compared the results of his analysis of skeletal remains to nineteenth century skeletal samples of almshouse residents (Higgins and Sirianni 2000), free African Americans (Rankin-Hill 1997), South Carolina plantation slaves (Rathbun 1987), pioneer settlers (Larsen et al. 1995), and other samples. The results of his work integrating archival research of labor regimes with skeletal evidence reveal a picture of significantly greater labor stress, degenerative change, and skeletal robusticity for these inmates compared to other nineteenth century groups.

The only CT-based cross-sectional geometry for slaves is that of the probable late eighteenth century slaves from Cape Town, South Africa (Ledger et al. 2000). The authors of this study compared properties of the humerus and tibia from the Cape Town skeletal remains to those of a hunter-gatherer sample and a modern forensic sample of unclaimed bodies. Their analysis included paired humeri and tibiae from the three contexts and compared measures of cortical area (CA), percent cortical area (%CA) as well as second moments of area I_x and I_y, polar moment of area J, and I_{max}/I_{min}, a shape and bending strength measure. Paired humeri permitted comparisons of bilateral asymmetry in upper body strength. Problems for comparison of their study samples included differences in age composition. With this caveat in mind for their measures of bone strength and cortical area, they found significant differences in upper limb strength measures among the samples, with the enslaved standing out as being bilaterally strong probably due to the effects of heavy manual labor. The hunter-gatherer sample and the modern group displayed greater asymmetry in upper limb measures compared to the enslaved laborers, suggesting lateralized habitual behaviors within both groups.

The results are consistent with many of the findings for hunter-gatherer and agriculturalist comparisons, namely that the enslaved group and the modern group show evidence in the tibia for reduced mobility suggesting more sedentary lifestyles. As expected, the enslaved male sample shows marked upper body strength in humeral properties compared to the other groups. The enslaved females are on par with the modern sample in terms of upper body strength. The upper body robusticity of the male slaves is consistent with their status as agricultural laborers, while the marked dimorphism among the slaves suggests that women were involved in domestic chores similar to that of modern groups. This is corroborated by the historical record for the Cape Town area.

Previous Comparative Study of Newton and Hagley Plantations

A preliminary bioarchaeological comparison of life stresses for Hagley and Newton Plantations was conducted by Shuler and Stevens (2009). The study involved comparisons by element due to commingling of the Hagley remains. In this dissertation study, I revise age estimations derived by Stevens (2008) in order to account for commingling. The auricular surface of the innominate, the most frequently preserved age indicator, was also re-scored within the sample using the Osborne et al. (2004) phases rather than using the Lovejoy et al. (1985) method. Revised age estimation data for adults and subadults are presented in Table 2.1. Mean adult age at death was substantially lower for Newton Plantation (26.24 years) compared to that of Hagley Plantation (39.11 years). Table 2.2 places mean age estimates from Shuler and Stevens' data and revised age estimates from the current dissertation in comparison to age estimates derived from other studies of contemporaneous and enslaved populations. Mortality curves derived for Newton and Hagley Plantations' skeletal samples are presented in Figure 2.1. Comparison of adult mean age at death for Newton and Hagley Plantations versus similar eighteenth and nineteenth century contexts is revealing in that Newton is among the lowest of the samples. Hagley's adult mean age estimates are skewed by the underrepresentation of females in the estimate, but otherwise the skeletal age data are comparable to Rathbun's data for Remley Plantation.

Wright (2009) constructed a survivorship curve based on the standing age distribution of the enslaved at Hagley Plantation in March 1864 derived from the probate inventory of the estate of Plowden Weston. The inventory recorded 183 enslaved individuals at Hagley consisting of 95 females and 88 males. Wright found comparatively few young adults in the 15 to 25 year range, suggesting the effects of a possible epidemic affecting young children in the latter 1830's to 1840 time range. This finding is consistent with that of Ricards and Blackburn (1975) who found a similar trend for Georgetown County as a whole based on the 1850 census. Considering the date of St. Mary's Chapel's construction, 1859, the probate data and the cemetery are contemporaneous. Shuler and Stevens' (2009) mortality curve for Hagley demonstrates a peak in the 9 to 10 and the 15 to 18 age brackets suggestive of considerable child and adolescent mortality. Wright compared survivorship from the probate records with age estimates derived from initial study of Hagley's skeletal remains (Stevens 2008) and found differences between the curves likely caused by underrepresentation of subadults due to preservation and sample recovery biases. Despite discrepancies between the standing distribution and the cemetery sample, which also occurred in the middle age ranges (20 to 45), skeletal data and the standing cohorts did coincide in indicating that approximately 50 percent of deaths occurred prior to age 22 (Wright 2009).

Preliminary comparison of Hagley and Newton Plantations situated the two samples in comparative context to other eighteenth and nineteenth century samples for stature, revealing Newton's slaves to be comparatively tall compared to other Caribbean samples, and on par with heights derived from northern North American contexts (Shuler and Stevens 2009) (Table 2.3). Hagley's enslaved males were similar in height to Rathbun's (1987) and Rathbun and Scurry's (1991) South Carolina samples, while females at Hagley appear particularly short. Difficulty in sex determination due to commingling and preservation in the this dissertation study suggests that this initial estimate for female stature at Hagley may be biased due to omission of stature estimates for those of indeterminate sex. Nevertheless, Hagley's skeletal sample appears on par with similar lowcountry South Carolina rice plantation contexts, demonstrably short due to presumed highly stressful childhoods and compromised nutrition in later life (Rathbun and Steckel 2002:220).

Osteoarthritis (OA) was scored for observable joints by Shuler and Stevens (2009) and tabulated for comparison between Hagley and Newton adults. Comparative frequencies by location are presented in Figure 2.2. The initial results convey a picture of widespread degenerative change among relatively young age groups.

Many individuals present severe degenerative change with marked joint modification (Figure 2.3). Considering the current study's revision of age estimates due to commingling, however, the results may indicate more about age-related degenerative change due to differences between the samples, with Newton Plantation being markedly younger on average. The results are also problematic as Hagley's data was gathered by element prior to attempted sorting of commingling. The present biomechanical study is deemed to be a far better gauge of labor-related activity patterns than the OA study since it derives from a sorted sample, minimizing the effect of repeated measures within single individuals.

In the next chapter, I will review aspects of the biology and history of slavery, focusing particularly on the American South and the Caribbean in order to provide biocultural and historical context to my interpretation of the results of my comparative studies in later chapters.

Table 2.1 Revised Age Estimates for Hagley Plantation Based on Auricular Surface of the Innominate (Osborne et al. 2004), Sex Estimations based on (Phenice 1969).

	Right	Phase	Left	Phase	Mean Age	Sex
Paired innominates	172	6	330	n/a	58.9	female
	329	6	167	6	58.9	male
	328	n/a	332	2	29.5	female
	176	1	170	1	21.1	male
	169	4	173	4	47.8	male
Unpaired innominates	327	2			29.5	male
	326	n/a				male
	175	n/a				male
	165	4			47.8	female
			163	n/a		male
			331	3	42	female
			164	1	21.1	probable male
			166	1	21.1	probable female
			177	3	42	male
			178	n/a		male
			171	6	58.9	male
			168	1	21.1	female
			174	4	47.8	Indeterminate

Table 2.2 Mean Ages for Newton and Hagley Plantations in Comparison to Other Enslaved and Historic Period Skeletal Series.

SITE	N =	Mean Age	Mean Age Adult	Mean Age Males	Mean Age Females	Source
Newton	45	19.95	26.24	29.8	25.22	Shuler, 2005
Newton (dental)	103	--	29.3 *	--	--	Corruccini et al., 1982
Hagley	22	26.16	39.11	43.03	36.73	Present Study
Clifts	10	--	32.3	30.5	34	Aufderheide et al. 1981
Colonial US	29	--	37.2	35.7	38.6	Kelley and Angel 1987
ABG New York	419	22.5	37	38	35.9	Blakey,Rankin-Hill, 2004
St. Peter Street	13	--	35.0	33.0	37.0	Owsley et al. 1987
Belleview	13	--	--	40+	45+	Rathbun and Scurry 1991
Catoctin	31	--	38.5	41.8	35.3	Angel 1980
Waterloo	38	--	40 *	--	--	Khudabux 1999
Remley	36	--	37.5	34.7	39.7	Rathbun 1987
US African Soldiers	18	25	25	25	0	Rathbun and Smith 1997

Table 2.3 Mean Estimated Adult Stature for Newton and Hagley Plantations in Comparison to Other Enslaved and Historic Period Skeletal Series.

Location	Period	Stature M (cm)	Stature F (cm)	Source
Newton	1660-1820	169.7	159.3	Shuler 2005
Barbados *historic	1819-1825	167.5	159.1	Higman 1984
Montserrat	c. 1751	163.0	152-157	Mann et al. 1987
Suriname	1796-1861	162.9	156.8	Khudabux 1999
Hagley	19th century	168.5	154.5	Stevens
Belleview	1738-1756	166.0	161.0	Rathbun&Scurry 1991
Remley	1840-1870	167.4	160.6	Rathbun 1987
Catoctin	1776-1903	171.6	156.4	Angel 1980
Colonial US	1690-1820	172.0	155.9	Kelley and Angel 1987
US soldiers	1863-1865	167.6	--	Rathbun&Smith 1997

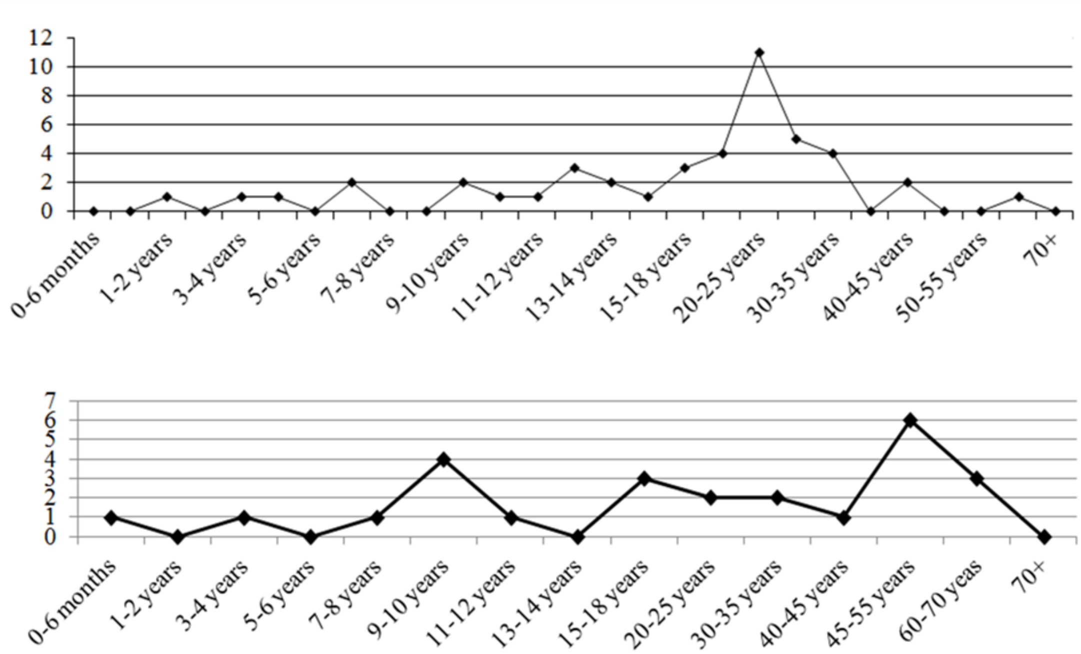
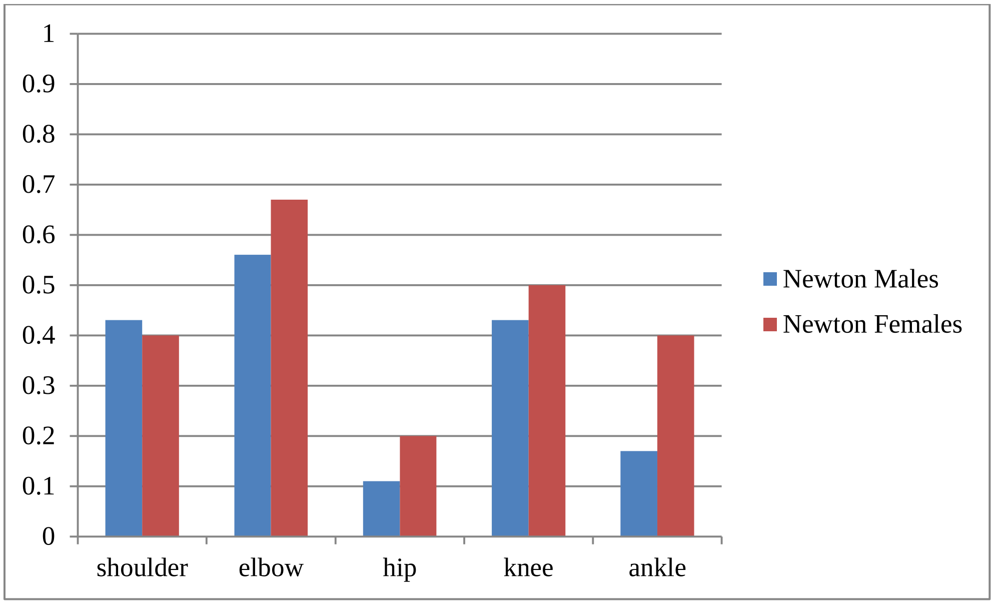


Figure 2.1 Mortality curves for Newton (Top) (Shuler 2005:275) and Hagley (Bottom) Plantations.



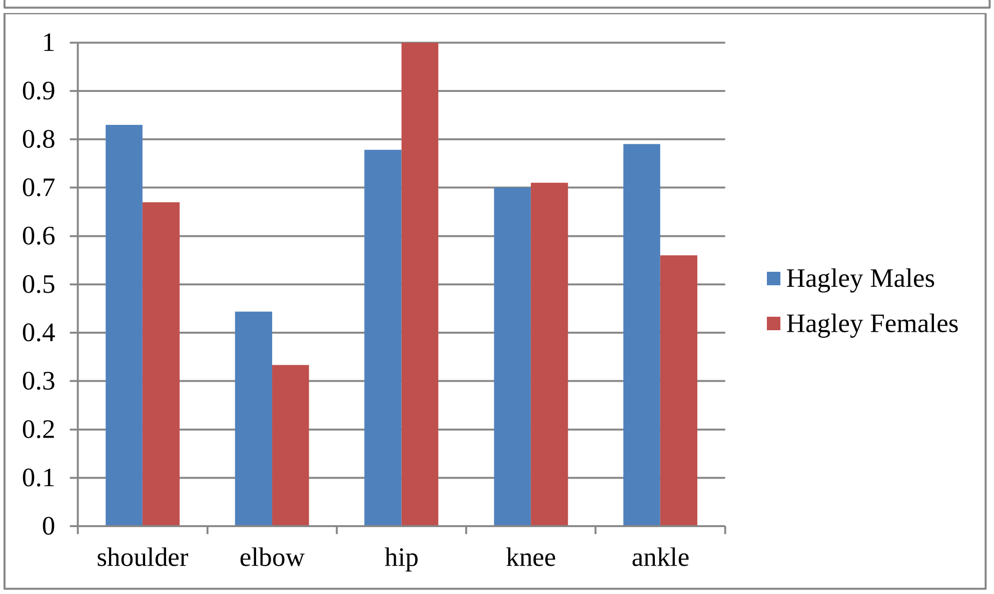


Figure 2.2 Frequency Distribution of Osteoarthritis (OA) by Major Joints by Sex for Newton (Shuler 2005:269-270) and Hagley Plantations.

Figure 2.3 Severe Osteoarthritis of Knee (Left Femur) with Eburnation at Hagley Plantation.

CHAPTER 3

BIOHISTORY OF SLAVERY

In this chapter, I review the pertinent aspects of the biohistory of slavery in North American and Caribbean contexts in order to inform my consideration of health variables for the comparative study of enslaved labor. The biological and lived experience of enslaved Africans within the context of plantation slavery is a broad scholarly concern spanning many disciplines, especially history, economics, historical demography, biology, medicine, and anthropology. Life experiences for slaves varied greatly across geography and time (Young 1993). Just as Africans shaped the culture of the New World, their experiences of health and disease as well as African diseases themselves contributed to the character of life in the New World for all its inhabitants. The issue of quality of life, health, and nutrition of the enslaved became a concern during the time of slavery and began as a focus of debates started by abolitionists such as Frederick Douglass. Benjamin Franklin, David Hume, and Theodore Weld (Douglass 1854; Fogel 1989; Rathbun and Steckel 2002; Weld 1839).

Demography and Population Performance

Scholarly investigation of health, disease, and living conditions within slavery are connected to the broad question of the demographic performance of enslaved populations by economy and region. Arguments pertaining to natural increase and decrease of enslaved populations are discussed by nearly every scholar of slavery and an in-depth review of them is beyond the scope of this dissertation. Debate and discussion of population performance began during the slavery period and abolitionists used mortality and fertility figures indicating poor performance to demonstrate the inhumane conditions of slavery (Fogel 1989:117). The efforts of English abolitionists are exemplary of this as they cited the failure of slaves to reproduce their numbers in Jamaica and the British Caribbean (Higman 1976:99). Broadly speaking, North American slaves, especially those of the Old South, faired better than did Caribbean slaves in terms of population reproduction (Fogel 1989; Genovese 1976; Higman 1976; Stampp 1972).

The American south was unique, maintaining a slave labor force that reproduced itself, growing from 400,000 imported Africans to a population of 4,000,000 by 1860, owing, in Genovese' view to features of southern paternalism and plantation size and structure (Genovese 1976:5). Stampp cites a figure for the natural increase of southern slave populations of twenty-three percent per decade between 1830 and 1860 (Stampp 1972:320). There is consensus that the crude birth rate for the Caribbean as a whole derived from historic birth records is too low for population replacement given the mortality rates in the Caribbean (Campbell 1984; Corruccini et al. 1989; Craton 1971; Craton 1975; Craton 1979; Eblen 1972; Farley 1965; Higman 1984; Kiple 1984; Kiple and Kiple 1980; Roberts 1952; Sheridan 1975; Tadman 2000). Higman (1976:101-105), however, presents a mixed picture of population performance by Caribbean region and estate type with temporal shifts that correlate well with the seasoning period for newly introduced Africans. The differences in performance and mortality rates between creole versus African-born populations is significant for most regions of New World slavery.

Imbalanced sex ratios are also highly significant and dependent upon region, economy, and temporal trends (Higman 1976).

The linkages between New World slave health and that of West African populations continue to be explored using multiple lines of evidence. Earlier efforts are characterized by statistical and anthropometric approaches to issues such as slave trade and Middle Passage mortality rates and heights derived from slave manifests as indicators of nutritional status (Eltis 1982; Miller 1981; Steckel 1979). A common vein running through these and other contemporary studies was the conception of West Africans as disadvantaged from the start, prior to captivity and enslavement; due to historical nutritional inadequacy and population genetics (Gibbs et al. 1980; Handler and Corruccini 1983; Handler 2006; Kiple and King 1980). Another area in which diasporic health connections have been explored is the examination of African cultural dietary and weaning practices and their persistence through time and geography (Covey and Eisnach 2009; Eltis 1982; Gibbs et al. 1980; Hall 2007; Handler and Corruccini 1983; Kiple and King1981; Kiple and Kiple 1980; Luke et al. 2001). Other scholarship which considers these connections includes infectious-disease focused studies which emphasize the effects of African-derived diseases and parasitic infections on the New World health of both African and European-derived groups (Alden and Miller 1988; Craton 1991; Handler 2006; Kiple 1984, 1986, 1988; Kiple and Higgins 1992). More recent efforts continue to seek an understanding of the historical biocultural processes which have shaped the health and nutrition experiences of Africans in diaspora in light of temporal and regional transitions, often linking past population health dynamics to modern health problems and political-economic forces (Armelagos 2005; Armelagos and Maes 2006; Blakey 2001; Jackson 2005; Luke et al. 2001; Moramarco 2010; Wilson and Grim 1991).

Demographic Profiles of Sugar and Rice Plantation Slavery

Sugar and rice were produced in similar tropical disease environments, share British colonial roots, and involved similar poor demographic performance, including great loss of life with reliance in many periods on great numbers of slave imports. Southern rice plantations and Barbadian sugar plantations both stand out from the demographic patterns common to similar plantation systems within North America and the Americas, respectively, according to historians of slavery. The rice industry in the Carolinas and Georgia was marked by population decrease during much of its tenure and at best only able to achieve low rates of natural increase in contrast to the outstanding rates achieved by industries such as cotton (Dusinberre 2000; Fogel 1989).

Sugar is widely believed by historians to be the most brutal and taxing form of plantation industry in the Americas, in terms of labor requirements, and mortality (Eltis and Engerman 1993:311; Higman 1984). Caribbean sugar producing populations are most often associated with high mortality (Fogel 1989; Higman 1976). Barbados is unique in that it alone among sugar producing islands achieved low positive natural population increase in contrast to the profound decrease in slave populations characterizing many other sugar regions. Thus, while the two crop systems stand at the extremes of their respective demographic profiles, they are remarkably similar. Higman (1976) notes the difficulty of disentangling the role of the demands of the labor within sugar regimes from the effects of the tropical environment on population performance, and suggests that more diverse economies seem to have better performance compared to strict mono-cropping structures. These differing demographic profiles are of course best conceived as the result of dynamic political, economic, and historical processes rather than categorical generalizations. Population growth rates changed over time in response to myriad factors (Higman 1976). From the perspective of sugar planters of the Caribbean, poor population performance was largely a “negro problem”, tied to low birth rates resulting from promiscuity, lack of morals, induced abortions, and the effects of venereal disease (Fogel 1989:118-119).

Abolitionist efforts were crucial in spurring amelioration that resulted in improved conditions of slavery toward the later end of the period. Morrissey (Morrissey 1991) describes amelioration in Barbados as exemplary and resulting in improvement. These changes included the improvement of labor and living conditions, couple with systems of encouragement and reward for births and resulted in the achievement of low levels of positive increase. Her research suggests that this was not necessarily the picture for the rest of the Caribbean. Women were likely under more work pressure in Jamaica and Cuba than in Barbados and Martinique. Genovese describes improvements and changes of planter tactics in response to slave rebellion in South Carolina. Conditions of the early eighteenth century in the coastal part of the state were characterized by “great disregard for human life”. Natural increase occurred during the earliest part of the century but turned negative following large imports from Africa post-1720 through 1739. The “Stono Rebellion” of that year caused slave holders to rethink many of their policies. The regime managed to return to productivity following the end of the eighteenth century as rice and sea island cotton became established (Genovese 1976).

Diet and Nutrition During Plantation Slavery

Cliometrics and the Use of Aggregate Data

Diet and nutrition are a focal point in the debate surrounding the health and quality of life of enslaved African Americans (Blakey 2001; Hall 2007). The political-economic work of Genovese (1967) presents one of the earliest modern efforts to critically assess the long-held historical view of the homogeneous "hog and hominy" diet of enslaved African Americans. His argument regarding the inadequacy of slave diets rests largely on documentary evidence and proposes a link between inadequate nutrition and historical evidence pointing to the low productivity of southern slave labor (Genovese 1967:44). Genovese appears ahead of his time in recognizing and evaluating connections between nutrition, disease, and productivity (Genovese 1967:46).

Fogel and Engerman's (1974) cliometric approach followed closely and reached a startlingly different conclusion. The slave diet was quantitatively and qualitatively as adequate as that of whites of the period, in their view, and even surpassed modern diets in caloric content and recommended daily allowances of nutrients. The researchers undertook broad statistical and quantitative analyses of southern plantation demographic, census, and production records in order to critically evaluate and explain the function of the economy of slavery. Their noble intentions of bridging the gap between pure scientific approaches and humanistic approaches to the examination of the institution met with considerable backlash (see Gutman (1976)). Fogel and Engerman are, however, credited with raising important questions pertaining to the sufficiency and variety of slave diets (Hall 2007:35).

Use of Height as an Indicator of Nutritional Status in Slavery Studies

Height is used by historians, economists, and anthropologists within health and nutrition studies as a means of making population-level comparisons within and between socioeconomic groups and in demonstrating health trends and phenomena of secular change (Angel 1976; Coelho and McGuire 2000; Fogel and Engerman 1974; Gibbs et al. 1980; Kiple 1986; Kiple and King 1981; Margo and Steckel 1982; 1983; Steckel 1979a). Many scholars leveled critiques on cliometric and anthropometric approaches to the study of plantation slavery on methodological grounds. Early research contained statistical errors, inappropriate analytical units, and bias due to the aggregate nature of data and one-sided nature of planter records.

The cliometricians completely ignored the differences between the nutritional needs of men, women, and children (Gibbs et al. 1980:229). Fogel and Engerman (1974) employ adult height as an indicator of nutritional status as well as calorie counts as indicators of gross nutrition (total nutrient intake), fertility rates, census returns, and planter records of weekly food allotments. The researchers rely almost exclusively on aggregate data derived from large southern plantations- the exception rather than the norm, according to Hall. The reality was one of smaller plantation size, and great variability in their contexts (Hall 2007:39).

Sutch (1975) raised an immediate backlash in which he drew from similar cliometric data but argued to the contrary that slave diets were not at all adequate and if they ever were, it was due to the slaves' ingenuity and dietary supplementation rather than to the allowances bestowed them by southern planters. Still other researchers (Vinovskis 1975) agreed with Fogel and Engerman regarding nutritional adequacy but contended that their demographic methodology was flawed. In light of the consideration of net nutrition (the result of dietary intake minus claims made on that intake by labor), which adult height primarily reflects, Sutch (1976) argued strongly that the diet, although on-par in quantity with other groups, was clearly not adequate for people involved in enslaved labor. More nuanced and biocultural understandings followed, which developed into a more current conception of the slave diet, its adequacy, and its effects on growth. Fogel's later work emphasized the complexities inherent in interpreting heights by age as nutritional indicators with the realization that the same nutritional input can have different growth outcomes due to environmental factors. Examinations of child growth profiles and height by age cohort paint a better picture of slave nutrition during childhood (Fogel 1989). The consensus now appears to be that slave children were incredibly small owing to protein-calorie malnutrition, early weaning, low birth weight, endogenous factors and malformations, contamination and deficiency of food. Their entry into field labor is marked by a characteristic catch-up growth spurt (Fogel 1989:141-143; Rathbun and Steckel 2002; Steckel 1986b).

Quantity vs. Quality

The string of arguments that arose in response to cliometric interpretations resonates with intense debate centered on the issues of quantity and quality. Again, in being somewhat forward thinking, Genovese's (1967) argument was one of the first to describe the southern slave diet as deficient. He refers to the "specific hungers" and "dangerous deficiencies" of protein hunger due to the starchy, high fat content of typical plantation ration (1967:44). In examining the work capacity of southern slaves, Genovese proposed that malnutrition and its sequelae led to a cyclical pattern of chronic disease and reduced productivity. The high fat, low protein content of the largely planter-supplied diet, he argued, kept up healthful appearances of slaves, but allowed only for short bursts of energy rather than for the endurance necessary to perform long hours of strenuous labor. Planters lacked the knowledge, training, and resources to maintain an adequately nourished and productive slave labor force. He cites slavery period supervised tests of labor output in which slaves under direct observation produced considerably greater output than normal, as indicative of the perpetual state of exhaustion experienced by slaves (1967:46). Genovese' omission of other human factors such as resistance and even basic energy conservation is a bit unsatisfying. His appraisal of the adequacy of the slave diet appears to be one of dietary imbalance and quality rather than insufficiency of quantity.

Seeking to explore nutritional adequacy with the goal of addressing the linkages between diet, health, and work capacity, Gibbs et al. (1980) conclude that dietary quantity and quality varied significantly during the antebellum period but that protein deficiency was similarly the primary contributing factor to the cycle of malnutrition and disease. The researchers cite plantation location, size, type of industry, status of slave, capabilities of supplementation, and the nature of control and allocation of food resources as important considerations within dietary examinations (1980:179). Savitt (1978) echoes a similar concern with variation and diversity and criticizes the blanket assumption that slave diets were deficient. The evidence for malnutrition and deficiency diseases is largely unconvincing, according to Savitt, due to the nonspecific nature of the symptoms of these conditions, poor diagnosis, and the poor record-keeping characteristic of the antebellum period (1978:86-87).

Kiple and King (1981) were among the first to incorporate concepts of genetic and biological population histories and adaptive frameworks into the discussion of the nutritional status of enslaved southerners. Their core question is not whether the diet of slaves was qualitatively adequate in general, but whether it was qualitatively adequate for persons of West African descent. They propose a biocultural analytical framework that includes consideration of the relationships among nutrition, genetics, and environment. The genetic heritage of blacks, in conjunction with southern dietary staples, created a diet that, while adequate for whites, was insufficient for the enslaved (1981:71-72). Blacks, they contend, were not able to absorb, utilize, and benefit from the nutrients provided by the southern dietary traditions as effectively as whites were.

Similarly to Savitt (1978), Kiple and King admit that the difficulty of diagnosing nineteenth century deficiencies and illnesses is a complicating factor due to the lack of satisfactory morbidity and mortality data. The authors propose an inductive means of testing this theory based on the examination of historical food types and the assessment of the nutritional yield of these foods in the context of modern data regarding the ability of blacks to metabolize certain nutrients. They propose to then be able to “discover” the expected diseases and subsequently match nutrient deficiencies with specific disease. Further components of their testing framework include the examination of possible genetic and environmental mitigating and complicating factors which may impact these dietary deficiencies as well as an approach to comparing morbidity and mortality between racial groups to reveal differential impact on blacks and whites (Kiple and King

1981:72). This and similar perspectives have received heavy criticism as being biodeterministic and race-based (Blakey 2001; Vinovskis 1986).

The Core Diet

Prior to the advent of African Diaspora studies, anthropological and biocultural studies, and historical archaeology investigations of marginalized groups such as southern slaves, our historical conception of the diet of enslaved African Americans was primarily derived from the written history of the upper class, southern nostalgia, oral traditions, narratives, and folklore. The result was a view of the planter-supplied "core diet" of staple rations as the primary means of subsistence for the enslaved. Even accounts of food ways and dietary practices given by ex-slaves during interviews are shown to vary considerably depending on the race of the interviewer and present other interpretive difficulties (Hall 2007:39). Twentieth century research has revealed a far more complex picture of regional, seasonal, economic, temporal and individual variation among the dietary patterns of slaves within the plantation economy.

Gibbs et al. (1980) fault scholars for a complete failure to recognize the regional and ecological diversity of the south. Crader (1990) views the notion of a "slave diet" as nonsensical due to contextual variation and period changes within the south. In addressing the biases inherent in the written and oral histories of slavery, scholars produce a heterogeneous picture of the diet, culinary traditions, and nutritional status of slaves, which acknowledges variation, resistance, supplementation, technological contribution, and African agency in the development of the agricultural economy of the southern states (Carney 1998; Hall 2007; Littlefield 1981).

Most historical sources and researchers describe a core diet of salted fat pork and cornmeal supplemented with molasses and, to varying degree seasonally and regionally, with fruits and vegetables (Etheridge 1988:106; Fogel and Engerman 1974; Genovese 1967:44-45; Gibbs et al. 1980:209; Kiple and Kiple 1977; Savitt 1978; Stampp 1972:282). Fogel and Engerman's (1974) cliometric approaches stressed the limited nature of the availability of supplemental, planter-supplied rations such as fresh meat, vegetables, and fruits, due mainly to seasonality, land-use premiums, and the challenges of storing fresh foods. Food preservation challenges dictated that most foodstuffs be treated with techniques such as salting, pickling, drying, brewing, and smoking, most of which result in considerable perishable nutrient loss (Gibbs et al. 1980:226).

Sutch (1976) attacked Fogel and Engerman's (1974) assessment of the core diet based on methodological grounds. He argues that their "residual" technique of estimating food intake; the view that the leftovers of production were used as slave rations, fails to consider the role of other food consumers and results in an overestimate of the variety and quantity of food available to slaves (1976:242). Regardless, the picture is a complex and variable one. Stampp (1972:288) notes that on smaller plantation holdings, the same cook prepared meals for both black and white families and in many instances, they probably shared tables.

Dietary Supplementation and Regional Variation

A broader picture of dietary traditions is emerging in light of new interpretation of the origins of African domesticates, technology transfer, and patterns of indigenous knowledge which suggests that slaves may not have been simply victims of their nutritional circumstances as they were once viewed (Carney 1998:526). Supported by an increasing body of archaeological data, the historical conception of dietary supplementation within slavery contexts is of considerable importance. Even within West Africa, dietary practices are far more diverse than they have been described within the European canon. Plant domestication and the consumption of a variety of meat and protein sources have deep traditions within West African diets (Hall 2007). Hall believes that slaves from yam and rice-based societies carried with them the knowledge and equipment, throughout the arduous and inhumane middle passage, necessary to survive despite abysmal conditions (2007:20-24).

Most contemporary scholars agree that the monotonous core diet typical of southern plantations was heavily supplemented by the efforts of enslaved African Americans and planters alike (Gibbs et al. 1980:209). Consideration of new evidence and regional and ecosystemic comparisons reveals a diverse and varied economy of dietary supplementation. Campbell refers to records from several Georgia plantations that demonstrate considerable efforts at diversification and self-sufficiency, which contrast with the deleterious southern tradition of mono-cropping (Campbell 1984:795). While this effort to grow fruits and vegetables in addition to profitable crops like cotton clearly represents a planter-sanctioned undertaking, it nonetheless embodies the recognition on the part of planter and slave of the importance of dietary variety for human health and needs. There is also historical evidence of regularly allotted time within the task systems and daily regimen of plantations in Georgia and South Carolina for slaves to hunt, fish, and trap (Gibbs et al. 1980:220). Hall suggests that this active supplementation may have been crucial in the south due to the notorious "proteinstinginess" of southern planters. Regional differences in meat provisions provided by planters become readily apparent in comparisons of historical records from the South Carolina lowcountry to those of the Chesapeake Bay area. Southern slaves had to be enterprising in hunting and fishing for wild species, and also probably cultivated a wide array of edible plant species (Hall 2007:28).

Savitt provides other interesting examples of planter-issued supplements including occasional fresh beef, which would have been very beneficial in consideration of the dearth of iron in the typical meat source, salt pork (Savitt 1978:93). Oddly, by modern standards, southerners did not hold beef in high regard. It may have been raised solely as a slave supplement in some plantation contexts (Savitt 1978:102). Molasses presents an interesting conundrum among plantation-issued fare. Savitt (1978) questioned whether the substance was provided purely as a sweetener or if planters actually understood its nutritional benefits. A daily serving provides 250 calories and one half of the adult male recommended daily allowance of iron (Savitt 1978:94). In light of more recent Caribbean research, Follett (2005) leaves no doubt that cane syrup and molasses were given to slaves in abundance on sugar plantations with the goal of improving physical performance and appearance of the enslaved (covering up underlying symptoms of malnutrition). Whether knowingly or unknowingly benefiting his slaves in Virginia, Thomas Jefferson himself recorded his regular seasonal substitution of fish for pork in his plantation records. This was likely due to efforts at economization, but, nonetheless, provided slaves with a far better protein source (Savitt 1978:95).

Documentary and archaeological evidence indicate that slaves regularly cultivated their own plots, on which they raised poultry and hogs and grew vegetables (Hall

2007:29; Savitt 1978:95). The reality, in many cases, may have been that slaves sold most of this produce for profit in saving for the purchase of their freedom as well as other material items, liquor and tobacco products (Savitt 1978:96). Savitt and others also refer to the historically high rate of thefts of goods such as meat and livestock by slaves on southern plantations as a form of supplementation, protest, and resistance. These goods were often concealed in clandestine root cellars (Crader 1990; Fountain 1995:74; Savitt 1978:98).

Archaeological and Zooarchaeological Contribution

Archaeological and zooarchaeological investigation of slave living spaces within plantation slavery contexts is widely acknowledged as having greatly informed the present understanding of the questions surrounding the ongoing quality of life and nutritional debates within slavery studies (Crader 1990; Fountain 1995; Gibbs et al.1980; Handler and Corruccini 1983; Orser 1998; Otto and Burns 1983). Otto and Burns (1983) were among the first to recognize the potential of historical archaeology to reveal information that is not obtainable from the historical and documentary record. Ambitious and thorough undertakings such as the archaeological analysis of slave cabins on the grounds of historic Monticello reveal a previously untold pattern of complexity and site function (Crader 1990).

Root cellar excavations at a known slave cabin revealed evidence of the concealment of probable stolen goods, use as a trash receptacle, and also as a storage area for cooked and uncooked surplus food items. The presence of faunal evidence of both low and high quality cuts of meat calls into question the notion of the typical poor quality of slave meat rations, but also may indicate reuse of plantation seconds or refuse. Crader concludes that the observed complexity in the patterning of depositional and taphonomic processes indicates variations in occupation, use of the cabin, and temporal changes in slave lifestyles.

Gibbs et al. (1980:179-181) present archaeological evidence of food processing and storage techniques such as utensils and pots as limiting or determining factors of aspects of slaves' dietary status. Utensils and handling techniques are related to nutrient loss due to problems associated with the storage of "one-dish stews" or "one-pot meals" meant to last for days. They also address questions surrounding the rate of consumption of allotments and resources through the analysis of evidence such as cribs, jars, and cellars (1980:224). These forms of storage probably permitted the average meal to be stored for about a week's time. The practices of drying, pickling, and smoking of meat and vegetables, of course, would have prolonged their shelf life considerably (1980:226). Rathbun and Scurry (1991) also examine food storage-related material and cultural health ramifications in a study of skeletal lead levels. They associate high skeletal lead levels and disparities between planter and slaves, to the degree of reliance upon food storage methods employing glazed pots. Further material evidence recovered within southern plantation excavations such as musket balls, fishing weights, and the remains of traps, inform the historical record of dietary supplementation with wild game resources (Gibbs et al. 1980:212-213).

Disease Environments and Regional Health

An exploration of the dietary and nutritional experiences of Africans and African Americans within plantation slavery is not complete without an examination of the linkages of these variables to the diseases of the era, especially those occasioned by the unique environmental conditions of the antebellum south and the Caribbean, and, importantly; those brought from Africa to the New World as a result of the slave trade. These disease environments, in their extreme, as represented by coastal Georgia and South Carolina, Louisiana, and much of the Caribbean, presented wet and warm climates which were not only well-suited for rice and sugar cultivation, but provided ideal conditions for the breeding of disease-carrying insects, as well as bacteria, fungi, and nematodes that acted as virulent disease vectors. Contamination of drinking water by human and animal feces, which were often used as fertilizer throughout the south, led to dysentery, cholera, and typhoid (Gibbs et al. 1980:190; Patterson 1989). Endemic and epidemic diseases of insect, parasitic, and other origin placed severe stress on southern populations, black and white, as evidenced by the period's remarkably high morbidity and mortality rates. Patterson (1989:165) describes the overall effects of the slave trade on New World populations in terms of loss of life both black and white in terms of a form of "biological revenge" from Africa.

The disease environment of the American South was distinct in that it carried a "heavy burden" of the infectious and non-infectious diseases common to the North and to Europe, in addition to the three "formidable diseases of African origin"- *P. falciparum* malaria, hookworm, and yellow fever (Patterson 1989:152). Perceived black resistance and immunity to many of these conditions in southern environs resulted in the medical perception of Africans as medically distinctive (Patterson 1989; Stampp 1972:309). Most of the fevers and afflictions associated with coastal and tropical environments were attributed to miasmas or poisonous swamp gases resulting from the decomposition of animal and vegetal matter (Stampp 1972:308). These pre-germ theory medical perspectives, coupled with the apparent distinctiveness of blacks, were the catalyst for myriad public health debates and calls for reform throughout the slavery era, especially intertwined with abolitionist arguments (Patterson 1989:162). The heroic forms of medical treatment characterized by the pre-1860 era, including purging, emetics, and bloodletting did little to mitigate the effects of widespread disease (Stampp 1972:308). South Carolina's rice economy is exemplary of the population health effects of fevers perceived as "miasmatic" in origin. Planters had great difficulty during much of the rice period maintaining slave numbers. They did well if they could avoid natural decrease. Stamp cites the impact of land clearing for rice agriculture on health. Historical evidence of frequent purchase and imports of slaves to this region indicates a lack of expectation of many planters that their populations would grow. Planter reluctance to purchase land in the worst areas is indicated by the low prices of tideland land on the Savannah River (Stampp 1972:297).

Patterson (1989:152) divides the American South into four epidemiological "subregions"; the Appalachian, Atlantic Coastal Plain, Gulf Coast, and Interior. Patterson argues that underdevelopment in the south coupled with warm climates and poverty created the kind of conditions characteristic of modern day developing countries. The major causes of death were infectious diseases and death rate was high, "appallingly so for infants and children" (1989:153). The same types of respiratory and gastrointestinal diseases coupled with helminthic infections, cancers, heart disease, which would have been common in the north, were also present in the south. The synergy of disease and malnutrition and their effects on the southern population, especially women and children, were profound. Vitamin deficiencies resulting in conditions like pellagra and rickets were common and compounded by the effects of malaria and hookworm in the south (1989:156-157).

The three diseases brought to the south by African slaves (*Plasmodium falciparum* malaria, yellow fever, and hookworm infection) were the greatest contributors to southern distinctiveness. *P. falciparum* is far deadlier in its effects than *P. vivax* and began to thrive immediately in the warm south, especially with the clearing of forests for agricultural land and damming of rivers and creeks undertaken in rice agriculture. *P. falciparum* came in the bodies of African slaves and found the native *Anopheles* mosquito as a highly effective transmitter of the disease. Patterson notes that blacks had an "almost absolute genetic immunity to *P. vivax"* due to sickle cell trait, and possibly one quarter were also immune to *P. falciparum,* offset by the cost of death of one quarter of their offspring carrying the homozygous condition. Malaria's impact on southern mortality and morbidity rates was great, but is primarily viewed as a secondary cause of death in that it greatly increased susceptibility to other diseases (Patterson 1989:160-161).

Yellow fever's impact on the health of the south is described by Patterson as "spectacular" in the sense that its epidemics created widespread public panic and significant loss of life. It arrived in port cities such as Charleston primarily through contact with Caribbean vessels. Blacks, again, possessed some degree of genetic resistance, and the greatest toll came among adult newcomers to the areas. Acquired immunity was afforded to survivors, especially in children (1989:162). Hookworm, as will be discussed in more detail in the section on parasitic disease, likewise had a devastating effect on southern populations. Patterson notes that an understanding of the regional health differences of the slavery era is growing but hindered by poor period diagnosis and statistics which exclude hookworm due to ignorance, underestimates of malaria's prevalence, and the lack of inclusion of yellow fever epidemics in non-census years (1989:163). The connection of the gulf and the coastal south to the West Indies is, likewise, important to understanding the southern disease environment. Louisiana's ports, particularly, were affected by Caribbean scourges such as leprosy, Dengue fever, and yellow fever (1989:164).

The Caribbean disease environment is equally as peculiar as that of the south, similarly having the afflictions common to the effects of a lowland swamp environment, crowding, poor sanitation, and frequent re-infections brought by newcomers and transients Records from Jamaica indicate that even adjusted creole slave populations succumbed to these health hazards (Craton 1991). Similarly, the same fevers and gastrointestinal afflictions that plagued the south- dysentery, measles, and yellow fever, are identified as primary hazards in Barbados, especially impacting the health of children and infants (Handler and Corruccini 1983). Underrepresentation of infant and child death statistics, however, is a big impediment to assessing Caribbean mortality and morbidity rates.

Based on Craton's (1991) comparative mortality figures, the lowland tropical environment of Jamaica presents crude death rates roughly double that of other plantation contexts. Craton and others describe health characteristics which are peculiar to sugar plantations (Craton 1991; Fogel 1989; Higman 1976). The records suggest frequent epidemics of measles, smallpox, and yellow fever. Dysentery in the plantation context can be linked to unhygienic latrines and crowding. Typhoid fever was borne by food and water. Louse, flea, and mite infestations led to typhus. Cholera, the evidence suggests, became more of a problem later, after the British Colonial period. Malaria was widespread in Jamaica, but the real killer may have been yellow fever. Yellow fever led to jaundice from liver infection and was endemic to the area but presented occasional epidemic phases (Craton 1991).

Nutritional Deficiency Diseases

Arguments surrounding the evidence for nutritional deficiency disorders and diseases among slave populations are polemical due to the complexities involved in their assessment. Genovese (1967), as previously mentioned, citing protein deficiency and generalized vitamin and mineral deficiencies, concluded rather uncritically that these factors led to a host of "ill-defined" disturbances among slaves including xeropthalmia (dry eye syndrome), beriberi (thiamine deficiency), pellagra, and scurvy. Gibbs et al. (1980:200) place equal emphasis on the effects of protein deficiency but elaborate by making ties between modern medical knowledge and historical descriptions of the symptoms of afflicted slaves. They and other researchers describe protein deficiency's role in decreasing inflammatory response and inhibiting immune function and somatic growth. Protein needs subsequently increase due to complicating factors such as appetite loss and water and mineral loss due to diarrhea (Gibbs et al. 1980:200; Steckel 1986a:441).

Vitamin and mineral deficiencies among enslaved African Americans present complex relationships and synergistic mechanisms of bodily deprivation. Lactose intolerance, extremely common among African-derived groups due to the lack of the genetic or physiological mechanism to digest milk is frequently examined within slave diet studies. It is cited as the primary agent underlying widespread calcium and niacin deficiency (Gibbs et al. 1980; Kiple and Kiple 1977). The "Vitamin D Hypothesis" presents a compounding factor to the problem of calcium deficiency among people of African descent. The association of dark skin pigmentation with reduced ability to produce vitamin D, especially in areas of reduced sunlight exposure compared to the ancestral home of West Africans, is proposed by researchers as a major inhibitor of the transport and absorption of calcium and magnesium. The consequences of these deficiencies are childhood rickets and osteomalacia in adults, as well as increased risk of types of cancer including colorectal cancer (Gibbs et al. 1980:198; Hall 2007:38).

Convincing evidence for childhood rickets is found among skeletal samples of enslaved children buried in New York's African Burial Ground (Goode-Null et al. 2004a), as well as evidence of milder, yet widespread, forms of deprivation and nutritional insult; the manifestations of iron deficiency anemia or porotic hyperostosis and cribra orbitalia (Goode-Null et al. 2004b; Rankin-Hill 1997:157; Rathbun 1987:246). Hypercementosis and linear enamel hypoplasia (developmental defects in dental enamel) are frequently cited as evidence of nutritional deprivation among enslaved skeletal samples (Handler and Corruccini 1983; Rankin-Hill 1997:156; Shuler 2005).

The incidence of specific deficiency conditions such as beriberi and pellagra, a deficiency of incompletely understood etiology commonly linked to overreliance on corn or maize-based diets and niacin deficiency, illustrate the challenges to the interpretation and diagnosis of nutritional diseases among slave populations of the eighteenth and nineteenth centuries. A detailed history combined with autopsy results obtained from the records of a New Orleans physician provide the most convincing evidence of a specific nutritional deficiency: beriberi, according to Savitt (1978:88). Gibbs et al. (1980:207) make connections between beriberi in the south and the possible African origins of geophagy, the habitual consumption of dirt or soil, which may have an adaptive function in mineral absorption or supplementation. They caution that the lack of specific, documented clinical signs and the compounding factors of illness, probably attributable to the ingestion of pathogens from the soil as a result of geophagy, serve to obscure and inhibit diagnosis.

Pellagra was initially considered to be conspicuously absent from the historical accounts of slave disease, or largely unknown among southern physicians (Etheridge 1988:100). Kiple and Kiple (1977) contend that the condition must have existed as a result of the cornmeal core of slave diets but probably went unrecognized due to the lack of period medical knowledge and the confusion of many of its symptoms with those of other diseases. Its hypothesized endemic nature in the regions of the south with the poorest dietary supplementation may have served to disguise it, allowing its symptoms to account for a host of the so-called “Negro Diseases”.

The diagnostic impediments to the analysis of the specific nutritional deficiencies of slaves lie primarily in the fact that the interaction of diet and diseases of all types obscures and confounds the contributions of individual conditions (Gibbs et al. 1980:205; Steckel 2000:257). Further analytical problems stem from the fact that nutrient deficiencies do not immediately lead to disease or clinical symptoms. There is an inherent lag time due to the body's ability to store reserves of minerals such as calcium (Savitt 1978:89). The nonspecific nature of the symptoms and lesions of many nutritional disorders further inhibits the ability of the examiner to assess them (Gibbs et al. 1980:205; Kiple and King 1981; Savitt 1978:86-87).

Parasitic Diseases

Considerable research within slave dietary studies is devoted to the role of parasitic infection and its ties to nutritional adequacy among slaves and southerners in general (Coelho and McGuire 2000; Gibbs et al. 1980:203-204; Marcus 1988). Coelho and McGuire (2000) decry the failure of researchers to recognize the contribution of parasitism to growth disruption and nutritional inadequacy among southerners. In the most vocal of these studies, Coelho and McGuire (2000) strongly contend that anthropometric and cliometric approaches have uncritically assumed the validity of adult height as well as height by age cohort as indicators of nutritional adequacy. Their criticism proposes that prior research has omitted the central role of parasitic diseases among slave groups in affecting growth rates and determining average stature. They build upon their earlier work citing the childcare centers on southern plantations known as "crèches" as major incubators for parasitism. The majority of slave children in these contexts developed hookworm infections, resulting in stunting of growth.

Their argument is that the catch-up growth phenomenon noted by Steckel (1986c) and Fogel (1989) among others is the result of liberation from these oppressive situations as they entered the labor force, resulting in a unique pattern of growth. Steckel (2000) disagrees, contending that the role of parasitic disease was far less important in determining growth rates and final height and that the synergy of diet and disease creates a confounding and complex picture of slave growth and nutritional status. The phenomenon of postadolescent catch-up growth facilitated by improvements in adult diets over those provided by planters for children, he proposes, led to well-developed adults, and further masked the problem of childhood nutritional deficiency (2000:257).

Marcus' (1988) focus on the endemic nature of hookworm in the rural south hints at larger phenotypic and physiological ramifications which, he proposes, led to the "distinctiveness" of southern identity and forms of inequality and prejudice. The problem largely stemmed from the widespread use of feces as fertilizer, poor hygiene around living quarters, and the infrequent wearing of shoes (Marcus 1988:92). A period account describes South Carolina slave children as "ragged, dirty, shoeless urchins" (Stampp 1972). Hookworm disease or ankylostomiasis causes blood loss which depletes iron and protein stores, interfering with B12, A, and C vitamin utilization (Gibbs et al. 1980:204). Bacillary and amoebic dysentery also presented great hardships for the enslaved due to close and unhygienic living areas. These were major causes of infant mortality among plantation populations.

Other parasites such as threadworm, fish, beef, and pork tapeworm, and roundworm, were widespread and caused problems stemming from vitamin and mineral loss, decreased protein absorption, and the destruction of beneficial intestinal flora (Gibbs et al. 1980:203).

Following Steckel's and Coelho and McGuire's arguments further, the authors make additional important considerations. Steckel (2000) responds to Coelho and

McGuire's (2000) argument regarding the importance of disease (e.g. hookworm infection leading to stunting and malaria resulting in low birth weights) in explaining the small size of slave children and their subsequent phenomenon of catch-up growth. Steckel argues that improved net nutrition is the real motivator the growth pattern, while acknowledging that the synergy of diet and disease is very hard to "disentangle". Coelho and McGuire rely too much on a "crowding" hypothesis in Steckel's view. The nursery or "crèche" described by Coelho and McGuire should not be conceived of as a static, bounded space. The context of childcare and proximity to other children was constantly changing in consideration of period accounts. Also, slave children were clearly not the only slaves who went without shoes as clearly indicated in planter accounts and slave complaints about footwear. Steckel uses evidence and tabulations of seasonality of death to question the role of malaria in pregnancy outcomes- showing varied outcomes and fluctuations that do not necessarily align with malarial seasons. Steckel argues that diet has a very large role in the outcomes of many of diseases, including malaria and hookworm. They should not be viewed as so important of an effect on slave populations in terms of health and productivity level arguments.

The role of parasitism is almost identical in the Caribbean. Craton describes the great effect of regular "fluxes" on population mortality in Jamaica. These include bacillary and amoebic dysentery. Parasitic worms of many types were problematic for the area, but hookworm probably took the greatest toll. Ankylostomiasis led to symptoms including "flux", dropsy- fluid retention, convulsions, and geophagy. Many of these conditions led to stunting of growth, delayed onset of puberty, chronic anemia, and general dullness and apathy- what was regarded as the African phenotype or condition by planters of the period (Craton 1991).

Health of Women and Children During Slavery

Infant and Child Mortality

The health and wellbeing of enslaved women and children is of great concern and relevance to examinations of the economics and demographics of slavery. Within cliometric studies, researchers argue, the biases created by reliance on large plantation records were further confounded by the almost exclusive reliance upon adult (largely male) anthropometric data. Children (as well as pregnant and nursing females) are perhaps a better analytical lens for the assessment of malnutrition due to their greater sensitivity to insult (Coelho and McGuire 2000; Gibbs et al. 1980:229; Steckel 1986:429; Steckel 2000:257). It is generally accepted that slave children experienced extremely poor health as indicated by height data (they fall in the 1st percentile of modern NCHS statistics), mortality rates that are roughly double that of free populations, and the fact that less than 50% of live births to enslaved women survived until age 5 (Rathbun and Steckel 2002; Steckel 1986). Researchers note shockingly high infant mortality rates, especially in rice producing areas (Covey and Eisnach 2009; Dusinberre 2000; Fogel 1989).

Based on skeletal evidence and stature, Rathbun and Steckel (2002) observe that South Carolina slaves stand out as among the most heavily stressed of all populations during childhood. Skeletal indicators such as linear enamel hypoplasia (LEH) defects back up the archival records of compromised stature and growth disruption. Coastal South Carolina slaves from rice-producing areas are among the smallest children ever measured (Rathbun and Steckel 2002; Steckel 1986b;). Similarly, inland agricultural contexts of slavery reveal widespread evidence of child mortality and stress (Hodge 2009), as do late pre-emancipation slave children from Northern North American contexts (Brasor and Nystrom 2010) and West Indian sugar plantation slaves (Handler and Corruccini 1983; Shuler 2005). Recent bioarchaeological research lends considerable support to the view of harsh and inhumane conditions of slavery counter to apologist arguments about the benign nature of the system which has persisted in the form of views of slaves as prized and well provided-for forms of investment (Hodge 2009).

It is important to be aware of the many obstacles and impediments to assessing child mortality and reproductive health in the pre-industrial era and earlier. Records are incomplete and assessments of fertility and mortality often underestimated (Craton 1991; Higman 1991). Importantly, the failure to recognize these biases on the part of Fogel and Engerman (1974), is one of the points that led to a view of slavery as being more benign or on-par with the conditions of free laborers of the era (Sutch 1976). Referring to nineteenth century records from Massachusetts, Swedlund (1990) hints at the forms of political and social bias inherent to vital statistics of the day. Most period assessments of the extremely high infant mortality rates tended to conflate categories of race and ethnicity among others with risk for infant mortality leading to a naturalization of racial traits as risk factors and reasons for inherent deficiencies in health and biological inferiority. Stampp (1972:319) echoes this sentiment for the south, noting death rate discrepancies in Charleston, SC, but views the 1850 child death rates indicating that infant mortality for blacks was nearly double that for whites as doubtlessly significant. Records from British Colonial Jamaica, Craton (1991) notes, are plagued by incomplete recording and poor diagnosis, and the data span periods of temporal and demographic change including transitions from African slaves to “acclimatized” creole slaves. As in this context, it is often unknown to what degree infant deaths are underrepresented.

Women’s Health, Reproduction, and Labor

Investigation of the effects of slaveryon women and their reproductive lives is crucial to understanding the demographic performance of differing economies of slavery. Archival, skeletal, and oral tradition evidence all convey a view of great hardships placed upon women during slavery (Bush 1990; Dusinberre 2000; Fogel 1989; Hodge 2009; Morrissey 1991; Steckel 1986a; Sutch 1976). Dusinberre’s work is exemplary of the harshest views of the reality that enslaved women faced. He describes in vivid detail planter accounts and slave narratives of the reproductive complaints of enslaved women, including “fallen wombs”, frequent bleeding problems, aborted pregnancies, and stillbirths on South Carolina rice plantations. These conditions were frequently the result of lack of available hygiene, excessive labor, and corporal punishment. Dusinberre’s conclusion for large scale plantation enterprises like rice is that the care and nutrition of the adult labor force far outweighed the concern for care and feeding of infants and children, resulting in planter notions of an acceptable loss threshold for infant and child mortality. Along these lines, Covey and Eisnach (2009:96-99) argue, children may have suffered disproportionately due to differences in the apportionment of food based on age and participation in the work force. In many contexts it was not seen as important to keep those too young to work well-fed.

Planters' economic considerations during the sale and purchase of slaves often resulted in mother and child separations, exemplifying the view of the low value of children in certain contexts and heightened demand for slaves of immediate laboring age (Gutman and Sutch 1976). In many ways, children were viewed as an encumbrance. Steckel (1986b) examined plantation birth and death records for children by season and among different plantation crop staples. Fundamental to his arguments here are the ideas that overwork during pregnancy due to high value of women's labor, resting in part upon planter ignorance regarding childcare practices, as well as nutritional deficiency (maternal and for children) contributed greatly to the excess mortality of slave infants and children. Fogel's (1989) work portrays a mixed view of women's labor during pregnancy with some sources that indicate that slave women toiled late into pregnancy, while others indicate that pregnant women were removed from gangs to perform light duty tasks such as sewing. Fetal loss, Fogel agrees, was most often caused by malnutrition and the effects of labor on women. Stampp (1972:313) refers to the treatment of pregnant and nursing women in notable plantation hospitals in South Carolina and Georgia with a standard post-partum "lying-in" period for nursing mothers of four weeks prior to return to work. Fogel (1989) opines that, by and large, masters were not guilty of working field hands to death, but they were guilty of working pregnant women to an extent that was deleterious for the condition of the fetus and newborn child. Dusinberre concurs, painting a vivid picture of the overwork of pregnant women and its catastrophic effects for fetal loss and infant mortality on certain South Carolina rice plantations, as well as the impact on childhood health for those who survived (Dusinberre 2000:235-247).

As do Fogel and Engerman (1974), Steckel (1986b) interprets the historical evidence to suggest that labor demands were greater on larger plantations. Depending on context, older women and young girls were often relegated to childcare duties, serving to attenuate breastfeeding as older women returned to labor. The supplemental pap or gruel diet of infants was notoriously protein-deficient and often served in an unhygienic manner, promoting bacterial infection such as salmonella, shigella, and *E. coli*, especially in warmer regions and seasons. Neonatal tetanus also made large contributions to infant mortality rates and frequently resulted from improper dressing of umbilical cords (Stampp 1972).

An interesting question raised by Steckel (1986b) is the role of attenuated breastfeeding in fertility rates. This holds great relevance in comparative studies of industries like rice and cotton compared to sugar producing regions. More constant, year round labor regimes (rice and cotton) would have demanded shorter breastfeeding, thus probably leading to higher fertility rates than those of regimes like sugar with arduous, male-dominated labor and characteristic "laying by" periods. Seasonality of labor is also important as a consideration in light of the aforementioned phenomena. Rice stands out in Steckel's interpretation as a very high mortality crop, on the other hand, due to its year-round labor demands on women. He also cites the comparatively low (in relation to period whites) age at birth of slave mothers (around 20 years compared to 22 or so in the white population) was a further contributory cause to infant mortality.

According to Steckel and others, slave mothers lost 54% of pregnancies due to fetal loss, infant and early child mortality. He confronts issues of greater access to medical resources on larger plantations as a double-edged sword- most medical practices in nineteenth century and earlier were as likely to cause death as to provide effective treatment. The availability of childcare also varied with plantation size.

Fogel and Engerman (1974) and Sutch (1976) were among the first to examine the role of SIDS in infant deaths on plantation. Planter perceptions during slavery were that crib deaths were the result of intentional suffocation of infants by their mothers as a means of resistance to the system among other theories. Fogel and Engerman implied that differences in crib death rates between free and enslaved populations could probably be accounted for by the then newly recognized SIDS, demonstrating modern data showing current data revealing black and white population differences. Sutch (1976:292) countered their argument on methodological grounds and accused them of a biodeterministic slant to their assessment of racial differences in SIDS frequency. Sutch's view is more satisfying and hinges on the idea that SIDS and other child death factors should provide the view of extreme poverty, low birth weights, and poor postnatal care that Fogel and Engerman failed to demonstrate.

Follett (2005) takes a novel approach, combining plantation historical sources such as birth records with theory from reproductive physiology to examine seasonality of birth among Louisiana sugar plantation slaves. The pattern is unusual in Louisiana when compared to other southern plantation systems, such as South Carollina rice, due to the fact that peak conception occurs within the peak of the harvest. South Carolina conception based on recorded births, spikes in the "laying by" times in the winter months.

Louisiana, like West Indian sugar was an extremely harsh labor regime in which slave populations failed to achieve replacement rates. Factors are the severity of sugar harvesting, requiring very long hours in the field, shortage of women, high infant mortality, inadequate nutrition- particularly protein deficiencies. Follett also refers to female slave agency in resisting the “natalist” policies of slave holders by avoidance, contraception, and means of abortion.

Follett argues that the reason for the unexpected conception peak, contradicting both rice and West Indian sugar patterns, is due to seasonal and climatic variation coupled with the planter-provided ration of cane syrup or molasses which was fed in apparent great quantities to slaves during their labor rotation. It is the equivalent of a highly concentrated energy drink or Gatorade-like concoction in terms of sugar and calorie content. The practice provided short term high energy and the appearance of health and ability to work hard during the harvest and processing regime. Correspondingly, caloric adequacy and extra energy may have prompted increased conception and sexual activity than would be expected given the arduous nature of the work. Nevertheless, when molasses or cane syrup became unavailable, things returned to a very inadequate diet, ill health, haggard appearance, and poor reproductive rates, augmented by a sever disease environment of malaria, yellow fever, and typhoid among other risks. This artificial energy source aided the function of the sugar machine but was a component of the much feared and ruthless sugar economy.

Child Growth, Nutrition, and Infectious Disease

The children of slavery suffered due to a plethora of health and nutritional concerns, some previously mentioned and some to be addressed. They were very clearly disadvantaged from conception. Again, as in all historical assessments of slavery, there is a picture of great variability by time period and economy in the conditions of the treatment of slave children. Skeletal and documentary evidence suggest great health impacts on children for Barbados, brought on by dysentery, measles, and yellow fever (Handler and Corruccini 1983). Among the wealthiest of the rice plantations in South Carolina, there were noted planter attempts to alleviate the suffering of children through hygiene and other considerations. Stampp (1972:314) describes a high ground retreat for slave children on a rice plantation for summer months, indicating a clear recognition of the need to maintain the health of children.

Skeletal assessment of childhood stress is ubiquitous (Goode-Null et al. 2004; Handler and Corruccini 1983; Hodge 2010; Rathbun and Steckel 2002). Handler and Corruccini (1983) found linear enamel hypoplasia (LEH) and other tooth enamel defects in 98% of dentitions among Barbadian skeletal remains. The authors suggest primarily that nutritional inadequacy is responsible for these growth disruptions along with notable health problems of the period including dysentery, measles and yellow fever. Single, severe banded LEH defects support their nutritional argument as possible evidence of stress during post weaning time, probably manifesting itself in kwashiorkor or marasmus among other forms of protein-calorie malnutrition. Weaning is known to have occurred quite late among these groups, especially in the earlier periods. Into the nineteenth century, weaning age was probably still 18 to 24 months, longer than that of European populations, and stemming from African cultural practices.

Steckel (1986b) says the evidence suggests that infant and child mortality was extremely high across the board in New World slavery. Steckel's arguments rest on a number of medical and nutritional studies indicating that late fetal deprivation contributes to stillbirths, and later SIDS in the post-neonatal period; and low birth weight infants are more susceptible to nutritional and disease insults. Especially for nineteenth century North America, infant mortality and stillbirth rates were high due to maternal infections including rubella, hepatitis, cytomegalovirus, and toxoplasmosis. Damage to the fetus in utero led to the sequelae of later illness and growth retardation. Maternal malnutrition and anemia further exacerbate these problems. Child participation in the work force (especially during later industrial periods) also greatly increased disease exposure rates (Costa and Steckel 1997).

In conclusion, this review has provided context for the consideration of historical variables which affected health and lifestyle in the two regions under study. These factors will be considered within the biocultural framework of the comparative studies which follow. Chapter 4 provides a thorough review of approaches used by biological anthropologists for the sorting and analysis of commingled skeletal remains which will inform the approach that I develop in this study.

CHAPTER 4

APPROACHES TO COMMINGLING OF SKELETAL REMAINS

Commingling of human skeletal remains creates serious logistical and analytical challenges for biological anthropologists within forensic and medicolegal contexts. Similar problems apply to bioarchaeological and paleoanthropological studies. Determination of the biological profile for individual identification, reconstruction of past health and lifestyle, and paleodemographic studies all require skeletons to be as complete as possible (SWGANTH 2011; Vickers et al. 2014). The unfortunate tendency in skeletal analyses, depending on the scale of commingling, has often been to stop short, giving up on the potential for meaningful osteological data collection, demographic and paleopathological assessment, and comparative analyses due to lack of reliable methodology. Many skeletal series "languish" unstudied as a result (Baustian et al. 2014). Prior to this study, this applied to the commingled portion of Newton Plantation's skeletal remains, primarily due to lack of laboratory resources and space (Shuler, personal communication, 2012). Recent studies have shown promise in using elemental measures and portable X-ray Fluorescence (pXRF) analysis for the purpose of distinguishing individuals in commingled scenarios (Castro et al. 2010; Gonzales Rodriguez and Fowler 2013; Perrone et al. 2014). The methods remain in the validation phase, but preliminary successes suggest that pXRF may work best for archaeological contexts, when used in combination with other methods.

This study is among the first to attempt to develop a multi-method sorting procedure utilizing pXRF to sort an archaeological sample of skeletons into individuals in order to provide a basis for bioarchaeological comparison to another sample. It is hoped that the results may serve as a model for future such attempts involving extant or newly recovered commingled skeletal samples.

This chapter will present and describe the sample of skeletal remains from Hagley Plantation and evaluate the context of their disturbance and recovery. It then provides a comprehensive review of the scientific approaches to sorting commingling scenarios employed by biological anthropologists, with the goal of identifying the complementary nature of many of the approaches. These methods, when used in combination, may lead to higher confidence reassociations depending on scale, preservation, taphonomy, and demographic makeup of the assemblage. This section sets the framework for the methods applied to the sorting of the Hagley Plantation remains presented in Chapter 4, the results of which determine the nature of the type of biomechanical comparative inferences that can be made within this study.

The literature review in this chapter will permit the development of an approach tailored to the Hagley Plantation sample by consideration of archaeological context, completeness, and taphonomy. A key point made by many of the authors of the studies reviewed in this chapter is that there is no "right" way to analyze commingled assemblages (Osterholtz et al. 2014). It is widely agreed that the methods used to resolve commingling are best used systematically and in combination with one another depending on the circumstances (Snow 1948; Kerley 1972; Rosing and Pischtschan 1995; Ubelaker 2002; L'Abbe 2005; Adams and Byrd 2006; SWGANTH 2011; Chew 2014).

Archaeological Context of Hagley Plantation (38GE81)

Hagley Plantation was situated on the Waccamaw Neck, a narrow peninsula in coastal South Carolina between the Waccamaw River and the Atlantic Ocean, amid a row of adjoining large rice plantations. No standing architecture of Hagley Plantation remains, however archaeological evidence, ethnohistoric accounts (Devereux 1973), period art (Weston 1864) and local folklore provide intriguing imagery of the plantation's landscape and architecture. The area is now an upscale subdivision, Hagley Estates, and is bounded by Hagley Drive and the Waccamaw River (Figure 4.1). Remnant rice fields are evident from aerial and satellite view across the river from Hagley's plantation landscape (Figure 4.2).

Archaeological site 38GE81, Hagley Landing, was surveyed by archaeologist G. Ishmael Williams and others in 1976, 1977, and 1979 during the cultural resource survey of the area by Soil Systems, Inc. for the Atlantic Intercostal Waterway. It is described as located on a "Sangamon period bluff on the Waccamaw River" and containing a "wide temporal range of archaeological material including Middle Archaic, Woodland, Mississippian, and historic artifacts" (Williams 1980:126). The 1980 initial report of survey and recommendations describes the slave cemetery at 38GE81 as "recently bulldozed by an unknown party". Williams indicated that "the slave cemetery and associated historic features" were "completely impacted by clearing and construction activity and have no further research value" (Williams 1980:112). The "38GE81 Resurvey" notes the cemetery was located "122 meters (400 feet) southeast of Hagley Landing" and had been "recently bulldozed to make room for a new house" (Williams 1979:1). Williams'site survey record provides an estimate that the cemetery was located

“5 to 10 meters from the (Waccamaw) river” and located on the USGS Waverly Mills quadrant at UTM E 668970, N3700860 (Williams 1979)(Figure 4.3). Williams (1980:113) reported that “brick fragments and a few pieces of plain whiteware and bottle glass were also noted in the vicinity of the cemetery but were not collected. The slave cemetery and associated historic features have been surficially impacted by clearing and construction activity.” The change in wording from “completely” to “surficially” impacted is interesting and implies knowledge that the graves remained following the clearing and construction process. In conclusion, 38GE81 was recommended for “follow-up intensive survey and/or testing” based on good potential for intact cultural resources (Williams 1980:157).

The skeletal remains from Hagley Plantation were disturbed during residential construction work on July 26, 2006 at a new lot on Old Waccamaw Drive, Pawleys Island, SC (Figure 4.4). The remains were unearthed en masse by construction workers and are, as a result, commingled. They were then collected by Georgetown County Coroner’s Office personnel and transported to the coroner’s office. I was contacted by Georgetown County Coroner, Kenneth Johnson, who requested assistance with skeletal analysis of the remains. At that time, he stated that they were believed to represent individuals buried in a cemetery associated with St. Mary’s Chapel. Dr. Laura Cahue and I examined the remains on March 28, 2007 at the Georgetown County Coroner’s Office. We then packaged the remains in separate cardboard containers to prevent damage and transported them to the Biological Anthropology Laboratory at the University of South Carolina, Department of Anthropology.

The Coroner's investigation revealed that prior to the construction of a subdivision in the area of Old Waccamaw Dr. and surrounding Hagley Estates, a local funeral home was hired under contract prior to sale of the property in 1978 to remove and relocate the burials to another location (Johnson 2008, personal communication). The Georgetown County Coroner's Office has no record of the planned location of reinterment, or even whether they were actually exhumed. The funeral home is now defunct and the funeral director is deceased. Coroner Johnson and State Archaeologist Jonathan Leader expressed similar opinions regarding the likelihood of fraud on the part of the hired funeral director or possible partial disinterment with disposal of the remains in an illegal manner (Johnson 2008, personal communication; Leader 2008, personal communication).

Based on their location of recovery, the skeletal remains are believed to be associated with St. Mary's Chapel, a chapel built for enslaved African Americans and attached to Hagley Plantation, Pawleys Island, SC. Hagley was one of four plantations belonging to Plowden C. J. Weston. The chapel was built by Mr. Weston under the rectory of the Reverend Alexander Glennie of All Saints' Parish (Neuffer 1968). St. Mary's was one of thirteen chapels constructed for slaves under Reverend Glennie's rectory (State Historic Preservation Office 2007). Neuffer's (1968:53) volume of place names provides the following description of St. Mary's Chapel:

> Built primarily for the use of the Negro slaves, some of these chapels were of unusually pleasing design and furnishings. Perhaps the most notable of these was St. Mary's Chapel built by Mr. Plowden Weston at Hagley Plantation. The ceiling and pews were of cypress, with stained glass windows and Gothic arches adding to the dignity of this Chapel high above the Waccamaw River. […] St. Mary's Chapel fell into disuse in the early years of this century, and before it

> accidentally burned in July, 1931, Bishop Albert S. Thomas writes that its furnishings had been given to neighboring churches: to Prince George, the stained glass, clock and bell, and gold cup with cover, and paten; to Grace, Camden, an English granite font in which all the Hagley slaves had been baptised; to Prince Frederick's, carved oak choir stalls; to St. James', James Island, Bible, Prayer Book, Altar Book, oak book rest.

It is unknown at present whether any of the chapel structure or foundation remains evident at the site. Similarly, the original dimensions of the cemetery and fate of the aforementioned tombstones remain unknown.

Joyner (1984:20-21) refers to the construction of a "model" plantation chapel (presumably St. Mary's) in the following excerpt:

> For most of 1859 he [a slave named Renty Tucker] had been deeply involved in planning and constructing a model of a plantation chapel for the Slaves. Weston had secured permission from the vestry at All Saints Church Waccamaw for the erection of such a chapel and had ordered stained glass windows and a chiming clock for the tower from England. The chapel was constructed in the shape of a cross, with a high, deep chancel with a roof beam, three tall lancet windows, and high, deep transepts. The chapel's Gothic architecture, tall steeple, and clock impressed visitors.

As indicated by Joyner's research, the chapel dates to 1859. It is possible, however, that the cemetery predates the chapel building and that the area was probably in use as a burial ground for years prior to its construction. The present day landscape of Hagley Estates Subdivision and Old Waccamaw Dr. in particular contains many old growth trees and probably represents topography similar to that of antebellum Hagley Plantation.

Inventory and Analysis

A detailed inventory of the Hagley Plantation remains was undertaken by Stevens (2008) according to standard protocols (Buikstra and Ubelaker 1994). Each skeletal element was given an accession number and labeled in an inconspicuous location using permanent ink, and entered into a catalog Microsoft Excel file. Osteometric data were also recorded for the entire sample. The inventory of 38GE81 included several nonhuman bones and bone fragments as well as a small number of unidentifiable iron artifacts. No identifiable coffin hardware or wood fragments were recovered with the remains. Many of the bones (especially crania) display green discoloration consistent with staining probably due to the presence of coffin hardware, copper shroud pins, clothing fasteners or other burial goods. Assessment of the biological profile for the sample based on the commingled remains was initially conducted by Stevens (2008) and used in the comparative presentation by Shuler and Stevens (2009). Age and sex estimates were retabulated for the purposes of this study, following the commingling approach.

Review of Approaches to Commingling

The following section provides an extensive review of the literature pertaining to the development and implementation of approaches to sorting commingled human remains for reassociation into individuals. The approach of the current study will draw from the method and theory reviewed here in order to develop a protocol for addressing commingling among the Hagley Plantation skeletal remains.

Charles Snow's (1948) publication of the sorting procedures employed in the nascent U.S. Army Central Identification Laboratory (now CILHI) provided the model upon which most of the accepted anthropological techniques for sorting commingled remains are based (Byrd and Adams 2003; Byrd 2008; Damannn and Edson 2008). His protocol was based on reconstruction of fragmentary remains followed by morphological, metric, developmental, pathological, and articulation-based pairing, sorting, and exclusion processes. The model stressed careful documentation, photography, and elimination of all possible associations prior to considering positive identifications. Admittedly, he wrote that the process worked best when all remains were recovered, a rare scenario. McKern (1958) proposed one of the first "hi-tech" means of sorting commingled remains by subjecting a mixed skeletal assemblage to short-wave ultraviolet light revealing differing inter-skeleton patterns of fluorescence, presumably reflecting differing taphonomic experiences of the skeleton. The method was limited for real-world applications, however, as the tested remains contained specimens that had undergone very different postmortem experiences (i.e. prepared museum specimens versus archaeological bones), and would likely have little utility for remains from single events or mass burials.

One of the earliest statistical approaches to commingling was a small-scale application for forensic contexts involving skeletal remains of similar size and age where commingling is suspected, proposed by Snow and Folk (1970). It was based on total bone counts and likelihood of commingling in cases where the number of represented elements totals less than one complete individual. It tests the likelihood that the assemblage may represent one individual or a pair of individuals, based on number of recovered elements. See Ubelaker (2002; 2008) for exhaustive summaries of twentieth century commingling approaches.

Determination of MNI and Population Estimators

The determination of the minimum number of individuals (MNI) present is the first step for most analyses of assemblage of commingled skeletal remains. Simple MNI as well as a host of population estimators are derived from population biology and zooarchaeology methods used to estimate the size of living animal populations and assemblages of faunal remains. Goals within these fields are typically to either quantify a faunal assemblage in order to reconstruct past human activity and diet (zooarchaeology) or to estimate the number of animals that make or made up a living community (zooarchaeology and population biology) (Adams and Konigsberg 2008). MNI is the most basic estimator and most often employed due to its sheer simplicity, representing a count of the most-repeated skeletal element within a sample, thus providing a minimum estimate for the number of individuals that contributed to the sample or how many individuals are represented by the recovered assemblage.

MNI is widely criticized as a poor estimator of original population size due to numerous sources of bias inherent in the statistic (Chase and Hagaman 1987; Adams and Konigsberg 2008; Nikita and Lahr 2011; Kendell and Willey 2014). Many of the variables which affect MNI are features of taphonomy, defined by Lyman (1994) as the "science of the laws of embedding or burial". MNI cannot account for taphonomic variables such as the probability that a carcass or skeleton or portion of one was deposited at the site location versus elsewhere, the probability that individual elements have been moved from the scene by animal, natural, or human action, or the probability that individual elements will be recovered due to preservation or taphonomic factors (Chase and Hagaman 1987). The number of unknowns involved has made many anthropologists “content not to estimate numbers beyond the minimum indicated” (Ubelaker 2002). Adams and Konigsberg (2008) demonstrate statistically that MNI will only provide a true estimate of the number of individuals who contributed to a sample when all of the given elements used to determine the count are recovered. Otherwise, even in cases where nearly every bone is recovered, MNI provides an underestimate. Commingled skeletal assemblages are typically incomplete in both archaeological and forensic scenarios (Chase and Hagaman 1987; Nikita and Lahr 2011).

The taphonomic processes that affect the recovery and interpretation of archaeological human skeletal remains and zooarchaeological remains within subsistence studies are often identical, however goals between the disciplines are obviously different, with bioarchaeological studies being an assessment of the total number of dead and the construction of a paleodemographic profile (Adams and Konigsberg 2008). Lyman (1987) provides a detailed summary of the development of taphonomic theory from a zooarchaeological perspective with focus on the analytical challenges created by taphonomic processes. He defines taphonomic process categories in developing a model for linking them to taphonomic effects- namely disarticulation, dispersal, fossilization, and mechanical alteration. Taphonomic theory has progressed significantly in recent decades, achieving a melding of forensic and bioarchaeological viewpoints (Lyman 2006; Haglund and Sorg 2002; Saul and Saul 2002). Interdisciplinary studies have brought a standardization of method and a better understanding of the role of natural and human imposed factors in determining the nature of skeletal assemblages (Ubelaker 2002).

Taphonomic factors that have been extensively researched include chemical breakdown of bone, the effect of burning and cremation, transport of bones from the site, the effects of water environments, recovery biases, excavation damage, disarticulation due to animal or natural processes, intentional and cultural modification processes, mechanical alteration, fragmentation, weathering, and soil acidity effects, and variation in the survivability of individual skeletal elements (Lyman 1987; Haglund and Sorg 2002; Adams and Konigsberg 2008). Case studies exemplify the difficulty that taphonomic factors can create for the reassociation of individuals in fragmentary remains cases of small and large scale disasters (Adams and Byrd 2006; Mundorff 2008) and also in forensic cases involving secondary deposition or intentional disturbance by human action (L'Abbe 2005; Garrido-Varas and Intriago-Leiva 2012).

As previously mentioned, the overlap in method and theory resulting from similar analytical needs and similar challenges (i.e. taphonomic variables) within these disciplines has created the need to employ statistics that can circumvent frequently encountered sources of bias affecting the estimation of population size from skeletal assemblages. Zooarchaeologists and biological anthropologists have borrowed techniques for population estimation often referred to as "probable numbers statistics" from population biology fields in the effort to develop more realistic assessments of skeletal populations (Chase and Hagamn 1987; Winder 1992; Adams 1996; Adams and Konigsberg 2004).

The Lincoln Index (LI), is one of the most widely used biology-derived population number statistics within zooarchaeology and bioarchaeology. LI is a "maximum likelihood estimator" for wildlife populations that has been modified to convey population numbers from faunal or skeletal assemblages (Winder 1992). LI is adapted from animal capture/recapture studies of wildlife and applied to skeletal remains based on pair matchings. Bones from the left side are considered analogous to the first stage of random capture of individuals and bones from the right, to the second stage. The number of elements that can be matched from both sides within a recovered assemblage is analogous to the recapture of initially tagged animals. The bioarchaeological derivation of the LI is a statistic which considers numbers of right (R) and left (L) bones, and matched pairs (P) in order to derive an initial population number (n). An estimate of the original death assemblage is LI= LR/P (Adams 1996; Adams and Konigsberg 2004; Adams and Konigsberg 2008). Put differently, the MLNI estimate rests on the fact that the probability of obtaining P pairs from R right and L left elements from N initial individuals is predictable (Nikita and Lahr 2011).

MNI remains popular because it is very easy to apply, but, again, it only provides a minimum estimate of the number of individuals represented by a recovered assemblage. The LI and a modification of LI, termed “Most Likely Number of Individuals” (MLNI) are less subject to bias and more effectively estimate the original number of individuals represented by a bone assemblage (Adams and Konigsberg 2004). These formulae are advantageous because they allow for accurate estimates of the original population from assemblages where taphonomic data loss has occurred. With consideration of bone preservation, degree of fragmentation, and the scale of commingling, LI and MLNI are less misleading than MNI and provide a more accurate estimate of original population size for paleodemographic and forensic purposes (Adams and Konigsberg 2004). MLNI is a simple modification of the formula for LI and is designed to overcome sample biases. It is calculated as MLNI= (L+1)(R+1)/(P+1)-1. The resulting (n) value is derived as a truncated integer value (rounded down). Adams and Konigsberg (2004) developed a

Microsoft Excel MLNI calculator in spreadsheet form and discuss the calculation of confidence intervals for MLNI estimations.

Adams and Konigsberg (2008) more recently evaluated the behavior of MNI and MLNI as population estimators in consideration of population size and recovery rate, finding that when accurate pair matching is possible, MLNI provides much better results than MNI. The caveat inherent to the use of LI or MLNI lies in the potential for misidentification of pairs. In fragmentary contexts, pair matching may not be feasible and these estimators should not be used. Accurate pair matching is critical with these techniques due to their multiplicative nature. Theory and practice determine which paired skeletal element should be used to calculate these estimators. Gross morphology, biological indicators, and, to a lesser degree, taphonomy should be used as criteria for pair-matching. Experienced osteologists, Adams and Konigsberg (2004) found, are much more likely to overlook a potential pair, than to mismatch a pair.

Considerations for the selection of type of element for pair-matching within an assemblage should include the size of the element, the presence of distinct morphological traits, the potential for age and sex estimation, and the likelihood of survival of the element (Konigsberg and Adams 2014). The statistic for LI and MLNI is designed to estimate population size without the necessity of observing every animal (or bone in our case) and thus operates on the assumption that data loss occurs randomly in the given context (Adams and Konigsberg 2008).

Kendell and Willey (2014) recently explored the effect of bone mineral density (BMD) on survival of elements in the archaeological setting in an attempt to relate this to the demographic representativeness of the sample, assessing degree of preservation with regard to representation of individuals by age cohort and considering BMD by age, sex, and health status. Specifically, their study explored “MNI disparity” between subadults and adults in terms of BMD differences. They found a correlation between BMD and preservation, and between size of element and survival, concluding that demographies may be biased towards the young and healthy due to lack of survival of the immature and old, and that BMD and survival may be one of the intrinsic factors that causes MNI to underestimate the actual population size. They argued that these results refute previous conceptions that the loss of elements in an assemblage is a random process, as requisite to MLNI estimates (Adams and Konigsberg 2008), and proposed to investigate sex in relation to BMD in future analyses in order to determine the effects of sex differences on representation.

Nikita and Lahr (2011) proposed computer algorithms to circumvent problems inherent to both MNI and MLNI, namely taphonomic issues such as missing elements, and the misidentification of paired elements. MNI simply cannot account for missing individuals, due to its nature as a minimum estimate and MLNI rests on the assumption that pair-matches are correct, likewise, subject to taphonomy and sample bias. The authors provided two algorithms in attempts to circumvent the bias inherent in missing data, incorrect pairings, and the requisite assumption of random data loss. The first algorithm produces a number of potential pairs between elements, taking into account thresholds for asymmetry, based on osteometrics, size of muscle attachments, and degree of osteoarthritis. The second algorithm estimates the number of individuals in a commingled sample by incorporating the percentages of lost and altered bones into the analysis.

Sorting Procedures

Following initial inventory and often concurrently with population estimation, biological anthropologists strive to resolve commingling among skeletal assemblages, following a variety of methods, and often using them in combination. As the number of individuals increases, the complexity of the commingling scenario increases (SWGANTH 2011). Fragmentary remains present additional challenges, and may only be amenable to MNI type estimates (Adams and Konigsberg 2008). The reassociation of commingled remains is described as an "inductive, step-wise process" involving multiple steps and supplemental techniques depending on the context (Byrd 2008). As such, statistical assessments and the achievement of 'absolute' confidence in reassociation is not always possible (Byrd and LeGarde 2014). The current best-practice guidelines proposed by the Scientific Working Group for Anthropology (SWGANTH 2011) for the approach to commingling parallel many of Snow's (1948) guidelines with new provisions for GIS, data recording, and DNA technology. These guidelines emphasize a field to lab approach involving careful data recording and documentation, including detailed spatial and proximity relationships for skeletal elements as well as clear labeling and thorough photography.

Detailed inventory of a skeletal sample is the logical first step toward commingling resolution. Standardized data recording protocols enable efficient data collection, contribute to sorting within commingled scenarios, and permit intersite data comparison (Buikstra and Ubelaker 1994; Ubelaker 2002). The reconstruction and fitting of any fragmentary remains should be undertaken during or in advance of the inventory phase. The criteria for sorting human remains are largely morphological, but with increasing complexity often call for supplemental methodology (Ubelaker 2002).

Morphological pair matching of skeletal elements involves attention to numerous variables and is dependent upon degree of osteological experience (Kerley 1972). The method can be quite reliable when individuals of different sex or developmental age are involved, but it loses potency in scenarios involving similar individuals. Pairings of similar element (i.e. long bones or *os coxae*) can be easily achieved, whereas the strength of association diminishes greatly when attempts are made to match unlike elements within an assemblage. For this reason, articulation testing is used in conjunction with pair matching. Size, shape, sexually dimorphic features, robusticity, degenerative change, pathology, skeletal anomalies, bone density, developmental phase, and taphonomy are all considered within morphological sorting attempts (Ubelaker 2002; Rosing and Pischtschan 1995; Kerley 1972).

The process of elimination is also crucially important within many phases of reassociation, eliminating inconsistencies in size, shape, and articulation. Definitive association by process of elimination is possible, however, only in cases of commingling where the number of dead is known, thus exhibiting “epistemic closure”, meaning that case circumstances permit strong inference to be made on negative evidence (Byrd and LeGarde 2014).

Studies such as Schaefer’s (Schaefer and Black 2007; Schaefer 2008) exemplify growth and development-based methods of detecting and sorting commingling. The studies employed a three-phase system for scoring epiphyseal union among an identified Bosnian sample and created modal tree diagrams of fusion sequences which can be used to detect incongruities in skeletal assemblages based on relative fusion phases within skeletal growth centers. Buikstra et al. (1984) and L'Abbe's (2005) forensic case studies also provide good examples for the sorting of small-scale commingling in consideration of age-related discrepancies among individual victims. Schaefer's (2014) recent work continues the development of standardized means of data recording for epiphyseal union as a means of approaching commingling based on the analysis of the sequence of initiation of epiphyseal union, the sequence of completion of epiphyseal union, and detailed consideration of interphase relationships between epiphyses.

Recent work by Cheverko (2013) demonstrated that degenerative skeletal changes are also useful in sorting commingled remains. When scored by standardized criteria, the expression of osteoarthritic changes in synovial joints can be useful in sorting commingled individuals. Changes should be consistent throughout the skeleton, permitting the separation of discrete individuals and also aiding the assessment of articulation within this process due to corresponding changes in joint morphology within adjacent elements.

Osteometric Methods

Several studies have undertaken simple metric statistical analysis in order to determine congruency of elements within commingled samples. Buikstra et al. (1984) used reference material from the Terry Collection to examine relative dimensions of cervical vertebrae in order to assist forensic scenarios involving severing of the head. The metric evaluation of the hip joint in an attempt to assess articulation and association of commingled remains using the femur and acetabulum was investigated by London and

Curan (1986) and London and Hunt (1998). When accounting for metric difficulties among the Terry Collection reference sample, namely age related changes in measurement locations, the authors found good utility for the method when combined with morphological methods.

More involved multivariate methods for reassociation of commingled remains have evolved in recent decades and are referred to as “formal” osteometric sorting methods to distinguish them from simple sorting by element or seriation techniques (Byrd and Adams 2003). In assessing a test case with known archaeological individuals, Rosing and Pischtschan (1995) used mathematical continuous variables in a bivariate statistical test of known associations between skeletal elements. They concluded that even the highest correlations between bivariate bone measurements were not sufficient if the demand was an absolute or correct association. Simple bivariate measurements were too reductive and ignored many of the dimensional qualities of the bone that could be most informative. Their conclusion was, in part, that multivariate methods might show greater promise (a line of thinking that continues to be actively researched), but that expertise in methods of pair matching, sorting, and eliminating far outperform metric evaluations.

Formal multivariate methods of osteometric sorting continue to be debated and expanded (Byrd and Adams 2003; Adams and Byrd 2006; Byrd 2008; LeGarde 2012; Thomas et al. 2013; Vickers et al. 2014; Byrd and LeGarde 2014). The concept for osteometric sorting rests on the idea that the human physique varies in predictable population-specific ways (Roberts 1978; Ruff et al. 1991, 2000; Auerbach and Sylvester 2011). This variation is expressed in the size and shape of the skeletal elements in relationship to each other (Byrd and Adams 2003). The initial approach was based on size measures of unmatched elements compared to a reference sample derived from the Forensic Data Bank, Terry Collection, and CILHI. The method tested the null hypothesis that two specimens of concern were similar enough in size and shape to have originated from a single individual (Byrd and Adams 2003). Byrd and Adams' osteometric protocols were derived specifically to capture individual variation in robusticity due to muscle mass and to circumvent problems of fragmentation and taphonomy by incorporating denser regions of bone like regions such as the deltoid of the humerus. Byrd (2008) expanded the reference sample to include the University of Tennessee Bass Donated Collection and the Hamann-Todd Collection, developing a three phase model consisting of sorting protocols for comparing left and right elements based on shape, comparison of adjoining bones based on correlation of corresponding regions of joints, and the comparison of the sizes of different elements through regression models.

LeGarde (2012) investigated the effect of asymmetry in upper limb bones on Byrd and Adams' osteometric sorting model and found significant evidence for humeral asymmetry among her sample, probably related to handedness, and not borne out in the radius. In absence of a definitive conclusion, she expressed the need for larger sample size and more left-handed individuals in order to determine effects on sorting procedures. Her conclusions echoed those commonly found, that long bone breadths typically exhibit more asymmetry than lengths due to increased response to muscle mass (Auerbach and Ruff 2006). Byrd and LeGarde (2014) found that asymmetry has little negative impact on the proposed sorting methods. The main goal of these studies is to reduce the time involved in pair-matching or bilateral re-fitting by finding a method that produces likely pair matches from a larger assemblage and avoids the common statistical errors associated with larger sample commingling scenarios.

Further problems for osteometric sorting approaches delineated by O'Brien and Storlie (2011) include the problem of taphonomic damage to bones preventing measurement and obscuring possible matches, as well as the need to account for the factors that serve to distinguish individuality by species, since these methods are applied to both zooarchaeological and human material. Overlapping of bone measurements between individuals is also common in large assemblages, because bone size is normally distributed (O'Brien and Storlie 2011). Chew (2014) expressed concerns about Byrd's (2008) model in sorting a large-scale prehistoric sample. Her conclusion was that osteometric sorting alone is not capable of satisfactorily resolving large-scale commingling, especially in contexts where there are many individuals of similar size. Additionally, the modern "healthy" reference sample in Byrd's method did not perform well for regression on a prehistoric sample having a low degree of sexual dimorphism, and presumably, poorer health or nutritional status. The current state of the debate surrounding osteometric sorting procedures suggests that most researchers believe the method is helpful in reducing sorting time for large assemblages, is limited by taphonomy, and is most useful when implemented in conjunction with other methods (Osterholtz et al. 2014).

DNA and Medicolegal Methods

Beyond statistical means, and leading into a summary of the use of XRF in sorting commingling, other technological and archaeometric methods have been used to address commingling in forensic and archaeological scenarios. The forensic identification effort undertaken by the Office of the Chief Medical Examiner of New York following the September 11th terrorist attacks as well as the work of numerous forensic teams in worldwide human rights and identification work, have led to the development of DNA-led multidisciplinary team approaches to the sorting of large-scale incidents and mass graves. These contexts involve every aspect of anthropological sorting and documentation reviewed within standard commingling methods, but have the added ability of integrative DNA testing, funded by governmental and international organizations. Factors of cost, time, the limitations of DNA extraction techniques, and taphonomy, however, affect these contexts too. While modern forensic teams often adopt strategic sampling techniques for DNA based associations, traditional commingling inventory and sorting steps are usually employed preliminarily or simultaneously (Byrd 2008; Garrido-Vargas and Intriago-Leiva 2012). Improvements in spatial analysis techniques and documentation of crime and crash scenes have also contributed greatly to the function of forensic teams involved in mass disaster and human rights (Tuller and Hofmeister 2014).

Archaeometric Methods

Archaeometric, including elemental and isotopic methods for approaching individualization from commingled human remains continue to be seen as supplemental techniques (Ubelaker 2014). This is due to a number of factors that will be discussed in the following review, but include contamination and diagenesis, intra-individual variation in elemental concentrations, difficulty in validation of techniques due to sample biases and sampling technique, among other factors. For these reasons, the techniques are best employed in conjunction with other commingling protocols, and with consideration of archaeological and taphonomic context (Fulton et al. 1986; Gonzales Rodriguez and Fowler 2013; Perrone et al. 2014; Ubelaker 2014). The following section provides a summary and background for anthropological elemental studies of the human skeleton, diagenesis of buried skeletal remains, and the use of elemental analysis via XRF for approaches to commingling methodologies.

Elemental Studies of the Human Skeleton

Human bone is a "complex amalgam of compounds and chemicals" including elements and isotopes, within which, and in addition to its main components (calcium, phosphate, and water), a variety of minor and trace elements accumulate during the manufacture of bone tissue (Price et al. 1985). During the process of bone remodeling, inorganic trace elements are incorporated into skeletal tissue based on the chemical environment of the body (Darrah 2009). Human bone changes throughout the lifetime in response to normal physiological processes, mechanical strain, and environmental influence, while acting as reservoir for storage of necessary minerals (Jee 2001) and remodeling with a replacement rate of 5 to 10 percent of the skeleton per year in adults (Kini and Nandeesh 2012; Klepinger 1984).

Anthropologists have been interested in the elemental and isotopic composition of bone for decades beginning with trace elemental analysis for dietary inference in past populations (Gilbert 1975; Gilbert and Mielke 1985). Scholars have investigated dietary reconstruction, occupational exposure, and geographic origins, while simultaneously confronting the problems inherent to bone chemistry, namely inter- and intra-individual variation in the incorporation and storage of elements and isotopes, and diagenesis, the multifactorial taphonomic alteration of bone and exchange of its chemical signatures with the burial environment (Ahlgren et al. 1981; Bratter et al. 1977; Price 1988, 1989). At present, anthropological inquiry is still engaged in attempts to resolve many theoretical and methodological issues pertaining to bone chemistry and elemental studies (Pemmer et al. 2013; Swanston et al. 2012). Investigation of the complexities of bone chemistry has provided anthropologists with a healthy appreciation of the need for consideration of multiple lines of evidence (chemical, material, etc.) during the process of anthropological inquiry into past behavior, especially diet (Price 1989; Schoeninger and Moore 1992).

Elements such as zinc (Zn), copper (Cu), molybdenum (Mo) and selenium (Se) are predominantly associated with animal protein, while elements such as strontium (Sr), magnesium (Mg), manganese (Mn), cobalt (Co) and nickel (Ni) are essentially associated with vegetable sources (Martin et al. 1985). Essential trace elements such as Cu, Mg, Zn and possibly Sr play important roles in human health while toxic elements aluminum (Al), lead (Pb) and cadmium (Cd) for example, play a role in disease process (Amr and Helal 2010; Baranowska et al. 1995).

Initial studies for dietary reconstruction from Sr sought to address the proportion of meat versus vegetables in the diet and status difference in dietary access (Blakely and Beck 1981; Gilbert 1975; Klepinger 1984), as well as access to marine resources in past populations based on strontium to calcium (Sr/Ca) ratios (Schoeninger and Peebles 1981). Mammalian tissue discrimination against Sr in favor of Ca uptake was seen as a useful measure for distinguishing between herbivores, carnivores, and omnivores (Toots and Voorhies 1965). Variation of environmental Sr abundances, and the role of diagenesis, however, caused concern for the validity of these studies (Klepinger 1984). Strontium has also been used to address human origins and migrations, based on the concept that Sr uptake varies with geology, entering human tissues via plant consumption and substituting for calcium (Ca) in bone (Budd et al. 2000).

Barium (Ba) is an alkaline earth element like Sr that accumulates in the leaves of plants and derived from soil Ba content, being subsequently absorbed through the digestive tracts of animal and human consumers (Ahlgren et al. 1981). Ba and Sr are still considered useful measures for anthropological inquiry into diet and origins (Burton and Price 1990; Burton et al. 2003). Ideally, these trace elements should be used in conjunction with other methods, e.g. isotopic measures of Sr, Pb, and O (Price et al.1992; Budd et al. 2000), and with consideration of the caveats of sources of individual and post-depositional factors (Burton et al. 2003). Recent work has found evidence that the ratio Sr/Ca is capable of differentiating individuals reliably in many contexts based on geographical origins (Cucina et al. 2011; Rasmussen et al. 2013; Schutkowski et al. 1999).

Lead is of interest to anthropologists for many reasons, especially due to its impact on the health of past and present populations. Lead is incorporated into the hydroxyapatite matrix of skeletal tissue via exchange with Ca at the structural level and is thus deposited and diffused throughout the skeleton (Rebocho et al. 2006). Uptake of Pb occurs within both the respiratory system and the gastrointestinal tract (Wittmers et al. 1988). The measurement of Pb in bone is important for many reasons, and of interest in clinical, pathological, and historical anthropological research. Lead is a toxic nonessential element in the human body and its levels in bone serve as a useful proxy for cumulative or lifetime exposure due to its accumulation in bone stores and slow turnover rate (Todd 2014). Age-related increase in bone isotopic Pb reflects cumulative lifetime exposure to Pb (Darrah 2009). Children, elderly and osteoporotic individuals, as well as pregnant women are among the demographic groups most at risk for lead-related health impacts due to the potential for Pb stored in their skeleton to be mobilized or released from bone stores into their blood stream and organ systems (Todd 2014). Lead exposure during early childhood can become a significant problem in later life, and release of stored Pb can be harmful for both mother and infant during pregnancy and lactation periods (McNeill 2000).

Distribution of Trace Elements in the Human Skeleton

It is well known that trace elements are stored differentially throughout the human skeleton and within individual bones (Bratter et al. 1977; Ahlgren et al. 1981; Grupe 1988; Price 1989). Intra-individual variability in elemental signatures and ratios can often exceed inter-individual variance, thus presenting caveats for comparative study of elemental differences between individuals and groups of individuals (Ahlgren et al. 1981; Finnegan 1988; Grupe 1988). Biological sources of this variability include differential bone turnover rates within the skeleton, timing of tissue formation, and variation in storage of elements due to complexities of diet, behavior, and biology (Schoeninger and Moore 1992; Budd et al. 2000). Trace elemental signatures and levels also vary throughout the lifespan due to age-related metabolic and physiological changes (Darrah 2009).

The relationship between trace elements in bone and bone pathology is an area of considerable interest within medicine (Darrah 2009) and continues to provide new information about the distribution of elements in the skeleton. Recent technological advances permit the means to examine elemental distribution within the human skeleton on a microscopic scale, permitting quantitative studies of trace elements in relation to histological structures within bone.

Pemmer et al. (2013) recently demonstrated differential mechanisms of accumulation and distribution within bone structural units (BSU's) for trace elements Zn, Pb, and Sr within the skeleton by examining their distribution in pathology bone specimens via micro-XRF (uXRF) analysis in conjunction with advanced imaging techniques. The authors found Zn and Pb at increased levels in cement lines compared to surrounding bone matrix, and Pb and Sr levels to be correlated with degree of mineralization. In a study of archaeological diagenetic skeletons, Swanston et al. (2012) had success in matching synchrotron XRF (SR-XRF) measures of the spatial distribution of elements Ca, Sr, and Pb (elemental maps) to histological microscopic images, demonstrating the localization of these elements within discrete bone microstructural units, thereby providing evidence for biogenic elemental signatures.

Diagenesis

The promise of direct inference into paleodiet via the study of trace elements in bone faced serious setbacks due to realization of the effects of diagenesis on bone, and the method was supplanted to a significant degree by stable isotope studies of bone and teeth, in attempts to control or avoid the effects of postmortem alteration (Ambrose and

Katzenberg 2000; Burton and Price 2000; Ezzo 1994). Archaeological buried bone presents special considerations and caveats for bone chemistry studies since it is so susceptible to environmental taphonomic influences. Diagenesis has been well-demonstrated as an obstacle to dietary trace elemental and isotopic studies (Price 1989; Kohn and Schoeninger 1999; Ambrose and Katzenberg 2000; Hedges 2002), creating interpretive challenges to anthropological assessments. Efforts continue to address the complexities of bone preservation within isotopic studies (Lee-Thorpe 2002; Lee-Thorpe and Sealy 2008; Lee-Thorp and Sponheimer 2003) with progress in understanding the situations under which bone preserves biogenic signals within both the collagen and mineral phases of bone. A complete understanding of the correlation between preservation of bone histology, microstructures, and bone collagen within burial context remains has not been reached, but remains under investigation (Ambrose and Katzenberg 2000).

Diagenesis is a complex process, representing not just an additive process of contaminants, or a direct chemical alteration of biogenic bone apatite, but a combination of the two (Kohn and Schoeninger et al. 1999; Price 1989). Diagenetic alteration of bone is strongly dependent on the burial environment (Liritzis and Zacharias 2011) and prediction of the effects of diagenesis is a complex task due to the array of processes operating in the postmortem period and long-term burial environment (Hedges 2002). There is no universal trajectory of diagenesis, but a complex set of processes which operate on different levels including uptake of cations and organics, exchange of ions, breakdown and leaching of collagen, microbial attack, hydrolysis and mineral dissolution, and alteration and leaching of bone matrix (Hedges 2002; Smith et al. 2007).

Soil acidity and hydrological activity are known to dissolve bone, increasing porosity and in turn increasing dissolution rates in the manner of a soil/bone feedback mechanism of exchange with the burial environment (Hedges and Millard 1995; Pike et al. 2001). For reasons of lesser susceptibility to diagenesis, tooth enamel is frequently used for analysis preferentially over bone for anthropological studies (Budd et al. 2000). Grupe (1988) and others have found compact bone to be less susceptible to diagenetic influence than trabecular bone, and that long bone shafts are best suited for elemental analysis.

Indicators for possible diagenetic effect due to environmental influence include elevated Ca/P ratios, suggesting enrichment of bone values by soil Ca (White and Hannus 1983; Zapata et al. 2006; al-Shorman 2010). Elevated bone Sr, Pb, Al, and Mn levels are also indicative of diagenetic influence (Zapata et al. 2006). Studies also reveal the tendency of Fe to infiltrate bone matrix, one of the processes inherent to fossilization (Badone and Farquhar 1982; Ezzo 1994). Yan et al. (2010) recently used comparison of Fe profiles in bone and teeth with those of Zn and Sr for the purposes of assessing the biogenic versus diagenic nature of the latter via micro XRF. Differences between the consistency of element concentrations of Zn and Sr versus those of Fe within the two tissues demonstrated that Zn and Sr in their study context were likely biogenic and reflective of individual diversity.

Anthropological studies of skeletal Pb content have faced intense criticism due to the potential for diagenetic influence from soil Pb (Millard 2006; Rebocho 2006; Waldron 1983; Wittmers et al. 2008). Signatures of probable diagenetic influence within archaeological samples include elevated Pb levels overall (Millard 2006), higher Pb levels in subadults compared to adults (Wittmers et al. 2008; Shuler and Schroeder 2013), and elevated soil and groundwater Pb levels or the effects of burial practices that involve Pb (Rebocho et al. 2006; Wittmers et al. 2008). More recently, human teeth are seen as a preferable means for in vivo 'biomonitoring' of human health and nutritional status (Amr and Helal 2010), providing easily sampled measures of trace element levels (Brown et al. 2004) as well as determination of levels of toxic heavy metals (Grunke et al. 1996). Similarly, dental enamel is viewed as a preferable material over bone for studies within archaeological contexts due to its decreased susceptibility to diagenetic alteration (Budd et al. 2000). Recent bioanthropological studies of Pb have been combined with earlier-generated bone data (e.g. Corruccini et al. 1987) to reveal convincing evidence for cumulative toxic effects of Pb in past populations (Schroeder et al. 2013; Shuler and Schroeder 2013).

X-ray Fluorescence and Elemental Analysis of Skeletal Remains

X-ray fluorescence spectrometry (XRF) provides a rapid and non-destructive analytical tool for the determination of chemical composition of a material (Liritzis and Zacharias 2011; Pollard et al. 2007; Shackley 2011). Modern XRF equipment has evolved through technological developments from X-ray spectroscopy, which originated from Charles Barkla's discovery of a connection between X-ray radiation from a sample and its atomic weight in 1909 (Shackley 2011). The working principal of modern XRF analysis is "measurement of wavelength or energy and intensity of the characteristic X-ray photons emitted from [a] sample", thereby permitting the determination of constituent elements in a sample as well as their mass and concentration (Janssens 2006:1).

XRF has numerous scientific, medical, and industrial applications. Interest in archaeometric applications has grown steadily in recent decades as is evident from the publication of numerous XRF based studies of archaeological metals, ceramics, and stone tools, primarily geared toward determination of their constituent materials and origin or source (Garrison 2003; Johnson 2011; Liritzis and Zacharias 2011). XRF is now widely used in nondestructive museum specimen analysis, provenance studies of artifacts, conservation, art authentication, ceramic, pigment, and metal analysis, and many other applications. The advent of portable XRF (pXRF) hand-held units has made the technology accessible to researchers in many fields, especially archaeology (Liritzis and Zacharias 2011).

Medical applications of XRF include in vivo and surgical pathology studies geared toward understanding the accumulation and distribution of heavy metals such as Pb in bone (Chettle et al. 1991; McNeill et al. 1999; McNeill et al. 2000; Stokes et al. 1998; Todd et al. 1992). Within forensic science and bioarchaeology, applications of XRF are becoming increasingly common in both field and laboratory settings for the analysis of human bone and teeth.

Portable XRF analysis of human bone had been used for validation studies for elemental analysis in comparison to destructive quantitative methods such as ICPMS (Little et al. 2014; Byrnes et al. 2009, 2010), to assess the geographic origins of buried individuals (Byrnes et al. 2009, 2010), to sort commingled skeletal remains (Gonzales-Rodriguez and Fowler 2013; Perrone et al. 2014), to distinguish between osseous and non-osseous materials in a forensic setting (Christensen et al. 2012; Zimmerman 2010), to assess the role of diagenesis in elemental readings from bone (Gonzales Rodriguez and

Fowler 2013; Perrone et al. 2014), to investigate levels of Pb (Pb) in bone (Little et al. 2014; Rebocho et al. 2006), to identify chemical characteristics of historic funerary practices (Haddow 2012), and to investigate evidence for medicinal treatment in the past (Zuckerman 2010, 2012).

XRF equipment employs an X-ray source with a metal target used to induce fluorescent emission of secondary X-rays from a sample (Shackley 2011). Janssens (2006:1) provides one of the more succinct descriptions of the basis for XRF analysis:

> XRF radiation is induced when photons of sufficiently high energy, emitted from an X-ray source, impinge on a material. These primary X-rays undergo interaction processes with the analyte atoms. High-energy photons induce ionization of inner shell electrons by the photoelectric effect and thus electron vacancies in inner shells (K, L, M, …) are created. The prompt transition of outer shell electrons into these vacancies within some 100 fs can cause the emission of characteristic fluorescence radiation. Not all transitions from outer shells or subshells are allowed, only those obeying the selection rules for electric dipole radiation. The creation of a vacancy in a particular shell results in a cascade of electron transitions, all correlated with the emission of photons with a well-defined energy corresponding to the difference in energy between the atomic shells involved. The family of characteristic X-rays from each element including all transitions allows the identification of the element. Next to this radiative form of relaxation, a competing process can take place: the emission of Auger electrons. Both processes have Z-dependent probabilities that are complementary: the Auger yield is high for light elements and the fluorescence yield is high for heavy elements.

XRF analysis focuses on the “mid-Z X-ray region”, which limits its ability to detect rare-earth elements and elements with low atomic numbers. XRF provides a ‘mass analysis’, meaning that every component in the irradiated sample is included in the analysis, thereby limiting its ability to characterize small sample components (Shackley 2011). Other limitations include the thickness of the sample of interest. Elements commonly measured by pXRF include K, Ca, Ti, Mn, Fe, Zn, As, Rb, Sr, Zr, Ba, Hg, and

Pb (Liritzis and Zacharias 2011). Portable units (pXRF) commonly used in archaeological field and laboratory pursuits are typically limited to the detection of element numbers 9 to 92, fluorine (F) to uranium (U) (Shackley 2011). Data output from XRF analysis is presented in the format of spectra, or lines superimposed over a fluctuating background created by processes of radiation scattering (Janssens 2006; Pollard et al. 2007).

Sampling for Elemental Analysis

Sample choice for elemental analysis of archaeological bone varies widely according to instrumentation and scientific interest, but general tenets apply to elemental analysis via XRF and guide most current studies toward common sampling strategies. In general, cortical bone sampled at standardized locations is preferred. Elements such as Pb are preferentially incorporated into cortical bone over trabecular (Wittmers et al. 1988) and lifetime functional adaptation skeletal tissue remodeling ensure continued distribution of trace elements into cortical bone tissue (Martin and Burr 1989; White 2000). Trabecular bone is subject to misleading results due to normal variation and heightened susceptibility to ionic exchange with the soil due to surface area (Grupe 1988:128; Rebocho et al. 2006). Similarities exist in the incorporation of other elements such as Sr, Ba, and possibly Zn into cortical bone but the mechanisms for uptake and distribution are subject to a variety of processes biological and diagenetic in nature (Burton et al. 2003:93; Ezzo 1994).

Grupe (1988) found significant variation in trace element distributions within different locations in individual skeletons, but that fluctuations in trace element concentrations within single compact bone shafts were minimal. Individual and group comparisons were thus seen as feasible via the selection of standardized anatomical points for elemental analysis within compact bone, best representing total skeletal content. Wittmers et al.'s (1988) study of Pb at different locations on the long bone diaphysis likewise found no significant elemental variation across the bone. Researchers recommend sampling from multiple locations within single bones in order to obtain mean values for elements such as Hg which may distribute differently throughout the skeleton (Rasmussen and Boldsen 2008; Zuckerman 2010). Recent multielement XRF studies have found minimal interskeletal variation of elemental signatures in standardized anatomical sites, to include bone with thin cortex and trabecular structure (Gonzales-Rodriguez and Fowler 2013; Perrone et al. 2014). The midshaft of long bones was chosen by Perrone et al. (2014) presumably due to ease of standardization, thickest cortical location, and probably greatest bone mineral density (BMD).

Flat locations on individual bones are preferable for pXRF analysis due to the fact that they minimize air gaps between the instrument and sample, a potential source for erroneous readings (Little et al. 2014; Perrone et al. 2014; Shackley 2011; Zuckerman 2010). For this reason a vacuum pump attachment is often used in conjunction with pXRF equipment, to evacuate air from the instrument, minimizing X-ray absorption and permitting more precise measurement of lighter elements (Shackley 2011:30).

Techniques for surface preparation include light abrading and cleaning with distilled water (Zuckerman 2010; Gonzales-Fowler and Rodriguez 2013), cleaning with ethanol rinse (Perrone et al. 2014), and total removal of outer cortex via abrasion or burring (al-Shorman 2010; Little et al. 2014). Investigators employing the latter protocol are particularly concerned with diagenetic soil influence within Pb studies, concluding via comparison of ICP-MS and pXRF results that XRF readings from archaeological bone are particularly susceptible to diagenetic Pb due to the fact that the method provides a surface analysis rather than a bulk analysis (Little et al. 2014). Trapped soil particles may necessitate removal of the cortical surface in these contexts (al-Shorman 2010). Other researchers contend that the effects of surface contamination should be minimized due to the depth of penetration of x-rays during analysis, several millimeters (Shackley 2011:8).

Statistical Assessment of XRF data within Archaeometry

Approaches to the statistical assessment of elemental data derived from XRF and pXRF are varied and range from simple spectral overlay comparison (Liritzis and Zacharias 2011), to complex multivariate statistical software packages (Kotula and Rodriguez 2012). Many of the published archaeometric studies are geared towards archaeological sourcing and provenance studies for materials such as obsidians and basalts and employ statistical tests for the assessment of group affinity based on elemental similarities. These studies provide good models for anthropological hypothesis testing regarding material culture (McAlister 2011).

Glascock (2011) refers to the process of “data mining” as central to identifying elements or groups of elements which best enable the differentiation of materials in archaeological contexts. This approach involves the examination of elemental differences between sources one element at a time, the examination of series of bivariate plots, or the use of multivariate methods such as cluster analysis (CA), principal components analysis (PCA), or discriminant function analysis (DFA).

Cluster Analysis can be useful for assessing groupings via XRF-derived elemental spectra, especially when the materials under study are “more homogeneous” in origin and age. Liritzis and Zacharias (2011) detail software and complementary methods for the assessment of real groups within elemental data, but express the opinion that simple scatter plots and visual comparisons can often be equally as effective at assessing group membership or material similarity. Johnson (2011) similarly recommends bivariate plots of elemental concentrations for their utility and advocates the use of PCA to classify potential groupings and canonical distribution analysis (CDA) to confirm “bivariate and multivariate group affiliations”. Alternative approaches to the assessment of elemental groupings include classification tree (CT) analysis (Mcalister 2011) and multivariate software permits comparison of spectral data images via their shape and spatial arrangement (Kotula and Rodriguez 2012).

Early elemental approaches to commingling

Guinn (1970) discussed early hope for the application of forensic neutron activation analysis (NAA) as a means of qualitative and quantitative elemental analysis, to the forensic sciences. He proposed its application as a non-destructive means of measuring small samples such as hair for the determination of common origin and differentiation between samples at the minor and trace elemental levels. He foresaw the application of the technique to mass disaster and fragmentary remains, while not directly mentioning bone.

Fulton et al. (1986) found elemental ratios of dietary-related trace metals useful as a supplemental method for distinguishing individuals in a small-scale commingled fragmentary air crash scenario, using inductively coupled plasma atomic emission spectrophotometer (ICP). They found considerable variation in single element values throughout individual skeletons and resolved to use elemental ratios in order to control for sampling and sample size effects. Because of normal variation in measurement techniques and variation in elemental amounts in and within bone, they concluded that single elements were not useful in distinguishing between individuals. Arsenic was the only exception in their study, as it did show potential at discriminating between individuals. Their conclusions were that elemental measurements taken from standardized locations such as the bone midshafts showed greater reliability for inter-individual comparisons, and that the ratios Zn/Mg and Mg/Zn, supplemented by Zn/Na, Mg/Na, and Cr/Na could be useful in reassociation, especially when used in combination with established gross methods of sorting commingled remains.

Finnegan (1988) tested the efficiency of trace element ratios in separating commingled human remains among a small sample. He found that variation of sampled sites could vary more greatly within a skeleton in terms of elemental concentrations than between skeletons. He attributed some of the variation to sample site location, archaeological contamination, environmental contamination, and sampling procedure. He states they were able to tighten control over the procedure and thereby reduce intraskeletal variation, indicating that research into the method would continue. Continuing work by Finnegan and Chaudhuri (1990) suggested that trace element methods were useful only when the number of skeletons was low, and they were of diverse backgrounds. They examined the potential of using the isotopic ratio of Sr ($^{87}Sr/^{86}Sr$) as an alternative, finding that it could effectively segregate skeletons if bone and teeth were considered separately, adding that the ratio might be reflective of variation in geology of groundwater, thus individual background or origin.

Castro et al. (2010) recently tested the ability to distinguish between individuals in a forensic context with buried skeletal remains using quantitative measures of trace elements in bone (humeri and femora) and teeth obtained by laser ablation ICP-MS. Their protocol was designed to permit improved detection of trace elements in a complex matrix (bone) compared to other quantitative approaches (standard ICP-MS). Their sector-field based system (ICP-SF-MS), was chosen for its ability to overcome "polyatomic/isobaric interferences" in bone matrices and to improve detection limits within bone. The use of laser ablation (LA) for sampling permitted high resolution spatial analysis for the detection of variations in elemental concentrations within the bone matrix, providing the ability to assess spatial and quantitative elemental data as it related to biogenic signal versus diagenetic influence. They assessed diagenesis using Ca/P ratios to detect altered hydroxyapatite in different layers of the bone (periosteal, middle, and endosteal surfaces). This approach allowed them to isolate areas of presumed biogenic elemental signal in bone and develop a protocol for sampling which they applied to 12 individuals. Their analysis demonstrated significant differences for Sr, Mg, Rb, and Fe between individuals within their sample of buried remains. All of the elements from their protocol with the exception of Zn, (Fe, Cu, Mn, Mg, Sr, Ba, Pb, Rb, and Al) showed significant differences in elemental concentration between the humerus and femur. Using Canonical Discriminant Analysis (CDA), the authors achieved correct classification rates for the femur of 75.2% when testing discrimination between individuals, and 63.1 % for the humerus. Combined results (discrimination using both humerus and femur) were considerably lower for group classification (42.7%), suggesting the bones should be considered separately for application to commingling scenarios (Castro et al. 2010:22). Their conclusions which are most relevant to the present study are thedemonstrated potential for elemental analysis to be used as a complementary technique for reassociation, and the importance of sampling from the same anatomical location. Individual measures clustered in groups only when humeri and femora were considered separately. The authors point to this sampling concern as the likely result of differential elemental distribution within different bones, and possibly even within single bones.

pXRF Approaches to Commingling

Recent studies have tested the utility of pXRF in sorting samples of commingled skeletons or in distinguishing differences between individuals (Byrnes et al.; Gonzales Rodriguez and Fowler 2013; Perrone et al. 2014) in several contexts with varying degrees of success. Other studies have tested the ability of pXRF to distinguish between human skeletal and dental material and other materials within the forensic context (Zimmerman 2010; Christensen et al. 2012). Little et al. (2014) recently demonstrated the limitations of pXRF analysis for thequantitative analysis of heavy metal content in bone (Little et al. 2014). The general consensus of pXRF based studies for commingling is that the method can be a valuable tool for reassociating skeletons when context, sample size, taphonomic factors, and supplemental methods of sorting remains are considered. Variation in archaeological or forensic context and age of buried remains present differing scenarios which may require different protocols and elements for consideration.

The first study to use elemental analysis to address commingling was the previously discussed study by Fulton et al. (1986), although it was a destructive ICP based study. Inspired by concurrent usages of trace element analyses for dietary reconstruction, these authors applied this archaeometric method to a simulated commingling scenario in order to address questions surrounding the utility of elemental analysis to forensic contexts, namely asking the questions of whether elemental values or ratios of paired elements would be similar within the bones of one individual, and whether they would be measurably different between the bones of individuals. Fulton and colleagues' study is problematic in that the study samples included buried remains, macerated or chemically-prepared remains, and cadaver remains. Nonetheless, their findings brought to light many of the problems that are still being addressed, namely, the likelihood that elemental techniques will often lose discriminatory strength in larger sample sizes due to sampling concerns, burial environment, and instrumental noise.

Gonzalez-Rodriguez and Fowler (2013) investigated the ability of pXRF to discriminate between buried archaeological skeletons within a small sample (n=5). The authors selected an elemental protocol hypothesized to be useful in distinguishing between individuals based on diet, physiology, and metabolism. Multivariate statistical analysis of their elemental measures suggested the method is effective in small contexts, but (similarly to Fulton et al.'s findings) likely to lose strength with increasing scale of commingling due to diagenetic factors and overlap of elemental readings.

Building on the previous study, Perrone et al. (2014) evaluated the strength of XRF analysis in addressing commingling based on a mixed but largely surface-exposed sample of recent skeletons rather than a buried sample. Their approach used confidence intervals to determine the elemental measures of greatest discriminatory strength within their sample and concluded that the method has potential for gross sorting of mixed human remains, but should be used with careful consideration of overlapping elemental measures, sample size, and the effects of diagenesis (especially for buried remains). The next chapter draws from this review of scientific approaches to commingled remains in order to construct and implement a multiple method approach for the reassociation of individuals at Hagley Plantation, 38GE81.

Figure 4.1 Present Day Landscape of Hagley Estates Subdivision.

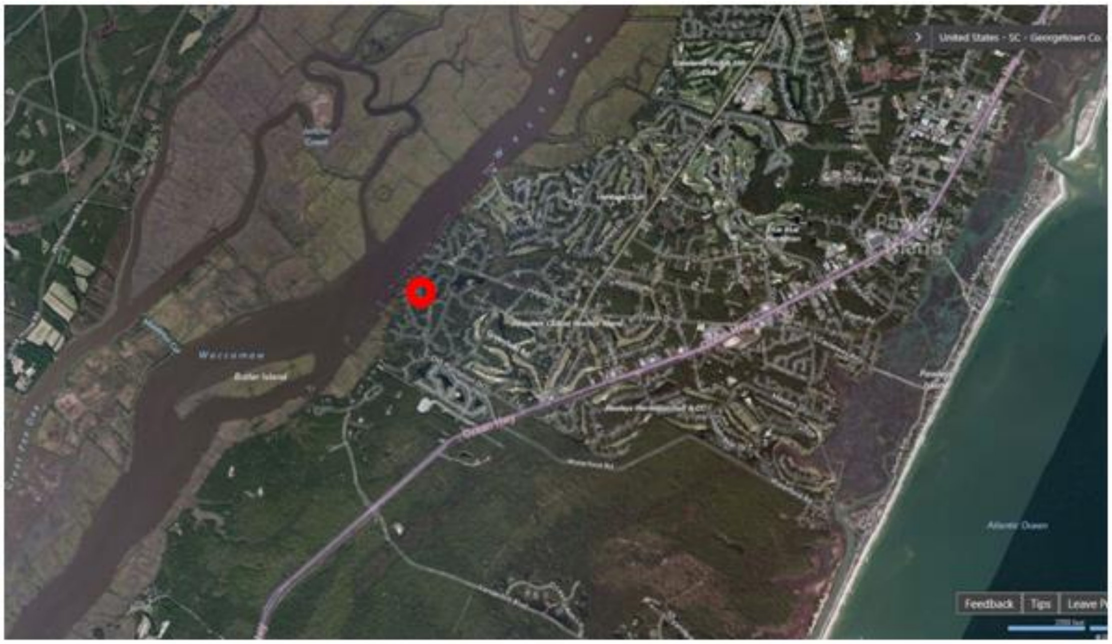


Figure 4.2 Bing (bing.com) Satellite Imagery Showing Remnant Rice Fields of Hagley (Red Circle) and Adjacent Former Rice Plantations Along the Waccamaw River.

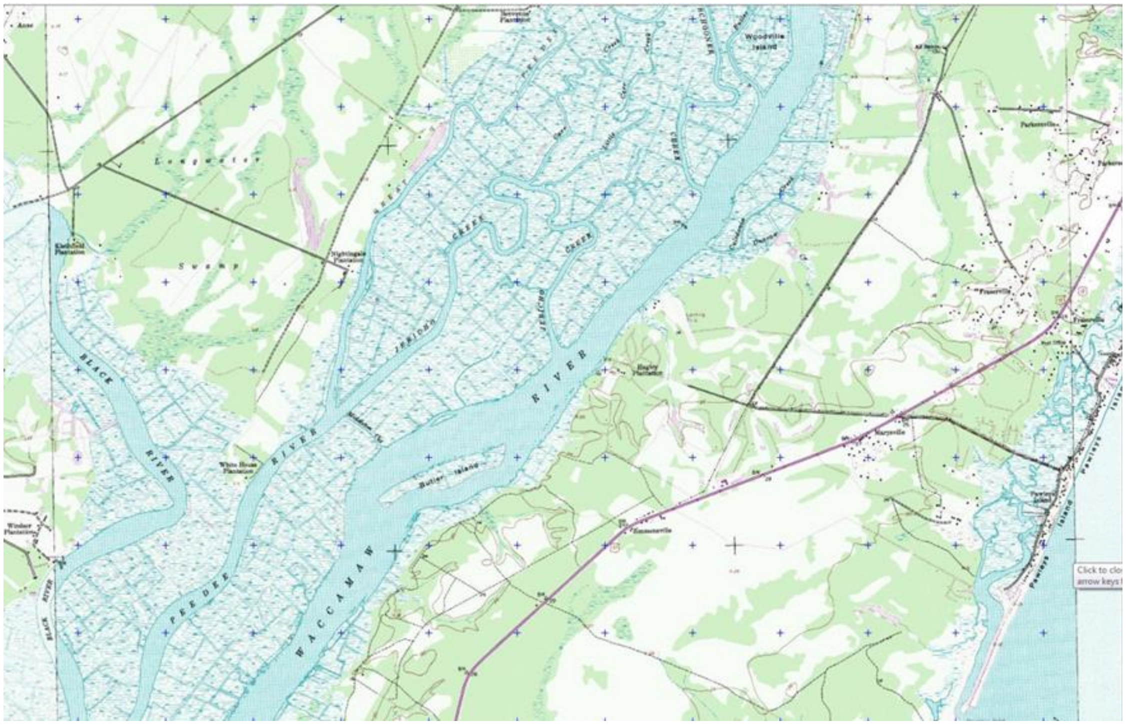


Figure 4.3 USGS Waverly Mills Topographic Map Showing Location of Hagley Landing- 38GE81.

Figure 4.4 View North During Home Construction on Old Waccamaw Drive Looking Towards the Waccamaw River from the Former Location of St. Mary's Chapel and Cemetery.

CHAPTER 5

IMPLEMENTATION OF A MULTIPLE-METHOD APPROACH TO COMMINGLING

In this chapter, I construct and implement a multiple method, multiple phase approach designed to sort the skeletal remains from Hagley Plantation and to resolve them into discrete individual skeletons to as complete a degree as possible. This approach is informed by the preceding chapter's literature review of methods and approaches to commingling of skeletal remains in archaeological contexts. Given the archaeological context and composition of the skeletal remains sample from Hagley Plantation, I construct testable expectations pertaining to the methods deemed most suitable for application to the remains from this site. The importance of this study is that it will demonstrate the potential and/or limitations of multiple method commingling approaches involving pXRF analysis, in order to inform future efforts and to develop protocols for making commingled samples more amenable to study, thereby increasing their interpretive potential within bioarchaeology.

Expectations and Hypotheses for Commingling at 38GE81

The immediate goal of the current study is to design a protocol for commingling at Hagley Plantation, implement it, and to achieve results in the form of a resolved skeletal sample consisting of discrete individuals. This derived sample will then be employed in a comparative biomechanical study based on cross-sectional geometric measures, comparing the remains from Hagley Plantation with those of Newton Plantation, Barbados. The composition of the resolved skeletal sample will in turn determine the methods and parameters for the CSG study. To do this, I adopt a combined approach utilizing techniques commonly applied to commingling scenarios such as morphological pair-matching, development, taphonomy, and process of elimination, supplemented with elemental analysis performed with portable XRF analysis.

The present study faces several core challenges due to historical demographic and archaeological contexts. The rice plantation communities of the Waccamaw Neck, where Hagley Plantation is situated, are characterized by historians as self-contained social entities with self-sustaining populations (Joyner 1984). For this reason, they likely contain a high degree of familial relatedness. Harris and Rathbun (1989) discovered probable dental evidence for kinship or familial patterning among the Remley Rice Plantation enslaved. Although not the focus of this study, gross examination of the Hagley sample immediately reveals characteristics of genetic relatedness in probable epigenetic traits such as the form of long bones including femoral neck length, femoral torsion, femoral head morphology, and other similar aspects of the long bones. Additionally, the Hagley skeletal sample (Figure 5.1) contains many individuals of similar size as revealed during sorting of the sample. For these reasons, coupled with the presence of considerable damage to the epiphyses of many long bones, inhibiting the required measurements, and the perceived lack of completeness of the sample, the techniques for formal osteometric sorting reviewed in the previous chapter are ruled out for further consideration.

Despite the aforementioned suggestion of relatedness and resultant morphological similarity within the group, it may be possible to sort and assemble a core sample of the Hagley individuals into high confidence groupings based on a combination of morphological pair-matching, articulation, elemental analysis via pXRF, developmental stage, pathology, and taphonomy. Following on the advice of Byrd (2008:208), this study operates on the premise that sorting of comingled remains is best viewed as a step-wise "inductive process" relying on series of tests and complimentary methods, and strongly dependent on the process of elimination over statistical assessment alone, owing to human variation and the complexities of commingling scenarios.

An additional problem for consideration in attempting reassociation of these remains is the open-endedness of the site. The sample is obviously incomplete, as was indicated by the initial skeletal inventory (Stevens 2008). Table 5.1 presents total counts by elements tabulated for Adams and Konigsberg's (2004) MNI Statistic, discussed later in this chapter. The discrepancy in number of elements by side indicates many individuals are only partially-represented among the skeletal sample. Archaeological evidence from 38GE81 also suggests that house construction intruded or bisected several graves. A hypothetical diagram (Figure 5.2) provides a suggestion of the type of impact that construction excavation likely had at St. Mary's Chapel Cemetery. Figure 5.3 provides the best evidence of construction impact to grave shafts. This photograph shows the southeast wall of the house foundation trench with either transverse sectioning of multiple, closely situated graves, or a longitudinal section of a single grave. The photographic evidence is not perfectly clear, and unfortunately, little more was available to reveal context due to the impact of construction excavation.

Byrd and LeGarde (2014) refer to similar contexts involving incomplete skeletons as lacking "epistemic closure" due to the unknowns surrounding completeness of recovery and original sample composition. Similar scenarios plague archaeologists and forensic scientists in contexts where the initial number of individuals, skeletons, and/or victims (in a mass disaster scenario) is unknown. Obviously, the possibility of resolution in these scenarios, via statistical probability, is greatly hampered, if not made impossible due to lack of "epistemic closure". Given that the present study is a relatively small-scale archaeological context, in which mostly intact skeletal elements were recovered, however, some of these problems may be overcome via application of appropriate methods.

Considering the aforementioned circumstances and challenges, the following approach to commingling at Hagley Plantation is presented as a step-wise process which includes testable hypotheses regarding the commingling context within the group. The present study does not undertake validity testing of XRF methods on human bone or set stringent goals for quantification of elemental readings due to known problems with quantification described by other researchers (Byrnes et al. 2010; Little et al. 2014). This effort seeks to determine the utility, within this archaeological context for sorting the sample using spectral comparison and relative values of selected elements by XRF. Given the limitations imposed by the lack of proper archaeological recovery and the lack of availability of appropriate soil samples, this study will make only limited assessment of the effects or extent of diagenetic processes at Hagley Plantation. Preliminary success at sorting buried commingled remains using pXRF (Gonzales Rodrigues and Fowler 2013; Perrone et al. 2014), however, provides sufficient justification for the use of this technique, especially in conjunction with other established methods.

Given the context of disturbance, the degree of incompleteness, and the varied preservation of the skeletal remains at Hagley Plantation, and the need to reassociate these skeletons to as complete a degree as possible in order to control for parameters necessary within a comparative biomechanical study, this study will develop a multi-method, multi-phase approach to the resolution of commingling based on the following expectations. These expectations will be tested during the sorting process and evaluated individually in the results and discussion sections.

Expectations for Basis of Skeletal Reassociation at Hagley Plantation

1) <u>Number of Individuals</u>

The measure of "most likely number of individuals" (MLNI) will be the best original population estimator for Hagley Plantation due to issues of preservation and incompleteness presumably resulting from manner of disturbance and recovery. Comparison of the end result of achieved associations to MLNI will permit a statement on the degree of success and taphonomic processes operating in this commingling scenario.

2) <u>Formal and Informal Osteometric Sorting Methods</u>

Formal metric methods will be severely hampered in their ability to sort individuals at Hagley Plantation and are excluded from application to this study due to the following factors. Many similarly-sized individuals are in the sample, probably due to familial relatedness and or nutritional factors. Rathbun and Steckel (2002) report South Carolina enslaved groups were among the shortest in stature among all New World preindustrial populations. It is possible that malnutrition resulted in stunted growth within the sample, reducing variation in adult stature. Damage to epiphyses is also widespread throughout the sample, precluding the ability to measure many landmarks required for formal osteometric sorting. Additionally, upper limbs are less well preserved within the sample, inhibiting the ability to measure them for reassociation purposes. The most effective means of linking lower and upper limbs within individuals will come from the combined use of morphological, elemental, developmental, pathological, and taphonomic variables, as well as the assessment of articulation and process of elimination.

3) Morphological

Morphological pair-matching should facilitate association of pairs of upper and lower limb bones which can then be used as known associations for the basis of testing confidence of the elemental similarities within bones of the same individual, in the manner suggested by Perrone et al. (2014). Pair matches can also serve as a base for testing articulation and processes of elimination.

4) Articulation

Assessment of consistent articulation of skeletal elements should prove useful for association of unlike elements and for elimination of incorrect associations provided that the associations are considered simultaneously with XRF data, taphonomy, and pathology.

5) **Pathology**

Skeletal pathology should in some cases serve as a means for determining associations via articulation and pair matching. Compensatory pathology in adjacent or articulating bones as well severe or outstanding osteoarthritic pathology within the group may aid the process of reassociation. Osteopenia or osteoporosis resulting in reduced bone mineral density (BMD) and resultant lighter weight may also assist in pair matching and inter-element matching.

6) **Developmental Age**

Observations of developmental age such as epiphyseal union stage will prove useful in establishing pair matches, and possibly in associating unlike elements.

7) **Taphonomy**

Unique appearance or condition resulting from differential taphonomic process, when considered cautiously in conjunction with other methods, within the sample should facilitate the process of reassociation. Preliminary inventory shows variation in bone texture, degree of weathering, and coloration, with distinct apparent individuals, presumably caused by microenvironmental conditions within the cemetery, burial treatment and associated artifacts, depth of burial, and other possible factors. Additionally, taphonomic damage induced by human action during the disturbance of these remains may aid reassociation in cases of overlapping or contiguous postmortem damage to bones within individual burials.

8) <u>Elemental Analysis via pXRF</u>

A) Elemental spectral analysis of a selected sample of the Hagley Plantation skeletal remains via pXRF will provide an effective method of sorting commingled bones at Hagley Plantation. Elemental differences reflecting biogenic elemental variation will provide the means of reassociating individuals. These differences should reflect occupational exposure, geographic origin, and possible dietary differences among individuals. Alternatively, elemental differences between individuals may reflect taphonomic processes brought about by differing geology or hydrology within the cemetery and/or differences in burial treatment or burial environment. Confidence tests for discrimination potential of elements and elemental ratios based on high-confidence morphological pair matches will provide the basis for the elemental comparison for assessment of associations.

B) Elemental spectral analysis of the Hagley sample will fail or lose efficacy due to the influence of the burial environment on the bones. This can be assessed to a degree since XRF analysis provides a means to make a limited semi-quantitative analytical statement about the effect of preservation on biogenic elemental concentrations by testing elemental concentrations between bones of varying conditions of preservation and considering elemental content of cemetery soil samples. Additionally, it is suspected that elements such as Fe and Cu should be considered with caution for their ability to distinguish between individuals.

Examination of the 38GE81 skeletal sample during inventory reveals localized metallic staining, both green and brown in color, suggesting that metallic grave artifacts may influence skeletal elemental content. Alternatively, grave inclusions may lead to the identification of outlying individuals.

C) XRF analysis may fail to prove a good segregator based on elemental readings due to individual similarities and overlap between elemental signatures of individuals arising due to the size of the sample and similarities in dietary and other elemental signatures.

Materials and Methods for Commingling

The reassociation process at 38GE81 followed protocols described by Byrd and Adams (2003) and Snow (1948). Lower limb bones were selected as the starting point in order to establish high confidence morphological pair matches to serve as the basis for elemental testing via pXRF. Femora and tibiae within the sample were chosen due to better preservation when compared to other skeletal elements. These bones represented the best subset for measurement and completeness of landmarks useful for morphological pair-matching. The remains were sorted by element and arranged by side and size (i.e. maximum length for long bones where possible and overall robusticity) following established techniques (Byrd and Adams 2003; Snow 1948). Most pair matches of elements were derived at this point, considering such factors as epiphyseal fusion and developmental phase. Sex was estimated for each assembled lower limb individual based on sectioning points for maximum femoral head diameter (Condon et al. 1998:33).

Sex estimation for tibia pairs which lacked association with femora was made using a sectioning point for proximal epiphysis breadth for African Americans (Symes and Jantz (1983).

Gross morphological comparison coupled with developmental and taphonomic observations permitted the establishment of seven pairs of femora. Similar criteria were next used to establish ten sets of paired tibiae. These paired elements were then compared to each other using the same criteria with articulation added for fit testing and elimination. The established test group of lower limb individuals (n=15) are presented in Figure 5.5.

In the next step, a sample of limb bones (n=138) was assembled to include all intact bones including those that were potentially eligible for inclusion in the biomechanical cross-sectional geometry study based on preservation of anatomical locations required for the CT scans. Sample breakdown by element follows: humerus (n=28), radius (n=13), ulna (n=13), femur (n=38), tibia (n=38), and fibula (n=9). Crania, flat bones, and irregular bones were not scanned due to their lack of relevance to the CSG study. Depending on the success of the initial study, the option for scanning additional bones was left open. Portable XRF analysis of the Hagley Plantation skeletal sample was conducted at the Warren-Lasch Conservation Center, Clemson University on June 5, July 2, October 9, October 16^{th} and 17^{th}, 2013 and January 9^{th} and 10^{th}, 2014 under the direction of Dr. Stephanie Crette, who facilitated the analysis and served as PI for the project.

The Hagley Plantation skeletal sample was analyzed using a handheld Bruker Tracer III SD pXRF unit (Figure 5.4). Elements of choice for the Hagley study include

As, Ba, Ca, Cu, Fe, P, Pb, Sr, Zn, and Zr, but all detected elements were considered in order to reveal potential unanticipated individualizing elemental signatures. These core elements were chosen for their likely potential to reflect elemental differences between individuals based on paleodietary differences, occupational exposure, and possible diagenetic influence of the burial environment.

The Bruker Tracer III SD was used in conjunction with a vacuum pump attachment study in order to minimize the effects of X-ray absorption caused by air gaps between the analyte surface and the instrument's aperture, as well as to permit more precise measurement of lighter elements as recommended by Shackley (2011:30). Cortical bone was chosen for scanning due to its regularity of structure and more predictable remodeling pattern compared to trabecular bone (Vass et al. 2005). The lack of a consistent smooth surface in trabecular bone may hinder spectral data readings by pXRF (Byrnes 2010). All bones were scanned at the midshaft which has been found to be the area of greatest bone mineral density (BMD) in several studies (Galloway et al. 1997; Kendell and Willey 2014) and is likely a good standard location for comparisons for elemental data collection (Fulton et al. 1986; Grupe 1988). The flattest portion of the midshaft of most elements was chosen as the location for scanning. This permitted an area of compact cortical bone from most intact bones to be placed on the aperture of the XRF unit with effort made to cover the entire lens.

Samples were prepared first by dry brushing and rinsing with distilled water at the location of scanning. The XRF unit was used with a vacuum attachment in 'Lab Rat' mode with voltage setting at 40kV and current at 15 uA. Each bone was scanned three times at 300 seconds with slight movement (approximately 1-3 mm side to side) in between scans. An average of the three readings was used for analysis purposes. In order to test sample homogeneity for elemental analysis, as recommended by Ubelaker (2002), powdered samples of bone were obtained by drilling with a Dremel brand tool using a carbide bit from the elemental sampling site on three bones (G199, G189, and G197). The powdered bone samples were analyzed on the XRF unit for comparison with dry bone readings. The results of comparison of these powdered samples to the bone surface readings will be discussed in the results section.

Spectral data for the elemental scans in the form of PDZ files were imported into Tracer Artax software and then exported to Microsoft Excel for sorting and analysis. Spectral readings were quantified using the preset bone method within the program Artax. Averages, minimums, maximums, and standard deviations were derived for each elemental reading per bone. A soil sample for comparative analytical purposes including the assessment of soil composition and diagenesis was obtained on July 2, 2013 at 10:00 am by soil coring of an area of apparent undisturbed ground with intact topsoil and subsoil approximately 40 meters southwest of the presumed borders of St. Mary's Chapel cemetery at Old Waccamaw Drive and Barnwell Court. This sample was scanned six times via the pXRF using the green filter with no vacuum and voltage setting 40kV and current 15 uA. I also examined the samples under varying magnifications using a Leica MZ95 stereomicroscope to determine composition of the soil. The soil contained mica, sulphur, and various other inclusions, probably relating to coastal shell marl formations.

This study derives an analytical method of data mining derived from models discussed by Glascock (2011) in order to determine the best elemental criteria for sorting commingled remains. Glascock and others employ these techniques to determine which elements or groups of elements best serve to differentiate materials within archaeological contexts (Glascock 2011, Jia et al. 2010; Liritzis and Zacharias 2011; McAlister 2011).

Gonzales Rodriguez and Fowler (2013) demonstrated success at discriminating between buried individuals in a small-scale archaeological context. Perrone et al. (2014) created a simulated commingling scenario based on a test case of mixed surface exposed, donated and macerated, and buried skeletons (n=20). Although their study is likely to have achieved good success partially in light of the differential taphonomic histories of these skeletons, their method provides a good model for this study in the assessment of interskeletal elemental concentrations. Additionally, they found minimal intraskeletal variation in elemental concentrations. The present study borrows and modifies their technique for the application of 95 percent confidence intervals to the assessment of elemental concentration differences between individuals in order to identify "the chemical elements that [show] the greatest discrimination between individuals" based on the smallest degree of overlap in elemental signatures (Perrone et al. 2014:154). These authors created a simulation of commingling from discrete skeletons, but stated that their method could be applied to an actual commingling scenario by employing elemental concentration measures from bones "clearly associated with the same individual" in order to create confidence intervals for testing associations (i.e. partial skeletons within a mixed assemblage) (Perrone et al. 2014:154).

My study uses this method to derive confidence intervals for each element within a test set of partial individuals (N=15) derived from high confidence morphological pair matching and other techniques, for the purpose of determining the elements or elemental ratios that best serve to differentiate individuals within the Hagley Plantation skeletal sample. I created 95% confidence intervals for each element and elemental ratio based on the standard error of the mean (SEM) for the elemental concentration within each test individual. Line or whisker plots with means were then created for each individual's confidence interval by element in order to assess elemental overlap and resultant failure rates and separating the 15 individuals. Failure rates for discrimination between individuals were calculated based on degree of elemental overlap or the number of test individuals that could be successfully separated based each element. Figure 5.6 demonstrates the overlap in elemental counts of the two best segregators, elemental ratios Sr/Ca and Sr/Pb. Figure 5.7 shows ratio Zn/Fe to demonstrate an outlying individual, and element Fe to demonstrate a case with a high degree of overlap among individuals. During the process of data mining and exploration of 95% confidence intervals, another individual association was discovered based on consistent articulation and elemental consistency. Individual 16 is a femur to tibia association which was then included in the assessment of clustering via elemental ratios. The results of this process are summarized for the top 25 elements and ratios, in table 5.2. Those with the lowest failure rates (Sr/Ca and Sr/Pb) were selected as the best potential discriminators for sorting commingling.

Due to the complexity involved in elemental analysis of archaeological materials, especially bone, assessment of groupings in elemental analyses is often just as effectively accomplished with methods of visual representation as with complex multivariate statistical tests. Researchers involved in archaeological material studies variously recommend visual comparison of spectral shape via overlay (Kotula and Rodriguez 2012; Liritzis and Zacharias 2014), or via scatterplots or simple bivariate plots (Glascock 2011; Johnson 2011; Liritzis and Zacharias 2014). Due to the number of individual bones involved and ease of implementation, this study mainly employs bivariate plots of Sr/Ca versus Sr/Pb in order to assess groupings of bones and individuals in relation to each other. Figures 5.8 and 5.9 present elemental clustering of the test individuals separated by sex using Sr/Ca against Sr/Pb. Other elemental combinations were considered and plotted against these ratios exhaustively in order to determine their potential for sorting. During this process, the ratios Sr/Ca versus Hg/Ca were also found to cluster well within the lower limbs of individuals but were not as effective for sorting as Sr/Ca and Sr/Pb.

I used decision tables such as Table 5.3 in order to test and demonstrate associations and make eliminations of inconsistent associations. The criteria considered in the tables included XRF elemental readings, developmental age phase (fusion of epiphyses), pathology, articulation, taphonomy, bone density/weight, morphology, relative robusticity, and gross size comparison. Figure 5.10 presents a flow-chart style representation of the phases of sorting using these comparisons and considerations. During Phase V of the sorting process represented in Figure 5.10, the attempted association of upper and lower limbs, the method lost strength due to increased complexity and inconsistent clustering. At this phase, I decided to use elemental measures based on spectral comparison to attempt to link upper limbs with lower limb associations based on elemental outliers. These association efforts were undertaken by using decision tables to generate candidates (Tables 5.4 and 5.5) which were derived from comparison of outlying elemental peaks derived from mean measures within associated lower limb individuals to similar outliers from the pool of upper limb bones (humerus, radius, and ulna). Figures 5.11 and 5.12 demonstrate these spectral comparisons for two elements, As and Cu.

Results

The combined-method reassociation protocol at 38GE81 resulted in the reassociation of 18 partial individuals (Figure 5.13) consisting of upper and lower limb bones by using established commingling approaches in combination with pXRF elemental analysis for purposes of corroboration of pair matches and generation of possible matches and associations based on elemental similarities. This study utilized pXRF in order to augment the potential of matching different skeletal elements by providing an additional scientific/archaeometric tool in order to reduce subjectivity of inter-element matches. Thus, inter-element association had to withstand both morphological and articulation consistency, as well as demonstrate similar and consistent elemental spectral readings. The process of elimination was on-going during this phase and elements with no likely pair were set aside for factoring in the overall individual or MNI estimates. The following section addresses the previously listed expectations in order in a succinct manner. More detailed discussion then follows this section, focusing in more detail on the results of the pXRF analysis.

Expectation 1. The reassociated sample consists of 18 partial adult skeletons. The composition of this sample is presented by element in Chapter 7 (Tables 7.2 and 7.3) in the materials and methods section for the CSG study. Simple MNI, or "Max (L, R)" method (Adams and Konigsberg 2004) derived from 38GE81's biomechanically-relevant sample (juveniles are excluded), is 22 based on the right femur. Amplified MNI is based on the resolved 18 individuals plus the largest number of repeated element incorporated in the established sample that can be excluded from belonging to it based on elimination.

This modification also equals 22 based on the number of repeated right femora. Long bones are prioritized over *os coxae* in the preceding determination at 38GE81 as they could more confidently be associated as pair matches or unassociated bones, mainly owing to preservation. The number of unassociated *os coxae* per side cannot be excluded from belonging within the sample, because articulation assessment was inhibited by taphonomic factors. MNI, MLNI, and recovery probability (r) for 38FE81 were presented in Table 5.1 which applies Adams and Konigsberg's (2004) MNI statistical calculation to the sample.

The fact that the reassociated sample (n=22) falls beneath values for MNI (L+R-P statistical method) and for MLNI suggests the effects of data loss due to recovery and preservation biases are operative at 38GE81. Confident pair-matching was achieved, but recovery bias and preservation likely led to the observed discrepancies between the assembled sample and population estimators MNI and MLNI. The low r value for *os coxae* (0.26087) reflects preservation biases that prohibited pair matching, whereas the humerus r value (0.695652) reflects a more complete recovery of anatomical individuals from a component of the cemetery. Comparing r values across elements, it is likely that the discrepancies may reflect the partial disturbance of some graves, especially since one of the largest elements (femora) has among the lower r probability values, suggesting that recovery bias is not the only operative factor. Some portions of individual graves may remain undisturbed at 38GE81, thus not contributing to the skeletal sample. Data loss is clear, but MLNI as demonstrated by Adams and Konigsberg (2004) likely provides the best overall estimate for the initial population at Hagley Plantation. It is unfortunate that non-destructive survey via ground penetrating radar or other technique was not possible in this study, as it may have provided another means of ascertaining both cemetery size and information on the number of partially-disturbed graves.

Expectation 2. Formal osteometric sorting methods were excluded from the reassociation process due to concerns about preservation, similar size of individuals within the sample, and incompleteness of the sample. Gross size comparisons proved effective within the establishment of pair matches of long bones via morphological comparisons.

Expectation 3. Morphological pair-matching proved effective for establishing testable associations for corroboration with pXRF and use in the generation of other possible associations. Pair matching was most successful within the lower limb bones and lost efficacy when smaller elements (i.e. the radius and ulna) were considered. Morphological pair-matches were made among femora (N=8 pairs), tibiae (N=9 pairs), humeri (N=9 pairs), radii (N=1 pair) , and ulnae (N=3 pairs) and innominates (N=3 pairs).

Expectation 4. The assessment of articulation proved most effective for the assessment of associations and elimination of associations between femur and tibia, and between femora and acetabulum in several cases. This is consistent with published opinions regarding the efficacy of articulation among skeletal elements within commingled context (Salado Puerto et al. 2014). The reliability of these associations in this context was enhanced by consideration of joint modification or pathology and in some instances, adjacent or contiguous taphonomic changes.

Expectation 5. The presence of skeletal pathology as well as general degree of degenerative change played a role, as previously mentioned in assessing consistency of articulations, most frequently in assessing the femur and tibia articulation. During the sorting process, I developed a general familiarity with the sample and used degree of expression or presence/absence of marginal osteophyte formation and adjoining areas of eburnation as a factor for the assessment of consistency of articulation in a small number of cases (n=4). Cheverko (2013) recently demonstrated the potential of similarity of degenerative change as a means of reassociation in commingled contexts. Additionally, several individuals (3, 8, and 12) displayed abnormally lightweight bones and clear loss of bone density not related to surface taphonomic change. These individuals' bones displayed age-related degenerative changes such as osteoarthritis and musculoskeletal stress markers, permitting them to be pair-matched when possible and eliminated from consideration with more dense, younger or healthier-appearing bones.

Expectation 6. Developmental Age assessment proved successful for pair-matching and elimination due to the presence of unfused epiphyses and the presence of incomplete fusion of epiphyses in one individual (14) and within the commingled portion of the sample, allowing them to be removed from consideration from other skeletally mature individuals.

Expectation 7. Taphonomy served to facilitate several associations when considered with caution. Individual 6 will be discussed in more detail in the following section, but was distinct from other skeletal elements due to a gray surface appearance. Taphonomic alteration for this individual was corroborated by similarly consistent elemental outlier status via pXRF analysis. Several other individuals (1, 6, 8, 10, and 13) presented unique taphonomic staining which, when considered in conjunction with other methods, was considered grounds for association. Additionally, in several cases, overlapping excavation damage aided the association of femur heads to *os coxae* via articulation.

Expectation 8. Elemental analysis via pXRF for the purpose of reassociation in a combined method approach served well for corroborating and generating potential pair matches and associations. The method, however, did lose strength during the sorting process. The following section will provide detailed discussion of the success and limitations of the method. Expectations 8A, 8B, and 8C were intended to be competing or alternative hypotheses. The results suggest that the results conform, in part, to each of the three expectations. The method provided a basis for generating effective elemental measures for sorting individuals as proposed in 8A. The best elemental measures for reassociation do appear to be in part biogenic and related to expected individual differences. Elemental ratios have worked better than all raw element counts at 38GE81. These results corroborate the conclusions of similar studies which recommend the use of ratios for the purpose of normalizing data, avoiding instrumental fluctuations, and reducing the effect of chemical background noise in the analysis (Fulton et al. 1986; Gonzales-Rodriguez and Fowler 2013:407.e3).

Probable taphonomic or burial environment influence is also evident in certain cases and served as a means for demonstrating outliers. Simultaneously, as suggested in 8B, the method lost efficacy due to factors that are difficult to sort out completely, but suggest diagenetic influence, and/or possible instrumental variation or setting discrepancies. These most greatly impacted the association of lower limbs with upper limbs. Elemental measures such as Fe and Cu exhibited high rates of overlap, between individuals, conforming to expectations that these elements may be localized in the bone due to the presence of grave goods. Lastly, as proposed in expectation 8C, individual overlap was evident, especially as data sets were increased to consider more associations. Confidence Intervals presented overlap and high failure rates, and bivariate plots illustrated the overlap in individual elemental bone content. For this reason, pXRF was most effective when considered with other variables.

Discussion

The elements that proved to be the most useful for discriminating between individuals conform to expectations based on those found successful in similar studies and within paleodietary research. The process of data mining was successful in locating the probable best discriminators within 38GE81. The findings for CI testing on the test sample (Table 5.2) list the elements or elemental ratios and their respective failure rates at the 95 percent CI level for sorting individuals.

Based on the construction of numerous bivariate plots, those with average failure rates below 60 percent were the ones that served the best to group bones by individual. Those in the range of 60 to 70 percent plus failure rate, however, were informative in other ways. The best discriminators were elemental ratios, conforming to findings presented by other researchers. Ratios are recommended for the purpose of normalizing data, avoiding instrumental fluctuations, and reducing the effect of chemical background noise in the analysis (Fulton et al. 1986; Gonzales-Rodriguez and Fowler 2013:407.e3). The elemental ratio with the lowest failure rate at 38GE81 is Sr/Pb, which was found to be effective by Gonzales-Rodriguez and Fowler (2013). Strontium is likely successful since it demonstrates potential differences due to diet and origin (Beard and Johnson 2000; Gonzales Rodriguez and Fowler 2013; Rasmussen et al. 2013). Lead is likely demonstrative of a combination of dietary or occupational exposure as found in related studies (Corruccini et al. 1987a; Rathbun 1987; Shuler and Schroeder 2013). Rathbun (1987) and Crist (1990) linked differential Pb content in bones to use of lead-lined cooking ware and possible alcohol consumption among enslaved men and women from Charleston, SC. Lead findings will be discussed further in Chapter 8.

Diagenesis and Archaeological context

This study assesses diagenesis in three ways in order to gain insight to the potential role of the burial environment on the elemental analysis of the bones and its effect on the ability to reassociate individuals via pXRF analysis. I conducted comparisons of powdered sample versus unmodified cortical surface in a small subsample of bones; secondly, assessed the overall sample in terms of Ca/P ratios; and finally, compared elemental ratios likely to suggest diagenetic influence between subsets of bones based on their stage of preservation.

Three bones (femora G189, G197, and G199) were initially sampled for a powder bone sample as recommended by Ubelaker (2002). This was done in order to determine the validity of readings derived from the cortical surface alone with minimal preparation (i.e. rinsing with distilled water) and to provide insight into diagenetic factors within the sample. Spectra for powdered bone samples were compared in overlay to that of each respective bone for the three test samples. The comparisons for two of these test bones are presented in Figure 5.14.

Mean Ca/P ratios for the powder samples were 4.4391 (SD 0.118) compared to 7.7517 (SD 0.4752) for the whole bone samples. The powdered samples are thus much closer to expected human bone levels, approximately 2.15 (White and Hannus 1983), suggesting that powdering the sample has removed diagenetic contamination from the sample presumably by removing the outer cortex. Additionally, the spectral comparisons suggest that diagenetic Fe and Zn may have been removed by the powdering process.

Femur G189, as noted in the previous section, was a component of Individual 6- an extreme outlier for Zn. The disparity between Zn raw count for powder and bone for G189 suggest that the elevated Zn level for individual 6 are diagenetic in nature.
It cannot be corroborated due to lack of archaeological context and associated artifacts, but it seems likely that Individual 6's grave may have contained brass or bronze grave goods based on the Zn levels. Differential staining on the paired tibia and femora of Individual 6 suggest that this may have been a coffin burial, possibly containing brass hardware. A bivariate plot (Figure 5.15) of Sr/Pb versus Zn/Ca for male lower limbs demonstrates the paired tibia and femora of Individual 6 as a clear outlier.

Despite the potential that powdered bone samples appear to show in terms of making spectral readings more homogenous, I resolved to conduct this study in as minimally destructive a manner as possible as originally intended. The remainder of the XRF sample was not drilled, receiving only surface cleaning. It is unknown whether powdered bone samples would have improved the elemental analysis in terms of potential for discriminating individuals.

Next, I examined Ca/P ratios in the entire scanned sample with hopes that the ratio could be informative regarding diagenesis as suggested by al-Shorman (2010) and Zapata et al. (2006). I first compared all upper limbs' raw elemental count for P (mean=485886, SD=175891) to all lower limbs' measures (mean=845310, SD=141361). Upper and lower limbs displayed significant difference in P values based on two tailed t-tests for unequal variance (F= 1.548. p=0.058, t=-11.38, p=.000). Upper (mean=16.53, SD=4.0) and lower (mean=8.86, SD=1.42) limb Ca/P ratios were also determined to be significantly different (t=12.51, p=.000). Figure 5.16 displays all of the limb bones by element in the sample graphically in a bivariate cluster of Ca to P, clearly illustrating the differential clustering of these measures. Considering this finding and in order to investigate the possibility of failure of the pXRF unit's vacuum attachment, which might have affected the machine's detection of light elements, I chose to examine detection of Si, a lighter element than P. Bivariate plots of Si/Ca did not reveal a similar pattern of distinct and disparate clustering for lower vs. upper limbs. The spectral data for upper limbs, however, fail to reliably detect Al and Mg, compared to the lower limb analysis. A potential issue for consideration other than vacuum failure is the fact that upper elements exhibit smaller surface area in some cases and may have failed to cover the instrumental aperture completely in cases. Air gaps would have been minimized with femur and tibiae due to greater diameter of the elements and flat areas of the bone architecture.

In order to provide insight into further sources of diagenetic influence, I chose to investigate elemental ratios to Ca and P in bones of varying states of preservation. This test also included elemental ratios that showed potential for individual discrimination and diagenetic influence. In order to do this, I chose subsets of bones displaying good preservation of the cortical surface recorded as “Stage 1” (N=21) within published bone weathering standards (Behrensmeyer 1978), and bones displaying severe weathering and exfoliation “Stage 4” to “Stage 5” (N=12). This approach was intended to provide insight into soil influence on the bones via either soil infiltration or chemical alteration of the bone surface. The role and effect of these processes will likely be difficult to distinguish using pXRF instrumentation, but the tests are potentially informative. I compared “Stage 1” elemental readings to those of “Stage 4” using independent t-tests for sample variance. Differences between “Stage 1” and “Stage 4” bones were found to be statistically significant at the 0.05 level for one elemental ratio, Fe/Ca (P= 0.0395) and significant at the 0.1 level for ratios Ca/Pb (P= 0.0593) and Sr/Pb (P= 0.086). Table 4.6 presents p values in summary for these tests. These ratios are represented graphically by stage of preservation in order to demonstrate these trends in box whisker plots for Fe/Ca (Figure 5.17) and for Ca/Pb (Figure 5.18).

Personal communication with the property owners of the former cemetery (2010) revealed that a high volume of fill dirt was placed over the impacted area of the cemetery, presumably brought in from another location. The landowners did not permit soil sample coring on the property due to their opinion that little of the original cemetery ground surface remained exposed. As discussed, my soil sample was obtained from a nearby location with intact topsoil. Relative elemental counts for the obtained soil sample, from which 6 scans were conducted, reveal peaks in Ca, Fe, and Si, with lesser peaks in Mn and Zr (Figure 5.19).

It appears likely, comparing these data to the findings from the previous powder to bone comparisons, that Ca and Fe are elements that have likely influenced the surface of the skeletal remains at 38GE81 due to ionic soil exchange or infiltration.
I was contacted by the landowner in 2015, who requested information from the present study, as possibly informative about her soil, in light of landscaping problems. She stated that an initial soil test that they had performed at the time of construction had been lost by the landscaping company. The original test results were later located (early 2016), revealing that the site's soil was rated "very high" in P (143 lbs./acre) and "high" in Ca (1044 lbs./acre).

A peak for element P was not apparent in the spectral readings for this study's soil sample however it may have not been measured due to the lack of vacuum use for the soil scan. The marine sediment of this area of Georgetown County is characterized by marine shell marl deposits which are rich in Ca carbonate (Cook 1936). Ca and P are thus likely to be present in high concentration within the sediments. The sandy soil of the Hagley Plantation area is Norfolk Sand, a siliceous loamy fine sand composed of well-drained marine sediments (Stuckey 1982:52-53). The A and B horizons of Norfolk Sand range from medium to strong acidity (4.5 to 6.0 pH soil reaction) (Stuckey 1982:95). Based on the soil profile photograph taken at the discovery of the remains, it appears that the burials at 38GE81 were relatively shallow, but probably intruded into the B horizon based on color change and depth (Figure 5.3), making soil acidity a prime factor for consideration within the taphonomic history of the site. The pH of burial soil matrix is an important component for diagenesis assessment as acidic soils are known to dissolve bone (Gilbert 1975; Keeley et al. 1977). Calcium and P may have had ionic exchange into the bone, whereas this study finds evidence that Pb has been lost in term of stage of preservation, and that Fe and Zn appear to have accumulated on bone surfaces from the burial environment as suggested by the powdered sample test.

The taphonomic history of the cemetery is complex, and it may not be possible to determine exactly what factors have led to differential elemental concentrations within the lower and upper bone samples. The fact that individual graves have been bisected, as indicated by the disproportionate representation of elements by side (see Table 5.1) and the differential representation of upper and lower limbs by frequency, suggests that the burials have been impacted by site disturbance. Upper and lower limbs mayalso be representative of different individuals due to the incomplete nature of burial disturbance. Clear grave outlines suggest that burials on the southeastern wall of the house foundation excavation were bisected or cut in transverse or along their north/south axis. As suggested in the archaeological report for 38GE81 (Williams 1979), bulldozing and heavy equipment use may have impacted the site many years prior to the excavation or house construction. There is some evidence for this in the form of white coloration suggesting ultraviolet light exposure on some bones. Other elements had rodent gnawing marks (N=3) indicating surface exposure of these bones. I also received anecdotal reports of bones being found in the yards of adjacent properties by neighbors according to a nearby homeowner.

The soil profile photo provided by Dr. Leader also shows a buried metal pipe protruding from the profile in close proximity to the grave outlines, further suggesting possible site impact prior to the house construction. The possibility of differential impact and disturbance of portions of the cemetery over time may account for variations in diagenetic trajectories and for elemental concentrations within the bones. Upper bones appear, on the whole to be less well preserved cortically than lower bones, and were less frequently recovered during the site disturbance in terms of percentage of the sample by element.

Considering the findings of Castro et al. (2010) reviewed in the preceding chapter, this study has reached a similar conclusion regarding elemental distribution within upper and lower limbs. Although this study uses a different technique, which is only semi-quantitative, the inability to reliably associate upper to lower limbs is born out. They attributed the finding as likely due to differential elemental storage within different bones. Based on the lack of any obvious instrumental setting variation in the present study, and in consideration of the suggested effects of diagenesis at Hagley Plantation, this study draws a similar conclusion about the likelihood that elemental distribution may be different between the upper and limb bones. It is unfortunate that the skeletal sample was not more complete in terms of the representation of elements besides long bones, as the presence more of the axial skeleton might have permitted the assessment of articulation and taphonomy among intermediate skeletal elements.

Conclusion

It is evident based on the successes and failures of this commingling approach, that this type of combined method approach will have success by degree and within context, depending on numerous factors of taphonomy, site impact and excavation, completeness of recovery, soil characteristics, length of interment and many other factors. XRF served well in conjunction with morphological and other established techniques to generate possible associations and corroborate pair-matches of like elements. It is apparent that biogenic elemental signatures are preserved within the best segregating elements and ratios, as the findings of this study are similar to those of others. The method proved to be of limited utility in making confident associations between lower and upper limbs. The process of data mining was useful in demonstrating elemental signatures and their relative success rates at individual segregation, but was hampered by increasing complexity due to elemental overlap between bones and individuals when larger samples were considered. Problems inherent to the analysis of human bone, especially buried bone, include lack of homogeneity of the bone matrix, influence of the burial environmental and diagenetic factors, and lack of analytical standards as described by other researchers (Byrnes et al. 2010; Little et al. 2014) are borne out in this study. Statistical problems for Hagley remains are presented by the manner of recovery. The presence of probable complete individuals as well as probable partial individuals hinders statistical comparisons and levels of certainty of associations.

The classification rates and strengths of association established in this study would obviously not meet the criteria for standards and error rates within a forensic or medicolegal context, but, nonetheless, they were of utility within this small to medium scale bioarchaeological study. The ongoing process of data mining via assessment of bivariate clustering of individuals was also successful in making unanticipated findings such as outlying individuals and inter-individual differences in unexpected elements such as Hg and Zn. These findings will be discussed further in Chapter 8. In conclusion, the results of the sorting process employed here permit the use of the Hagley Plantation skeletal sample in a comparative biomechanical CSG study with Newton, provided that appropriate controls and units of analysis are selected in consideration of the partial resolution of the sample. The resulting skeletal sample will facilitate the determination of many of the required parameters for the CSG study such as estimation of body size for individuals and size standardization of limb bones for CSG properties. It will also prevent duplicate measures of individuals within the sample. Chapter 7 presents the sample in table form, arranged for biomechanical comparison.

Figure 5.1 Skeletal Sample from 38GE81.

Table 5.1 Tabulation of Skeletal Element from 38GE81 for Adams and Konigsberg (2004) MLNI Statistic.

	Tibia	Os Coxa	Humerus	Femur	Overall
Left	14	9	11	14	48
Right	15	14	12	18	59
Paired	9	3	8	8	28
MNI	20	20	15	24	24
MLNI	23	36	16	30	26
r	0.62069	0.26087	0.695652	0.5	0.52336449
s.e.[r]	0.10582	0.120746	0.109576	0.108253	0.05867324

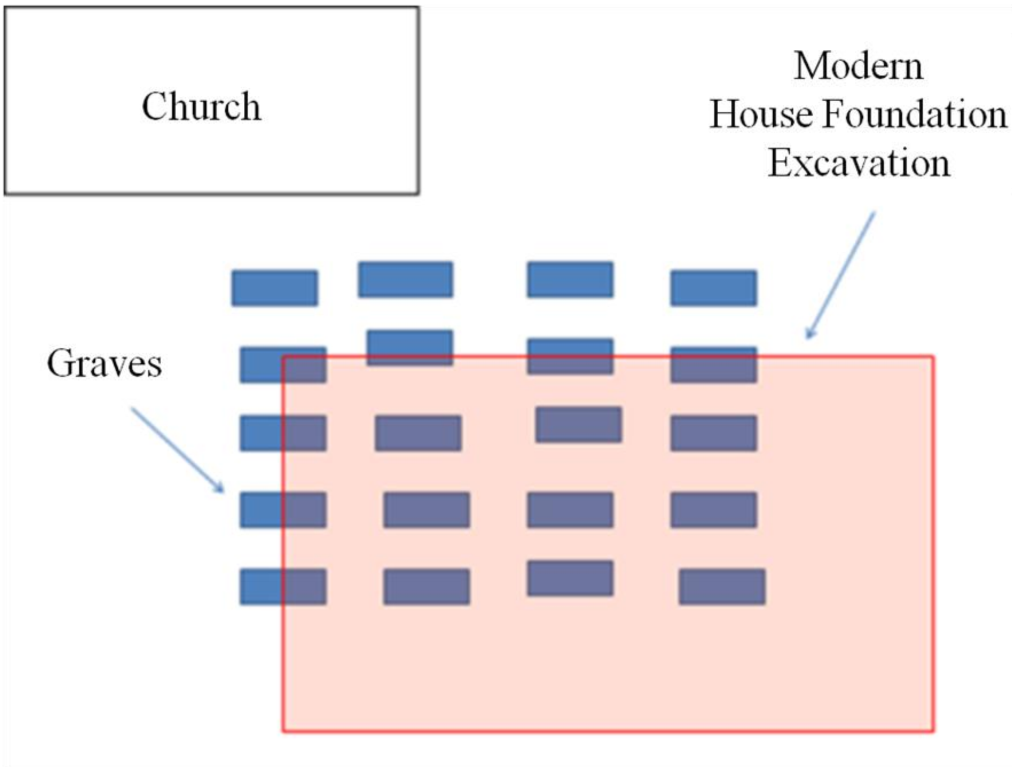


Figure 5.2 Hypothetical Diagram of Construction Impact to St. Mary's Chapel Cemetery Demonstrating Grave Disturbance and Possible Bisection.

Figure 5.3 Intrusion or Bisection of Graves at St. Mary’s Chapel Cemetery.

Figure 5.4 Scanning of 38GE81 Sample Using pXRF at Warren-Lasch Conservation Laboratory.

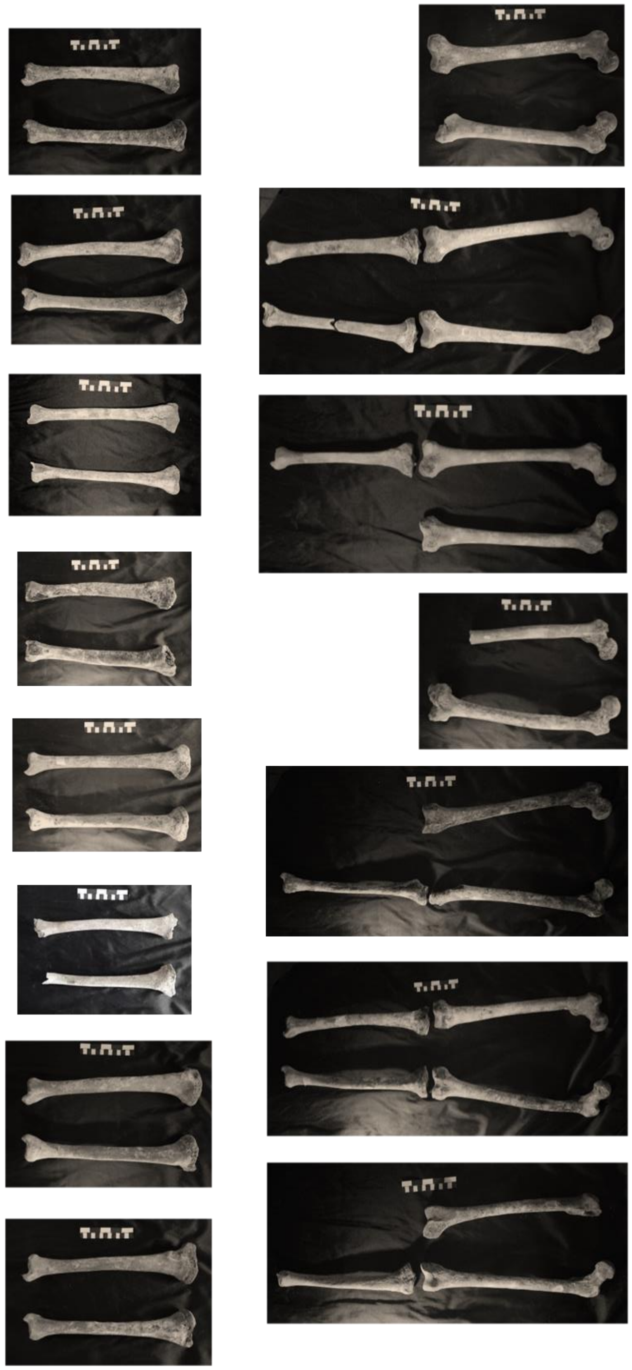


Figure 5.5 Test individuals (n=15) Based on Morphological Pair Matching at 38GE81.

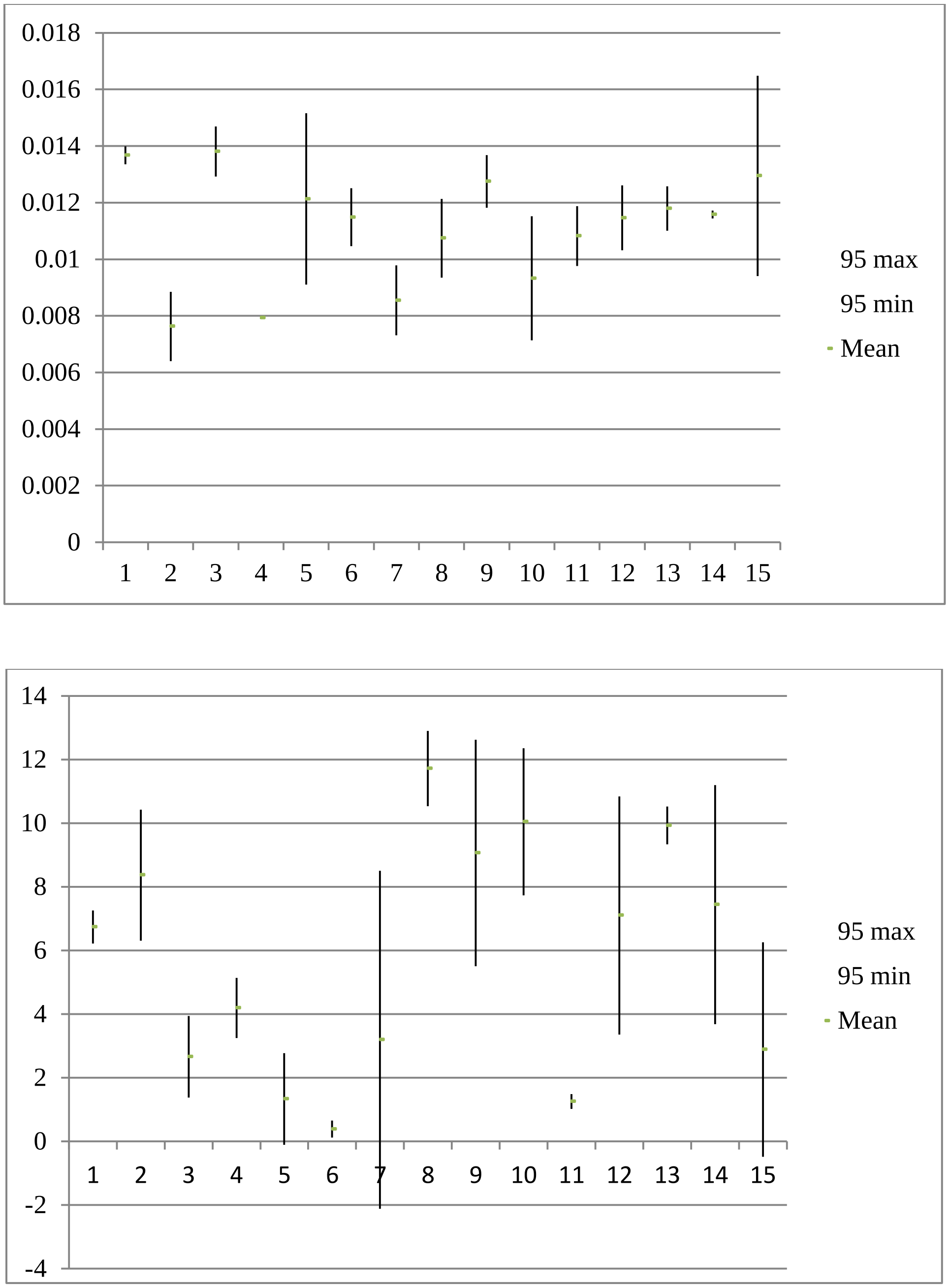
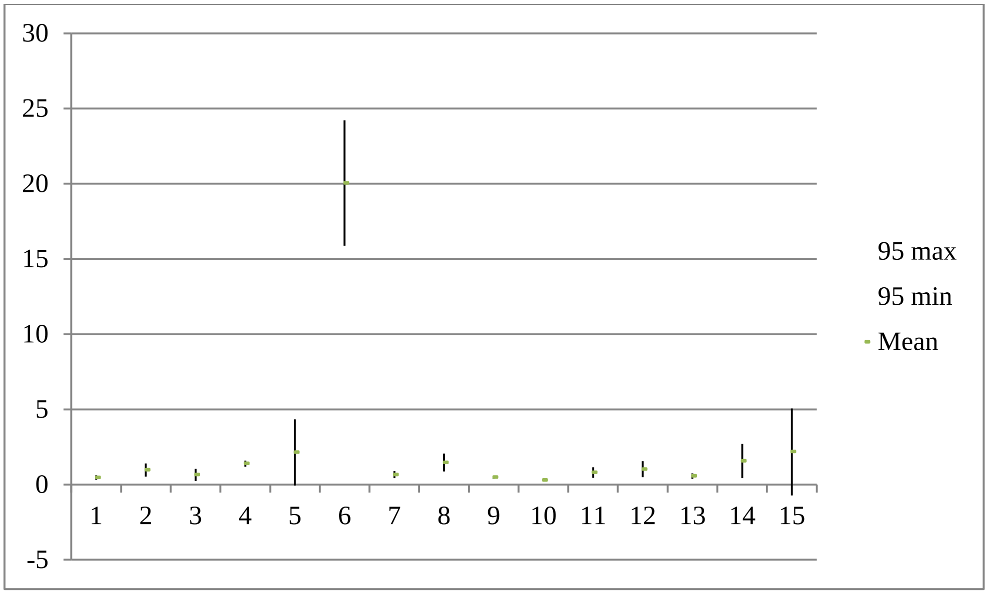


Figure 5.6 Line Plots of 95% CI's for Best Elemental Ratios, Sr/Ca (Top) and Sr/Pb (Bottom).



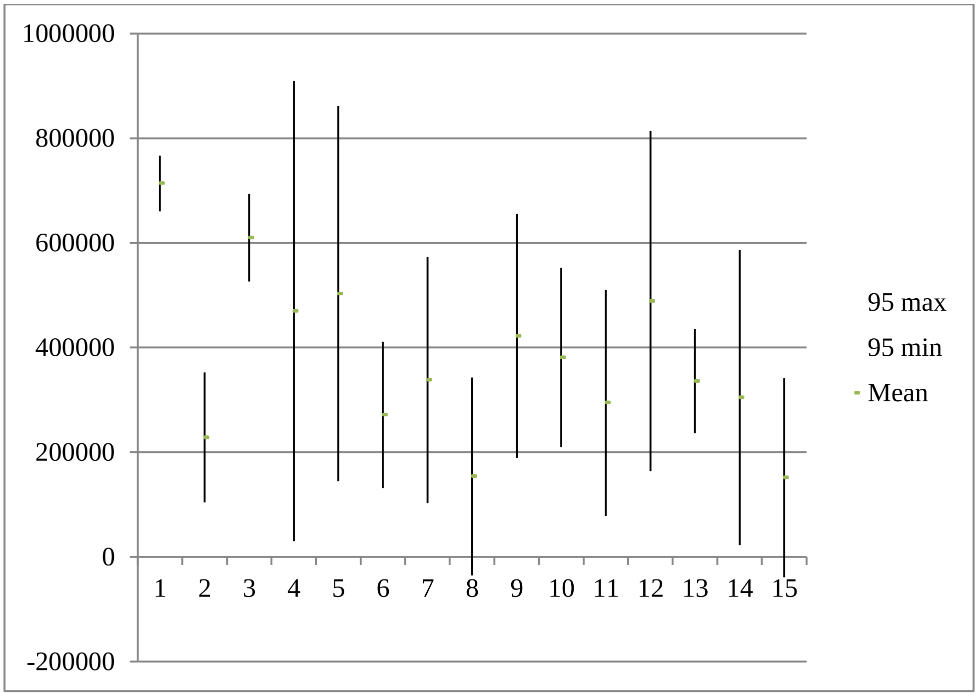


Figure 5.7 Line Plots of 95% CI's for Elemental Ratios, Zn/Fe (Top) and element Fe (Bottom).

Table 5.2 Elemental Failure Rates for Individual Segregation Based on 95% CI's at 38GE81.

Element/Ratio	Avg. Failure Rate
Sr/Pb	49.53
Sr/Ca	55.71
Sr	57.13
Zr	60.96
Pt	62.85
Pb	63.83
Pd	64.36
Yb	64.76
Hg/P	66.57
Zn	66.66
Sn K12	67.43
Ag	67.5
S	67.89
Cu	70.01
Hg/Ca	72.14
Au	72.85
Hg	72.85
Ce	73.33
Sr/P	73.81
Rh K12	73.81
Rh L1	73.82
Ni	75.24
Ca	75.72
Sn L1	78.48
Sb L1	79.05
P	80.48
Si	81.42
Se	81.91
Fe	84.77
Ba	85.73
Co	87.61
Ir	91.44
Sb K12	95.24

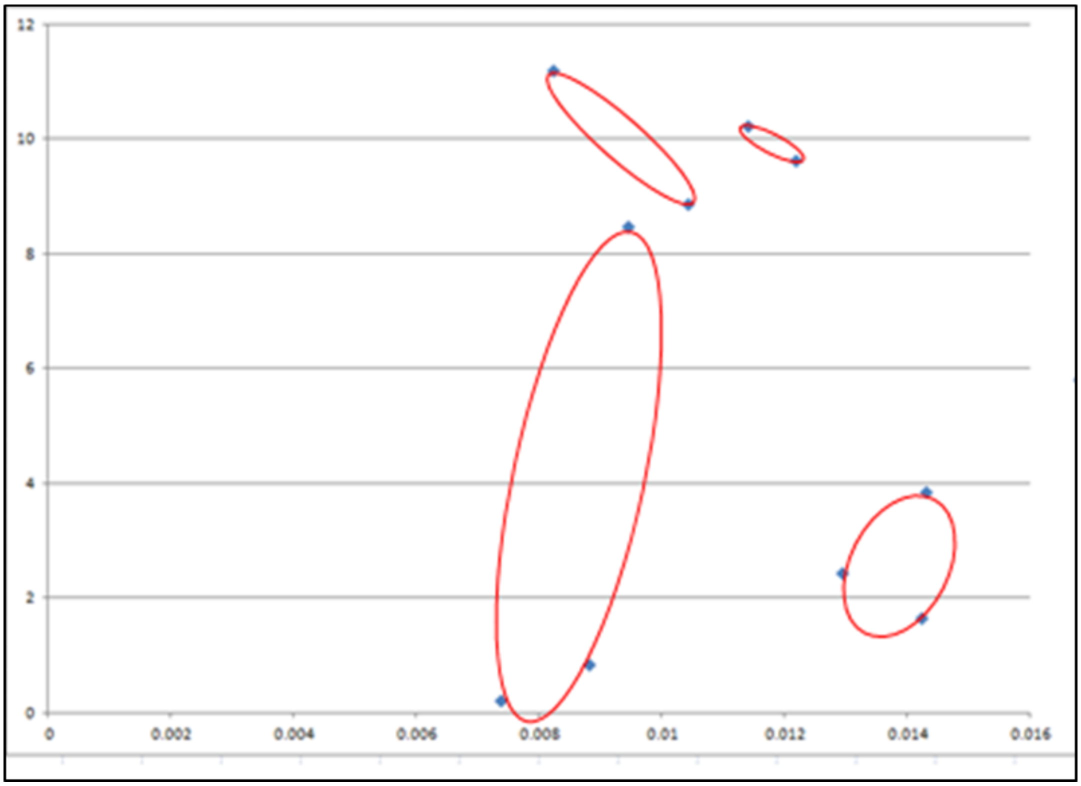


Figure 5.8 Clustering of Bivariate Plots of Ratios Sr/Pb Versus Sr/Ca for Female Test Individuals at 38GE81.

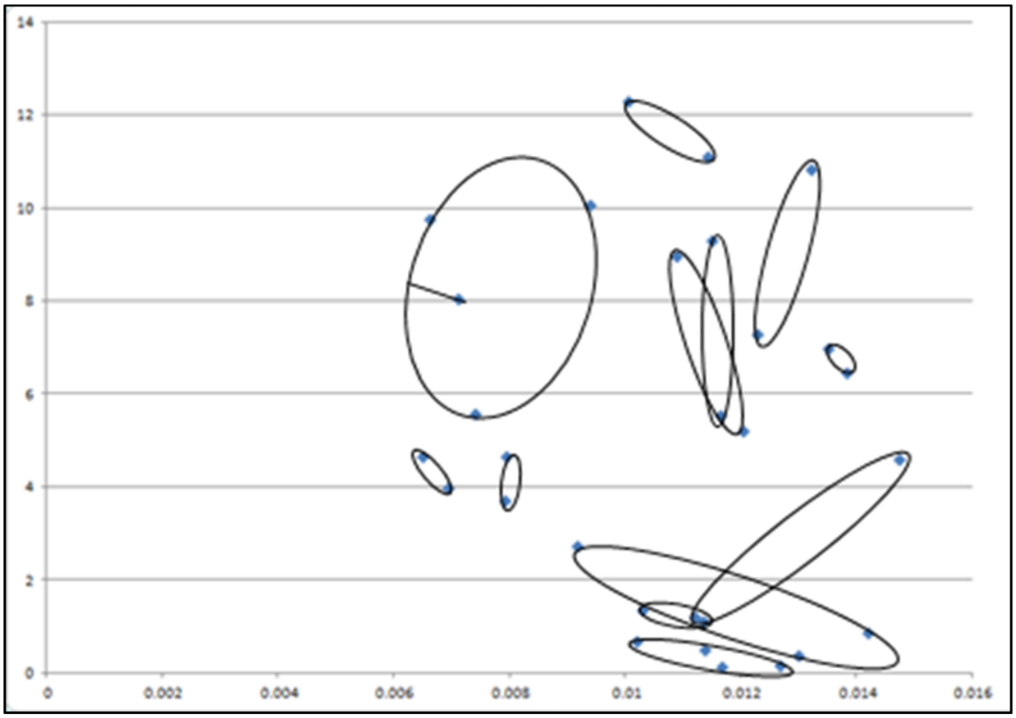


Figure 5.9 Clustering of Bivariate Plots of Ratios Sr/Pb Versus Sr/Ca for Male Test Individuals at 38GE81.

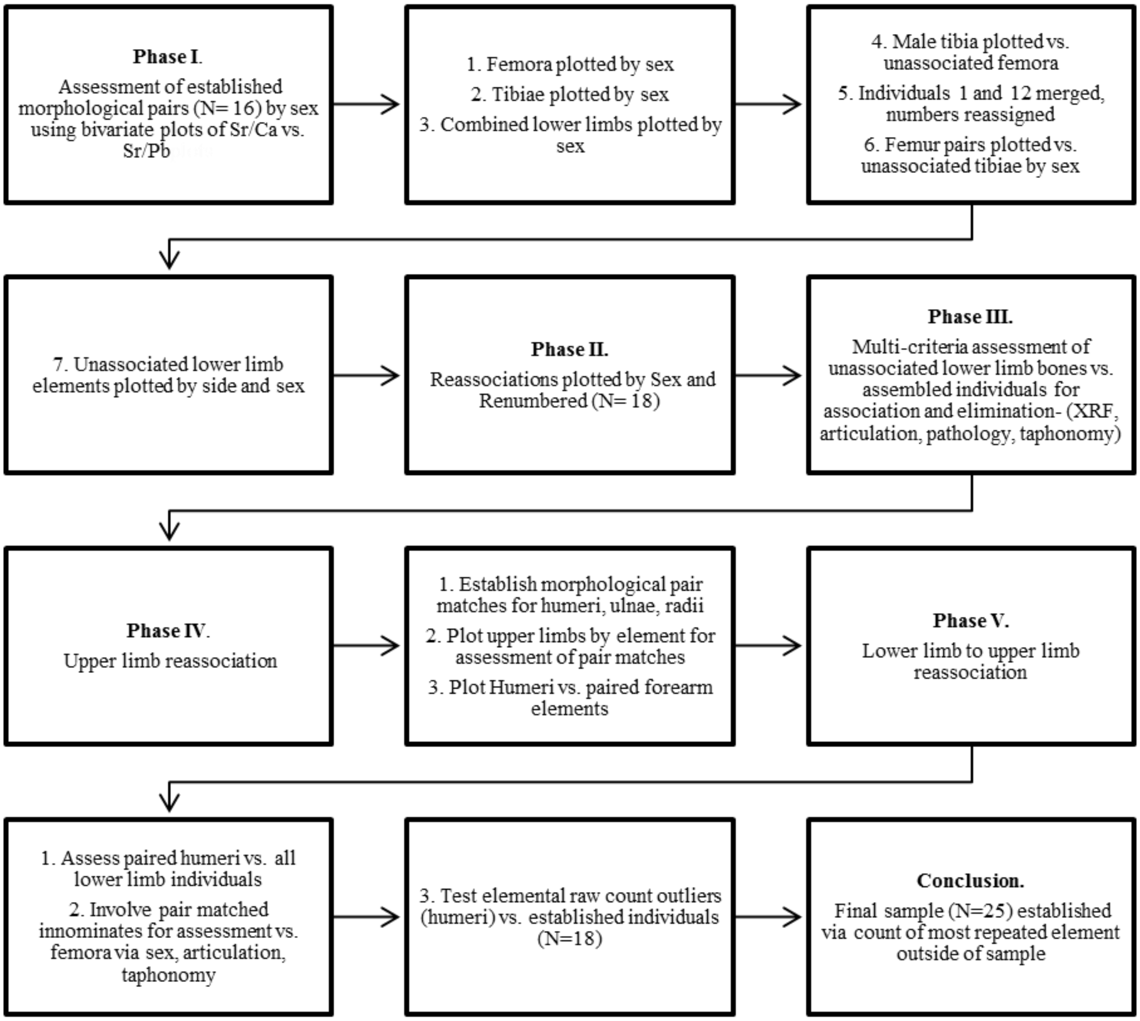


Figure 5.10 Phases of Sorting and Reaassociation at 38GE81

Table 5.3 Phase V. Decision table for Comparison of Paired Humeri vs. Individuals

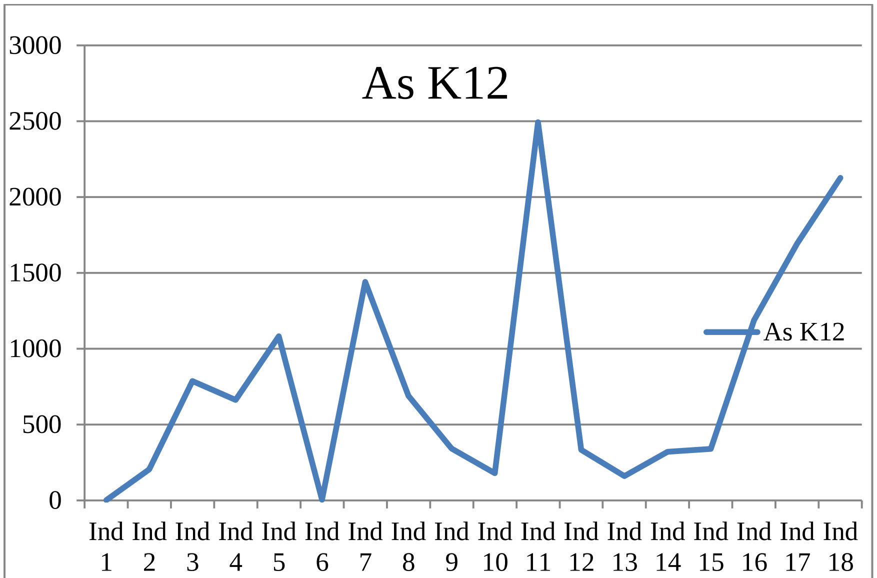
Individual	319/118	126/112	135/317	131/120	121/110	123/119	125/114	116/111	320/122
1	elimination unique taph.	elimination unique taph.	elimination unique taph.	elimination unique taph.	elimination - sex estimate	elimination - sex estimate	elimination unique taph.	elimination - sex estimate	elimination - sex estimate
2	no convincing association	no convincing association	no convincing association	candidate XRF and taphonomy	elimination - sex estimate	elimination - sex estimate	candidate XRF and taphonomy	elimination - sex estimate	elimination - sex estimate
3	elimination - sex estimate	elimination - sex estimate	elimination - sex estimate	elimination - sex estimate	eliminate bone density/taph	eliminate bone density/taph	elimination - sex estimate	eliminate bone density/taph	eliminate bone density/taph
4	no convincing association	eliminate ML rel. to femur	candidate XRF and taphonomy	no convincing association	elimination - sex estimate	elimination - sex estimate	eliminate ML rel. to femur	elimination - sex estimate	elimination - sex estimate
5	candidate unique taph	no convincing association	no convincing association	no convincing association	elimination - sex estimate	elimination - sex estimate	no convincing association	elimination - sex estimate	elimination - sex estimate
6	eliminate- unique XRF Zn	eliminate- unique XRF Zn	eliminate- unique XRF Zn	eliminate- unique XRF Zn	elimination - sex estimate	elimination - sex estimate	eliminate- unique XRF Zn	elimination - sex estimate	elimination - sex estimate
7	elimination - sex estimate	elimination - sex estimate	elimination - sex estimate	elimination - sex estimate	no convincing association	no convincing association	elimination - sex estimate	no convincing association	no convincing association
8	eliminate age and bone dens.	eliminate age and bone dens.	eliminate age and bone dens.	eliminate age and bone dens.	elimination - sex estimate	elimination - sex estimate	eliminate age and bone dens.	elimination - sex estimate	elimination - sex estimate
9	eliminate age/ BD/stature	eliminate age/ BD/stature	eliminate age/ BD/stature	eliminate age/ BD/stature	elimination - sex estimate	elimination - sex estimate	eliminate age/ BD/stature	elimination - sex estimate	elimination - sex estimate

Table 5.4 Phase V. Assessment of Individuals with Outlying Raw Elemental Peaks Versus Humeri with Outlying Elemental Peaks.

Element		Outlying Individuals					Outlying Humeri						
As	11	18					316	318					
Au													
Cu	16	18	14	8			130	318					
Fe													
Ga	6	11	15				317	316					
Hg	1	3	14	7	10	16	115	130	320	121	125	111	316
Ni													
Pd	6	8	12				135	111	122	319			
Sb L1	2	8	10	14			110	118	122	126	131	319	
Sn K12													
Sn L1													

Table 5.5 Phase V. Generated Candidates for Association of Humeri to Individuals Based on Elemental Outliers.

Individual	Outlying Element	Candidates for Association- Humerus						
1	Hg	115	130	320	121	125	111	316
2	Sb	110	118	122	126	131	319	
3	Hg	115	130	320	121	125	111	316
6	Ga	317	316					
7	Hg	115	130	320	121	125	111	316
8	Cu	130	318					
10	Hg	115	130	320	121	125	111	316
11	As	316	318					
12	Pd	135	111	122	319			
14	Cu	130	318					
15	Ga	317	316					
16	Cu	130	318					
18	As	316	318					



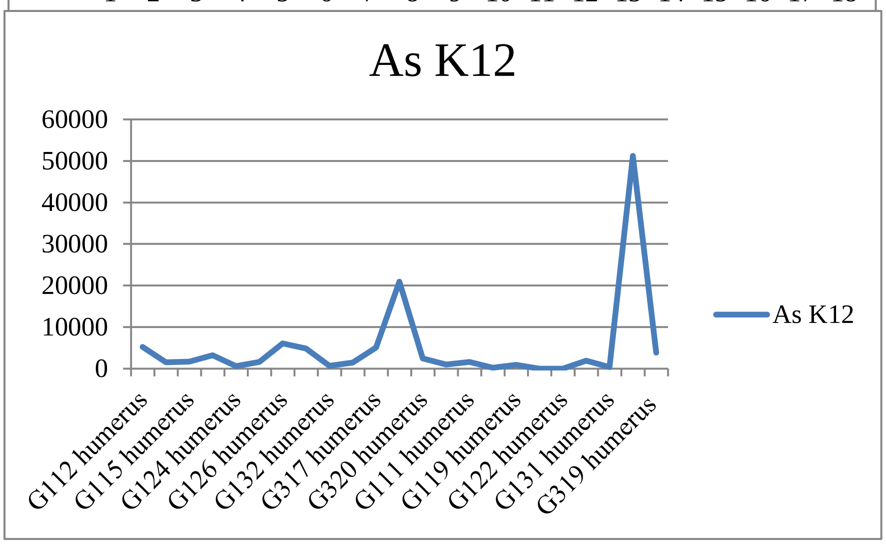
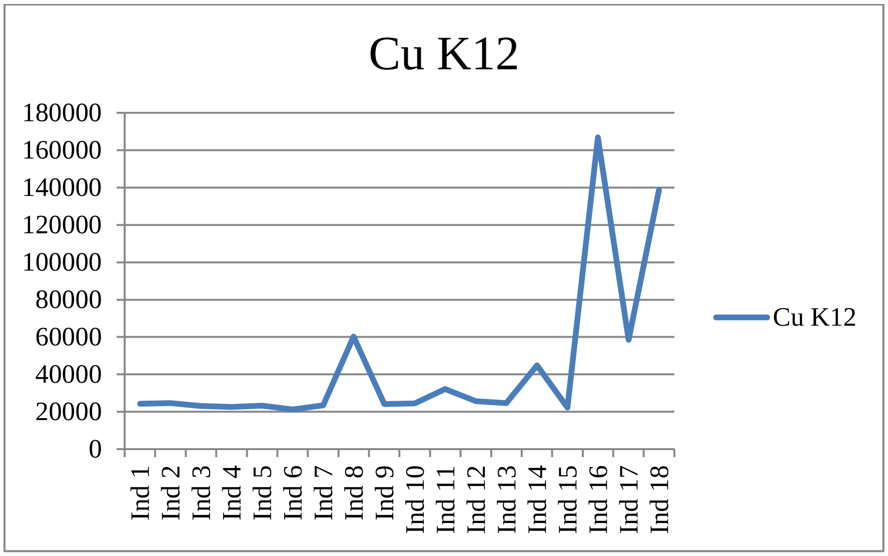


Figure 5.11 Spectral Comparison of Raw Elemental Peaks for As by Individual (Top) and by Humerus (Bottom), Used in Phase V. of Reassociation at 38GE81.



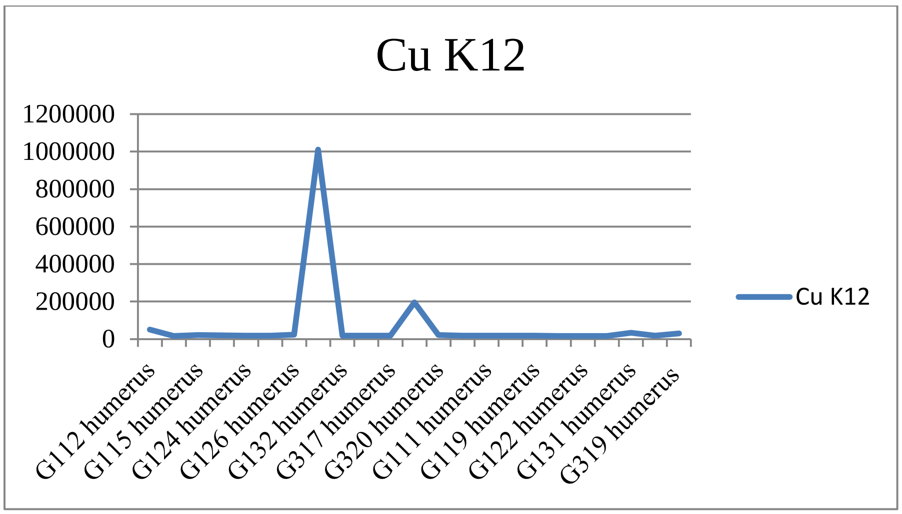


Figure 5.12 Spectral Comparison of Raw Elemental peaks for Cu by Individual (Top) and by Humerus (Bottom), Used in Phase V. of Reassociation at 38GE81.

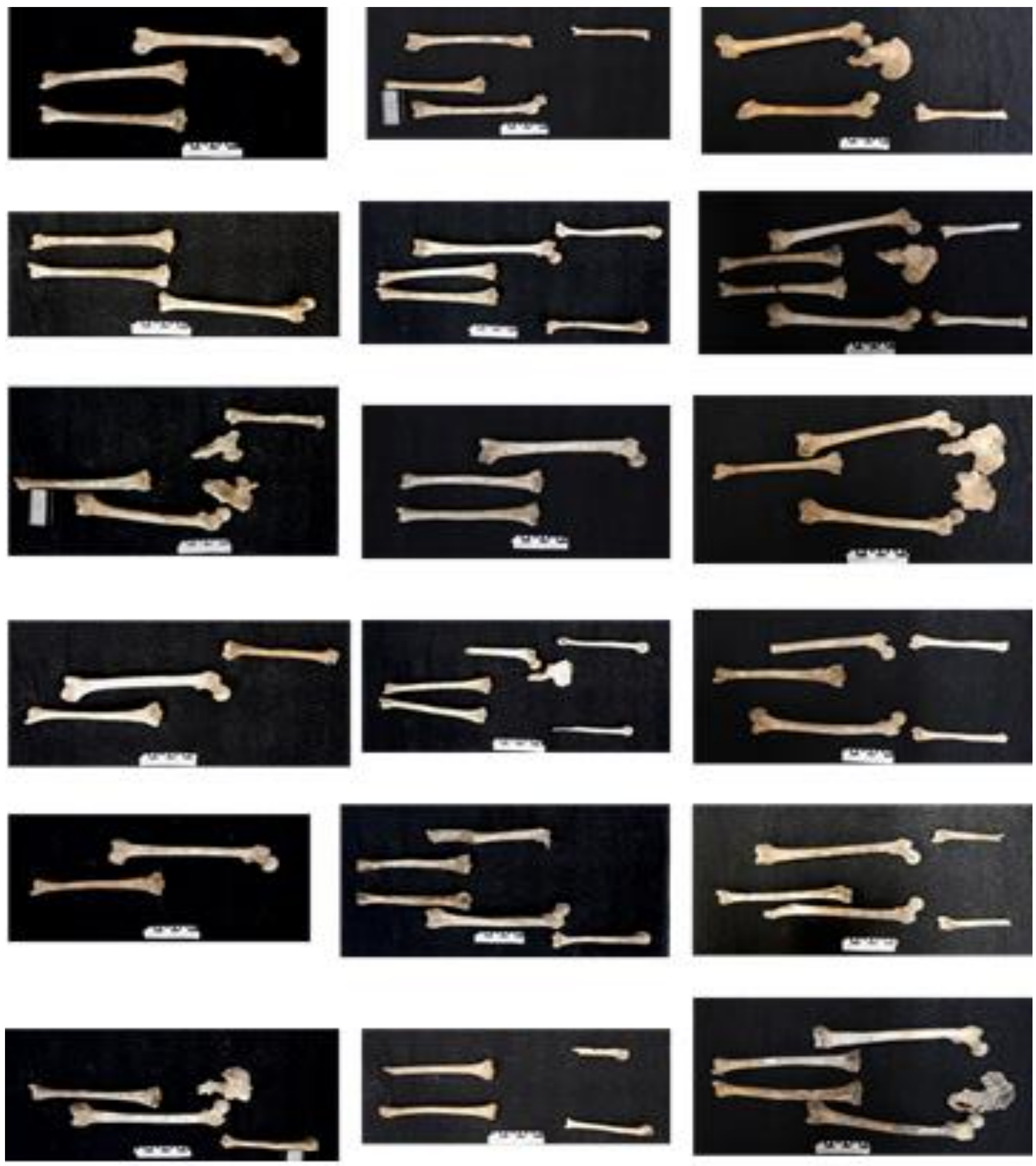


Figure 5.13 Final Assembled Sample, (n=18) Derived from Multi-Phase Reassociation at 38GE81.

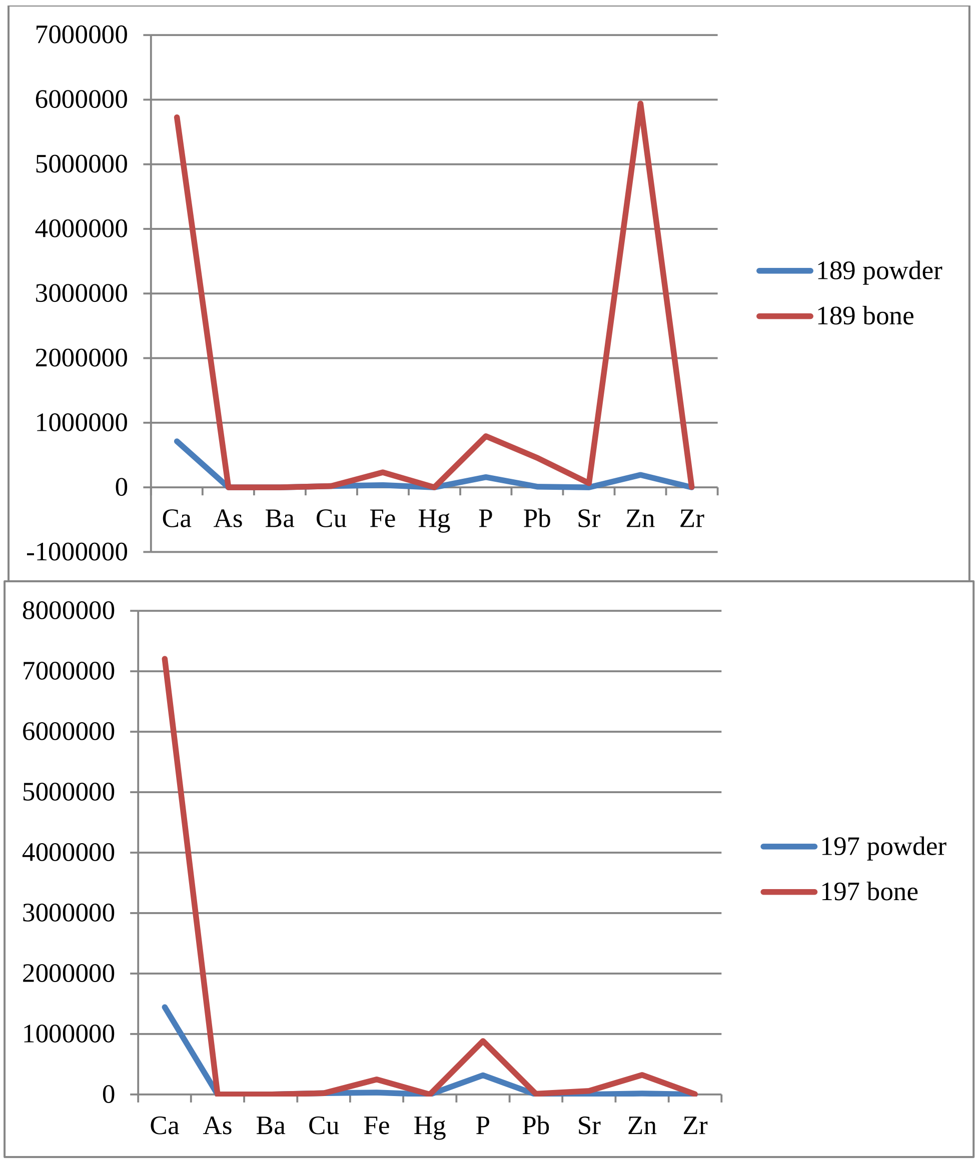


Figure 5.14 Spectral Comparisons of Powdered Samples to Cortical Surface Readings for Bones 189 and 197.

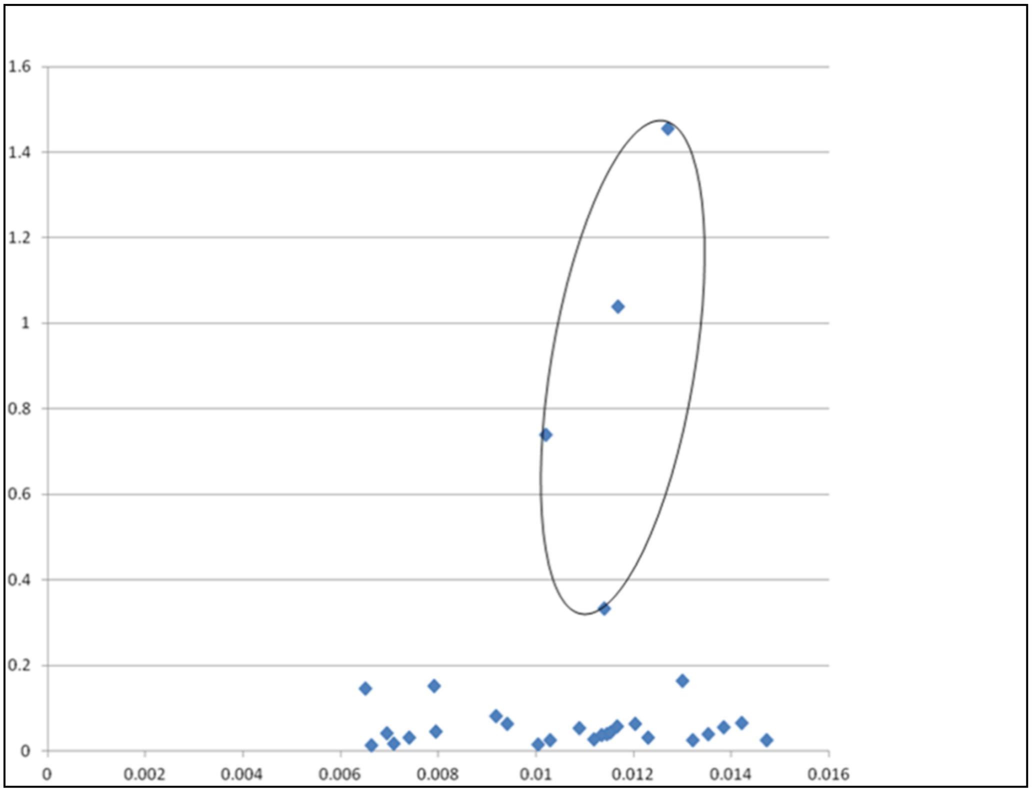


Figure 5.15 Bivariate Plot of Sr/Pb Against Zn/Ca for Male Lower Limbs Demonstrating Individual 6 Paired Femora and Tibia as Outliers.

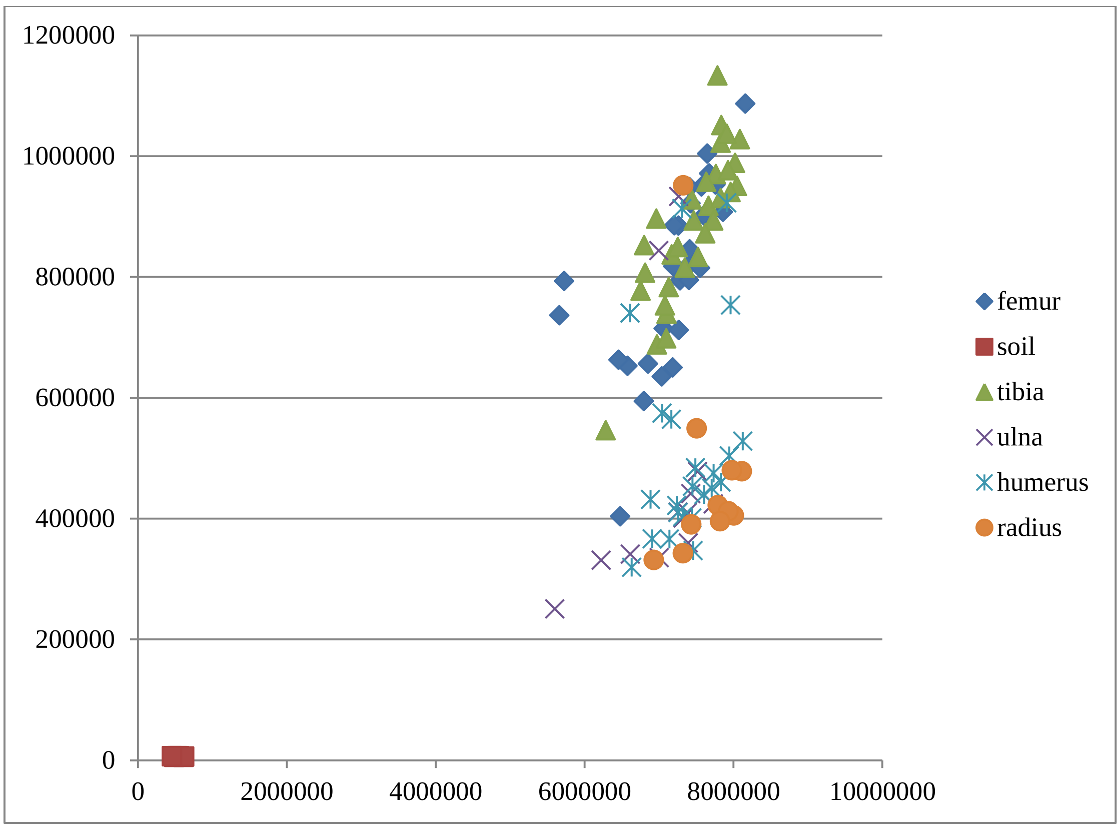


Figure 5.16 Clustering of Ca to P by Bone Type at 38GE81.

Table 5.6 Results of Independent T-tests of Elemental Ratio Distribution Between Sampled Elements of Stage 1 Compared to those of Stage 4 Preservation (Behrensmeyer 1978).

T-Test	P values
Ca/P	0.500848
Ca/Sr	0.341365
Ca/Pb	0.059374
Ca/Ba	0.83184
Sr/Pb	0.086071
Fe/Ca	0.039405
Si/Ca	0.17029
Pb/Ca	0.600571
Hg/P	0.846
Hg/Ca	0.854
Cu/Ca	0.22
Cu/P	0.294
Zr/Ca	0.165
Zn/Ca	0.495
Zn/P	0.494
Zr/Ca	0.165
Zr/P	0.19

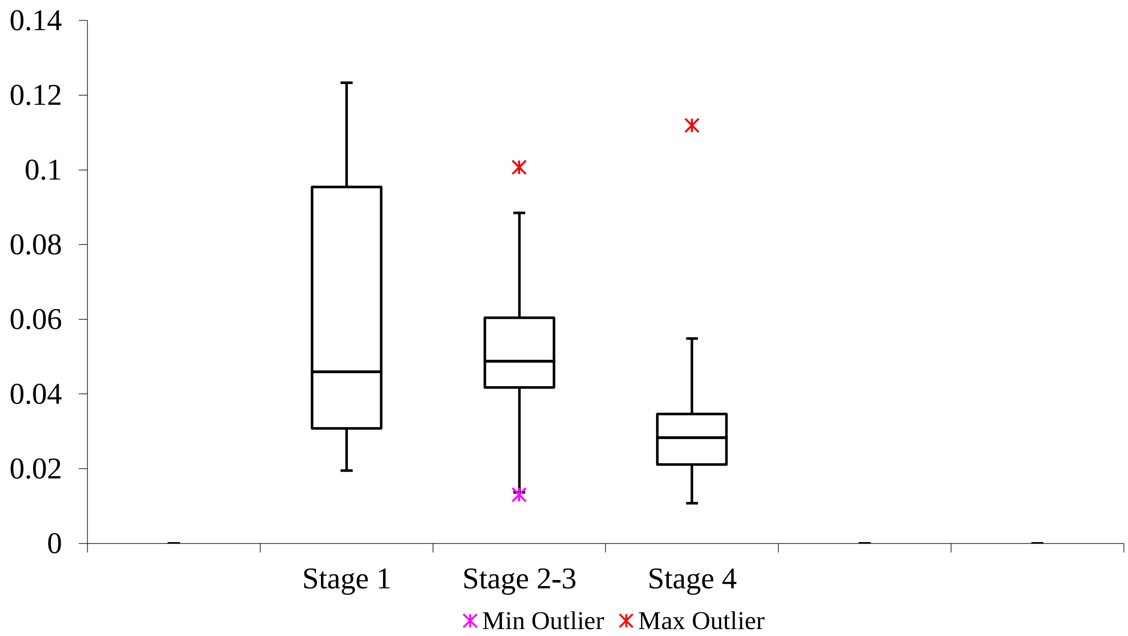


Figure 5.17 Boxplot of Quartile Distribution of Ratio Fe/Ca by Stage of Preservation.

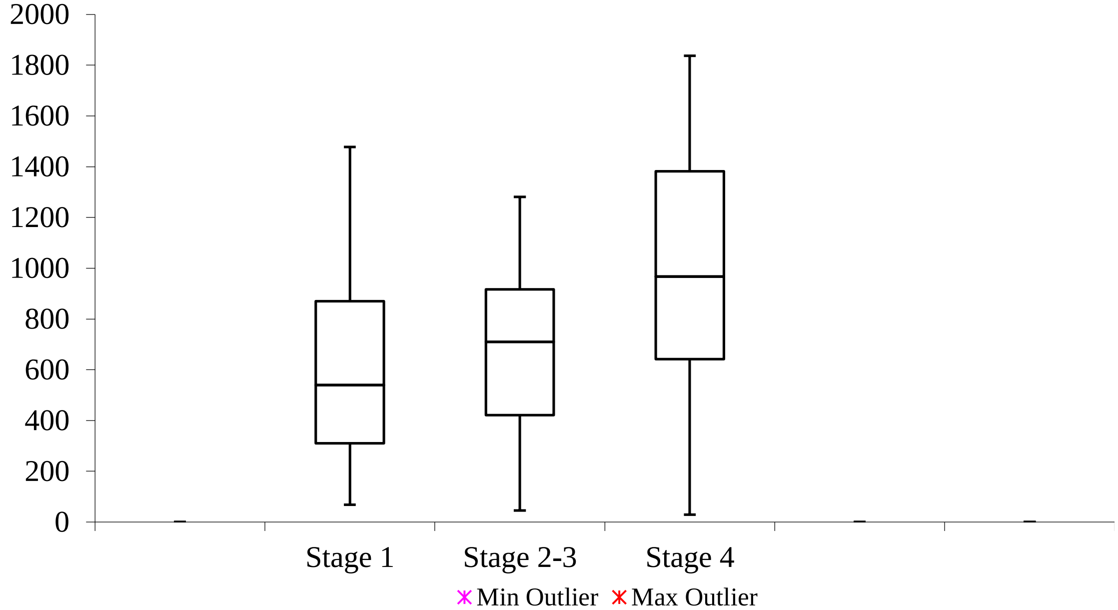


Figure 5.18 Boxplot of Quartile Distribution of Ratio Ca/Pb by Stage of Preservation.

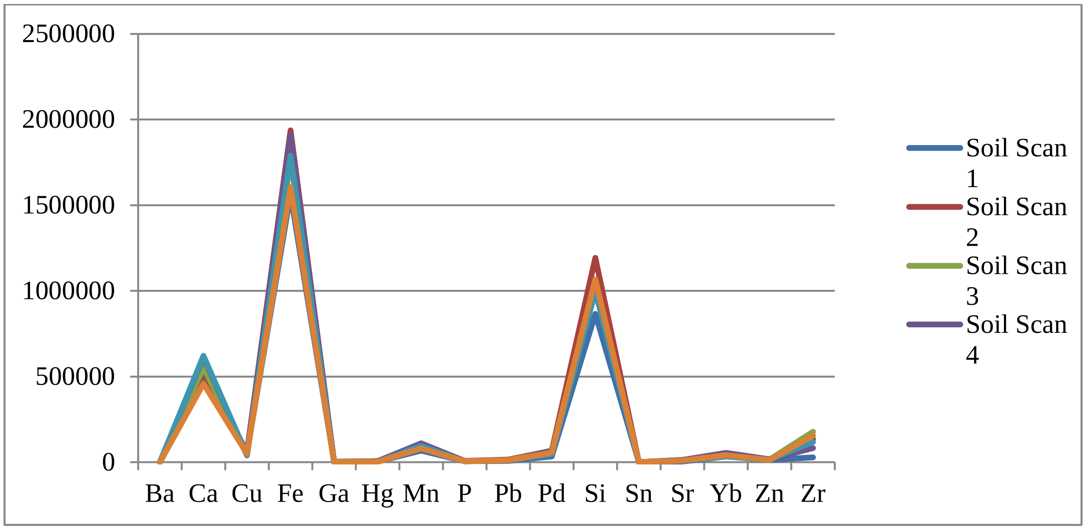


Figure 5.19 Relative Spectral Peaks from Soil Sample from 38GE81.

CHAPTER 6

BONE FUNCTIONAL ADAPTATION AND LIFESTYLE RECONSTRUCTION

Bone is a 'self-repairing structural material' which responds to changing mechanical circumstances throughout the course of an organism's life by altering its shape, mass, and properties (Jee 2001; Lanyon et al. 1982; White 2000). It is this premise that provides the basis for anthropological interest in behavioral reconstruction based on bone functional adaptation (Ruff et al. 2006). This chapter provides a general overview of bone anatomy and physiology as it relates to the functional adaptations of bone during individuals' lifetimes. As the present study focuses solely on comparative cross-sectional geometry (CSG) of the long bones, this review will primarily discuss processes and resultant changes within human cortical bone, rather than those which occur in trabecular bone.

The following summary includes an introductory discussion of bone anatomy and physiology on microstructural and macrostructural levels, a historical review of theoretical perspectives about bone functional adaptation derived from osteological, clinical orthopedic, and experimental research, an introduction to the biomechanical engineering principals applied within these studies, and a discussion of the relationships of mechanical and metabolic influences on bone from growth and development to adulthood. A detailed review of biological anthropology studies of bone functional adaptation and biomechanics as they pertain to bioarchaeological behavioral reconstruction follows this background, containing discussion of the methods and concepts used within them and a summary of generalized research questions and findings.

Basic Bone Anatomy

Bone is a composite material which consists of fibrous protein and collagen fibrils, stiffened by Ca phosphate filling, water, polysaccharides and proteins, living cells and blood vessels (Currey 1984:24). Bone's hardness and rigidity result from the fact that its collagen fiber matrix is impregnated with inorganic salts (Jee 2001; White 2000). Approximately 65 percent of bone is inorganic material, an impure Ca phosphate form known as hydroxyapatite, containing constituent compounds and elements- carbonate, citrate, magnesium, fluoride, and Sr. The organic component (35 percent) is roughly 90 percent collagen and 10 percent noncollagenous proteins (Jee 2001). This structure and composition allows bone to perform many roles, including support for our body, structure for movement and circulation, protection for our internal organs, containers for bone marrow facilitating hematopoiesis (the formation of blood cells), and a reservoir for storage of important minerals (Jee 2001).

Mammalian bone normally exists in three different forms- woven bone, lamellar bone, and parallel fibered bone (Currey 1984:26-27). Woven bone is disorganized 'provisional' material laid down relatively rapidly and soon resorbed and replaced by lamellar bone. It is characteristically present during fetal development and in bony calluses associated with fracture healing (Currey 1984; Jee 2001). Woven bone contains fine-fibered collagen, bone cells or osteocytes (sequestered in lacunae) and connecting via channels (canaliculi) with neighboring cells and blood vessel networks (Currey 1984:26-27).

Lamellar bone is deposited more slowly than woven bone and is arranged in sheets of approximate 5 um thickness known as lamellae (Currey 1984:26-27; Jee 2001). Collagen fibrils are laid down within the short axis of the plane of the lamella forming branching bundles. Parallel-fibered bone is an intermediate form between woven and lamellar bone types. It is highly calcified but without such randomized arrangement of collagen fiber bundles as those that occur in woven bone (Currey 1984). Primary fibro-lamellar bone is laid down initially within the human skeleton, forming from cartilage, but its arrangement of compact osteonal bone is replaced by secondary osteons early in life. Lamellar bone also exists as Haversian Systems or secondary osteons (the primary structural unit of developed bone) (Currey 1984:28). Primary bone is replaced by secondary bone either by erosion at its surface or by formation of Haversian systems during bone remodeling (Currey 1984:32).

Bone is classed as either cortical or compact bone (synonymous) or trabecular or cancellous bone (synonymous). Cortical bone is solid, allowing space only for osteocytes, canaliculi, capillaries and erosions. Trabecular bone has macroscopic porosity and is composed of primary lamellar bone or fragments of Haversian bone in adults, and possibly woven bone in subadults. Its appearance is of a fine randomized network of cylindrical struts (trabeculae). Different versions of trabecular bone are found in different locations within the skeleton. Randomized cylindrical struts trabeculae are found deep within bones (i.e. within marrow cavities) away from loaded areas while more regularly oriented types of trabecular architecture which include plate-like structures are typically found immediately beneath surfaces that experience relatively constant loading (i.e. joints and epiphyses). The space located between the structures of trabecular bone is occupied by marrow (Currey 1984:33).

Bones are normally referred to in three classes (long or tubular bones, flat or tabular bones, and irregular or short bones). These classifications have obvious structural and biomechanical implications- long bones having roughly circular shafts (diaphyses) with bulbous ends (epiphyses) covered with synovial cartilage, forming part of the synovial joint. Long bones possess bony projections, ridges, and tubercles for attachment of muscles and tendons. Flat bones are usually composed of two sheets of cortical bone separated by trabecular (diploe) as in the flat bones of the cranium or the sternum, excepting the body of the scapula, which lacks any sandwich-type arrangement. Irregular bones have similar dimensions in all directions (i.e. the tarsals) and have a thin cortex with trabecular filling (Currey 1984:36-37).

Bone Structural Unit and Bone Cells

The fundamental structural unit of mature bone is the secondary osteon (or sometimes simply osteon) also known as the Haversian System. Osteons make up approximately two thirds the volume of cortical bone, while the remainder consists of remnant osteon fragments and subperiosteal and subendosteal circumferential lamellae (Jee 2001). Osteons are formed following osteoclastic resorption around a blood vessel in bone (Currey 1984:28). The resulting tubular space is filled with circumferential lamellae and a canal containing blood vessels, lymphatics, nerves, and loose connective tissue.

These canals communicate via transverse “Volkmann’s Canals” that form branching networks (Jee 2001). There are five types of specialized bone cells which make up skeletal tissue, in concert with the cartilage cells: osteoprogenitor cells, osteoblasts, osteocytes, bone lining cells, and osteoclasts (Ortner 2003).

Bone Growth and Remodeling

Bone growth, modeling, and remodeling all depend on the vascular system for oxygen supply and as a source for bone cells. Aspects of blood flow and nerve supply to bone remain incompletely understood. All bone growth occurs appositionally due to the nature of bone tissue, thus activity occurs at either the periosteal or endosteal surface. The bone surface can be in one of three functional states: forming, resorbing, or quiescent. Bone forming surfaces possess osteoid and a layer of osteoblasts, while resorbing surfaces contain ‘scalloped concavities’ known as Howship’s Lacunae containing or associated with osteoclasts. Quiescent surfaces are free of osteoclasts and osteoblasts and characterized by bone-lining cells (Jee 2001).

Mechanical Loading of Bones

Bones experience mechanical loading through their joint surfaces and their fibrous insertions and attachments. The normal function of bones involves two distinct phenomena: the loading and deforming of bone tissue due to external phenomena, and the internal phenomenon of loads applied to bone via the muscles (Frost 1990; Lanyon 1982; Turner 1998). The cross- sectional shape of long bones is largely determined by overlying muscles but variation in cortical thickness and curvature of the bones result from functional uses (Lanyon 1982). From a an adaptive viewpoint, the curvature of bone shafts, although requiring greater bone mass to maintain stress ‘within safe limits’ increases the predictability that stresses will not exceed the failure limit of the bone- reducing fracture risk (Biewener 1998:71).

The stresses experienced by bone result from applied loads and are proportional to the amount of bone in a given location, as well as its position in relationship to the direction of loading. Stress applied to a given plane within a bone is measured as the force per unit of area (measured in Newtons per sq. meter or PSI) (Lanyon 1982). Stress on bone causes strain, deformation of the bone material, or changes in its length or breadth that can be expressed as Δ L/L or Δ B/B, ratios of dimensional change to original dimension (Currey 1984; Lanyon 1982). Normal strains thus cause dimensional changes in particular directions within the material. Stress is more complicated to measure, but resolvable into a vector expression- operating at three right angles in a Cartesian Plane (Currey 1984).

Bones can be subjected to a variety of loadings including compression, torsion, tension, bending, and shearing (Currey 1984). Bone is strongest in compression, weaker in tension, and weakest in shear (Biewener 1998). The orientation of an area across which a force acts is mathematically expressed as a unit vector ‘n’ and the force as a vector ‘f’. Stresses are described as normal stresses when n and f are parallel, and shear forces, when n and f are perpendicular (Cowin 2001a). Shear forces thus act on a material in opposing directions, resulting in angular deformation (Currey 1984). The relationship between stress and strain is usually expressed in a load-deformation or stress-strain curve which depicts measures of the phases of behavior of the material. The area beneath the curve from its point of origin gives the amount of energy absorbed during the phase of elastic behavior of the material (from which it has the ability to return to original shape). The angle of the curve provides the "yield point", beyond which the material begins to behave plastically (bending or deforming). This axis continues to the point of failure or fracture in bone. More brittle materials have less plasticity than others (Currey 1984).

The 'modulus of elasticity' or Young's Modulus (E) expresses the stress/strain relationship in the linear region of the curve in a standard compressive or tensile test. Young's Modulus is given in pascals (Pa) or newtons per square meter. The steeper the initial part of the curve, the greater the modulus of elasticity, meaning that the material is more rigid (resistant to bending) (Currey 1984). Many other independent more complex moduli are used to describe the elastic properties of materials (Currey 1984). Cowin (2001a) provides detailed discussion of the engineering principles underlying the mechanics of bone to include stress (T) and strain (E) matrices and their use in defining the physical forces that operate on materials.

Bone is an anisotropic material, meaning that its properties are different when measured in different direction or planes, thus stress-strain curves provide Young's modulus in a single direction, which may differ from the measure in other directions (Currey 1984). The concept of 'orthotropic symmetry' is characteristic to materials arranged in concentric rings or lamellae, like plant tissue, animal bone tissue, as well as industrial laminates and metals. The orthotropic symmetry of cortical bone is critical to consider when measuring its elastic behavior in stress-strain measures. Curvilinear orthotropy, in which the orientation of orthotropic symmetry coordinate systems is different from point to point, is particularly relevant to the structure of human long bone diaphyses (Cowin 2001a). Cowin presents an orthotropic cylinder model for demonstration of formulae that describe the stress and strain components of bone during multiaxial loading, centric compressive loading, pure bending, eccentric axial loading, torsion, and consideration of displacement and rotation during loading, all useful models for the complex loading patterns experienced by bone (Cowin 2001a).

In vivo Animal Studies

In vivo strain in bones is measured in living research animals such as sheep and has provided valuable insight in to bone tissue's behavior in response to loading regimes. Piezoelectric strain gages are typically installed on bone locations within test animals. These studies have provided valuable insight into the roles that patterns of repetitive deformation in skeletal locations play in the maintenance of skeletal tissues, in the degradation of these tissues, and in the role of injury and alteration of bone tissue- critical to research in orthopedics (Lanyon 1982:280; Wallace et al. 2014; Lieberman and Crompton 1998). The quantification of mechanical input for bone is crucial to understanding skeletal form and function. Determinations of the deformations that bone undergoes in normal use are part of the means of understanding the mechanotransduction system of bone- how organ level experiences are transmitted to the cellular level to induce maintenance and adaptational change (Fritton and Rubin 2001). While competing theories regarding bone's response persist, there appears to be consensus that there is no simple, direct result of the application of force to bone, and that the process of remodeling is best viewed as multifactorial (Lieberman and Crompton 1998).

Wolff's Law and the Biomechanics of Bone

As developed by Wolff in the latter nineteenth century, "Wolff's Law" states that bone remodels in the form of internal and external modifications to its architecture following observable and predictable mathematical rules as a consequence of "primary (pathological) changes in the shape and stressing or in the stressing of the bones (Wolff 1986 [1892]). Wolff had at his disposal numerous pathological and normal specimens and an informed view of engineering principles, but lacked physiological, histological and biochemical insight into the complex process. Modern understandings of bone functional adaptation are informed by an evolution of scientific inquiry within human biology, anatomy, physiology, histology, and genetics which has provided significantly more insight than Wolff had in understanding the linkage and relationships of variables involved in bone functional adaptation.

The main concepts developed by Wolff that have become incorporated in to a modern functional view of bone are the understanding of economy and 'strategic placement of skeletal elements' within the body and the capability of bone to make adjustments to is mass (Lanyon 1982:281). Ruff et al. (2006) provide a concise summary of the use of the concept within bone biology and skeletal studies, illustrating the caveats and analytical concerns central to anthropological comparative behavioral studies.
See Pearson and Buikstra (2006) for a review linking Wolff's Law and the basics of functional anatomy to the theory behind the engineering bases for modern studies- beam theory. These authors also provide a historical perspective on the development and influence of the German school of anatomy on our understanding of skeletal mechanics and functional anatomy. The late nineteenth century German medical and anatomical

schools of thought, championed by Rudolf Virchow emphasized the plasticity of the human body in response to ‘external forces’ and the earliest concepts of adaptation. These concepts influenced the thought of influential figures such as Julius Wolff, as well as important figures within anthropology such as Franz Boas and others (Pearson and Buikstra 2006:209).

Hrdlicka (1934 a, b) was one of the first anthropologists to examine skeletal form, especially comparisons of the architecture of the femur and develop theoretical perspectives on its variation. Interest in functional interpretation and behavioral reconstruction from the skeleton grew in the latter 20th century on the heels of influential works such as Washburn’s ‘New Physical Anthropology’(1951) and with the more holistic and early bioarchaeological research agendas pursued by E.A. Hooten, J.L. Angel, and T.D. Stewart (Pearson and Buikstra 2006).

The modern concept is one of “bone functional adaptation” stemming from the work of Roux (1881) and his modifications of Wolff’s theories The theory of symmorphosis also developed from the chain of ideas begun by Wolff, and concerns the means by which organisms adapt ‘economically’ to changing functional demands (Lieberman and Crompton 1998). Continuing more directly in the line of Wolff and Roux, the research of Pauwels (1980), based on pure anatomy studies, clinical orthopedic surgical practice, and biomechanical experimentation was influential in continuing the critical scientific approach to research in functional anatomy. A century plus of argument and critical reevaluation has led to the development of theoretical models for mechanisms of bone functional adaptation described in the following section (Turner 1998).

Theoretical Models of Bone Functional Adaptation

The concept of “Bone Functional Adaptation”, the idea that bone adapts to changes in its mechanical environment is derived from early work such as that of Roux (1881) and Wolff (1896), but has moved so far theoretically and scientifically that most of this initial work has been discredited. Wolff’s “Law” is best viewed as a philosophical statement that “over time, the mechanical load applied to living bone influences the structure of bone tissue” (Cowin 2001b). The “false premise” underlying Wolff’s work lay in the fact that he applied engineering principles pertaining to homogeneous isotropic materials to his object of study- trabecular bone. Among other flaws, the mathematical laws he derived, based on perceived stress trajectories in bone have been shown to be invalid (Cowin 2001b). The work of Roux better approximates an early view of bone functional adaptation since he investigated the ability of bone cells to respond to local mechanical stresses (Ruff et al. 2006:485).

Bone functional adaptation is widely accepted within biology and biological anthropology. Numerous experimental and observational studies provide demonstrative evidence of bone’s response to loading. Criticisms and competing theories regarding the processes that govern change in bone abound, however, and it is perhaps best to keep in mind that the role of the skeleton is not purely mechanical. The mass and shape of the skeleton represent a compromise between differing physiological demands (Currey 2003; Ruff et al. 2006).

While the overall shape and form of bones is genetically determined, bones possess the ability to adjust their mass, texture, and shape in response to use. The relationship between structure and function in skeletal tissues is achieved by the cellular population of bone and its ability to adapt, reinforce, remodel, and realign the elements of the skeleton in response to changes in mechanical circumstances (Lanyon 1982:274). Macrostructurally, bones adapt through modeling (deposition of new bone) or remodeling (resorption and replacement of old bone) (Lieberman and Crompton 1998). Numerous models, primarily cumulative and complimentary, and theories have been proposed to explain bone adaptation. This chapter will briefly review some of the most well-known.

Most of the evidence suggests that bone adaptation to loading histories involves a direct response to strain (Lanyon 1982; Lieberman and Crompton 1998; Ruff et al. 2006; Turner 1998). A simple feedback model of bone functional adaptation suggests that bone possesses an "optimum customary strain level" above or below which consequent increases or decreases in strain induce bone deposition or bone loss (Lanyon 1982). This idea is credited to Frost's (1964; 1987; 2003) research and has become known as the "Mechanostat Model". Within this model, strain in bones that surpasses a threshold induces bony response and results in increased strength, consequently reducing strain and returning the bone to mechanical equilibrium. Decreased strain in bone, alternatively leads to resorption in order to return to customary levels (Lieberman and Crompton 1998).

Stress induces strain which can trigger osteogenesis due to the fact that it can cause bone damage (Lieberman and Crompton 1998:78). Frequent high strain magnitudes induce bone growth while low levels result in resorption. Woven bone, parallel-fibered, and lamellar bone all respond to strains differently (Lieberman and Crompton 1998:78). The role of Haversian remodeling may be to repair fatigue damage caused by strain but the proximate action of force and the resultant activation of bone cells remains complex and poorly understood (Lieberman and Crompton 1998:86).

Lanyon (1982) details the working theories regarding strain-related control mechanisms which potentially govern adaptive change in bone. Theories suggest that intermittent strain experienced by bone may either 1) induce active substance in the cortex which diffuses to the bone surface causing a 'concentration-dependent reaction'; 2) affect the solubility of Ca ions leadbing to a local stimulus to bone cells; or 3) affect blood flow, creating an influence on osteocyte activity (Lanyon 1982:292). The theoretical framework for bone's sensory response system is summarized as "an interconnecting network of strain-sensitive osteocytes [which] would make feasible the sensing of strain gradients and appreciation of the bone's overall deformation pattern" (1982:294). This adaptive process may operate via patterns of electrical charge, especially sensitive to strain rate dependent electrical potentials- supported by the evidence that intermittent and high strain activities seem to stimulate greater bony response (1982:295).

The development of models of "mechanotransduction" contributed to the "mechanostat" model by adding to the understanding of bone's response to loading at the cellular level resulting in tissue changes, rather than changes in macroscopic structure (Duncan and Turner 1995). The concept of the transductional level refers to how bone cells detect and respond to strain. This process is not completely understood, but bone cells may sense strain through nerve arrangements in the periosteum and "pressure changes in fluid-filled canaliculi of osteocytes and … piezoelectrical potentials generated by collagen deformation" (Lieberman and Crompton 1998:79).

Turner (1998) developed three rules within the framework of mechanotransduction, namely that: 1) bone adaptation is driven by dynamic rather than static loading, 2) only short duration mechanical loading is necessary to elicit an adaptive response, and 3) bone cells accommodate to a customary mechanical loading environment making them less responsive to routine loading signals. Lieberman and Crompton (1998) proposed a simple model of mechanotransduction in which force producing strain illicits a series of constrained structural responses, followed by a transductional response, which is consequently affected by design constraints and in turn leads to adaptation via modeling and/or remodeling.

Intermediate processes and constraints listed in the model that mediate osteogenic response to forces are the following: structure (macrostructure- size and shape) and (microstructure- collagen orientation, density, mineralization, and lamellar organization). Within mechanotransduction, bone adaptation is viewed as ‘Error driven’ in the sense that the abnormal strains experienced by bone drive structural change. Bone cells accommodate or become accustomed to local strain environments (Turner 1998). Further limiting factors to bony response include vascular nutrient supply, specific unique structural features, and other ‘non-mechanical functions’ that determine their shape. Force is seen to induce modeling and remodeling through a series of ‘interrelated, hierarchical processes (Lieberman and Crompton 1998:79).

The theory of dynamic strain similarity (Rubin and Lanyon 1984) was implicit to viewpoints within the models of the “Mechanostat” and “Mechanotransduction”. It states that if bone tissue is designed to tolerate certain strains, then bones should respond to increased forces structurally by augmenting their mass in their principle planes of deformation, thereby decreasing the level of strain generated by a given force (Lieberman and Crompton 1998). Experimental tests of dynamic strains have affirmed some assumptions regarding directional and area response to loading stresses, but no simple direct result of the application of force to bone is easily detected. Remodeling is best viewed as multifactorial. Modeling and remodeling have been found to “coadjust to adapt to force-induced strain’, doing so in a varied and unpredictable manner (Lieberman and Crompton 1998). Some bones appear to respond macrostructurally by altering their shape and size within design constraints by modeling, while others appear to prefer to induce Haversian remodeling. Both of these processes may operate simultaneously in a “trade-off” style (Lieberman and Crompton 1998).

Long bone shafts, which are often curved, in fact represent a paradox in design (Turner 1998). They augment, rather than reduce the strains due to bending, presumably keeping strain on all points along the axis away from the neutral bending axis, thereby optimizing strain patterns for the variety of anticipated loadings. Bone adaptation is dependent upon strain magnitude, duration, frequency, history, and type, with principle tensile or compressive strains being most important for bone adaptation.
Adaptation occurs in response to dynamic loading, dilatational strains (volume changes in tissue) and a strain gradient (Turner 1998).

The idea of bones as ideally designed structures, primarily optimized to resist fracture is prevalent in biology but has become outmoded. The concepts of tissue economy and symmorphosis persist in conceiving of skeletal structure as a balance of optimal structure with a minimum of tissue (Lanyon 1982:274). Bones can be viewed as a design compromise between adaptation to normal loading and fracture resistance

(Currey 2003). Contrary to the idea that bones are designed to be resistant to fracture, they are highly mineralized and thus brittle. Currey (2003) argues that although the genetic and epigenetic factors that determine bony architecture may produce minimal mass structures optimized for normal loading, they are not produced to be optimally resistant to fracture. During development and normal use, there are many examples of bones that are highly susceptible to unique accidental type stress and resultant fracture. Bone variation in robusticity within the body is believed to be determined by variations in the normal and routine loadings they experience, therefore efficient for coping with fatigue damage, but not well-suited to cope with many accidental forces (Currey 2003:592).

Peck and Stout (2007) tested the hypothesis that heterogeneity of bone mass (intraskeletal variability by element) exists in individuals and is largely caused by variations in loading on each of the distinct elements. They used CSG measures based on direct section from cadaver specimens of each long bone to assess bone mass in regard to age and nutritional factors. They found males larger on average in all dimensions compared to females and demonstrated age-related effects of lower limb bone mass decrease for males and females. Their results suggest that lifestyle and diet are determinant factors for bone mass. They also demonstrate that bone mass of any element is intricately tethered to its loading environment, and that structural adaptation to loading is influenced by size and shape change in muscle structures (Peck and Stout 2007:91). Mechanical loading thus plays a very important role in the development and maintenance of bone mass in their opinion.

Henderson and Carter (2002) investigated the role of mechanical strain, pressure, and forces during growth and morphogenesis of skeletal elements. They hypothesized that bone morphogenesis is regulated by growth-related pressures and strains, in conjunction with local tissue, cell and molecular biological processes. They focused particularly on the role of compressive and tensile forces generated on the cellular level and to the extracellular level and theorized that the incompletely understood process of mechanotransduction should operate in the axial skeleton to signal morphogenetic cues during growth. Their conclusion emphasizes the need to improve the means of measurement of bony strains during skeletal development via the development of computational models based on developing imaging technology in order to better understand the complex nature of cellular and material changes that occur during growth and determine individual variation in skeletal morphology (Henderson and Carter 2002:651).

Anthropological Studies of Bone Functional Adaptation

Biological anthropologists have been investigating the relationships between human physical activity and bone remodeling since the 1970's (Lovejoy et al. 1976; Ruff 2014; Ruff et al. 2006). The concept that bone form reflects, in part, its mechanical loading history during life, is widely accepted within anthropology, and derived from "Wolff's Law" and modern understandings of bone "functional adaptation" (Ruff et al. 2006). Anthropological and paleontological studies examine direct skeletal evidence of aspects such as bone CSG in order to reconstruct past behavior and subsistence (Bridges 1992; Larsen 1997, 2002; Pearson and Buikstra 2006; Ruff et al. 2006; Ruff 2000). Used in conjunction with contextual information and material culture, and sometimes the written historical record, these studies permit comparative regional and temporal analyses of past human remains. The following chapter delineates the method and applications of bone CSG studies, as well as criticisms of underlying theory and method, and finally summarizes the current state of the method within biological anthropology. Current research within anthropology with regard to CSG-based activity reconstruction is aimed at disentangling the nature of the roles of genes, culture, and environment in the determination of bone properties, as well as standardizing the means of quantifying it for comparative purposes (Carlson and Marchi 2014).

Historical Background of CSG studies

The use of structural properties of long bones for the reconstruction of past human behavior is based on engineering principals and originated in the 1970's. Lovejoy and colleagues (1976) were the first to apply engineering principles to an anthropological question and did so by addressing the morphological trait of platycnemia (or flattening of the tibia in the mediolateral plain) from a biomechanical standpoint in order test the possibility the trait could be the result of functional adaptation rather than nutrient deprivation or other theorized causes. He concluded that platycnemia was likely a functional response of bone to greater bending strain in the anteroposterior plane rather than simply a weakened or compromised outcome for bone strength. The following decade saw a growing body of the application of biomechanical theory to population level questions within physical anthropology (Bridges 1985; Larsen 1982; Larsen 1984; Perzigian et al. 1984; Ruff et al. 1984; Smith et al. 1984).

Cross-sectional geometric approaches to behavioral reconstruction have expanded in scope since that time and are now applied widely within primatology, paleoanthropology, and bioarchaeology. These methods are of great utility within primatology and paleoanthropology in making behavioral and structural assessments about body size, shape, and function within modern primate species, and in behavioral analogies for fossil hominids (Demes et al. 1998; Grine et al. 1995; Lovejoy et al. 2002; Preuschoft 1971; Ruff 1999; Ruff 2002; Ruff and Runestad 1992; Ruff et al. 1993) . They are particularly important in fossil contexts where reconstructions are necessary due to the incomplete nature of specimens.

Engineering principles underlying behavioral reconstruction

The methods used by anthropologists are adapted from Euler-Bernoulli beam theory (Ruff and Hayes 1983) used within structural engineering for the assessment of material and beam strength. Anthropological studies model the long bone diaphysis as a hollow tube for strength assessments. Put simply, beam theory states that the farther material is located from a central axis of a beam, the stronger and more resistant it becomes to breakage or collapse under loading stresses; a buttressing effect. Cross-sectional properties of beams are assessed by engineers in order to measure resistance to bending and torsional forces. Engineers use properties of a cross-section described in values called "areas" to measure the amount of material in the section, and "second moments of area" to measure the distribution of material in the section (Larsen 2002). The measures of total area (TA) and cortical area (CA) of a bone cross section are proportional to the bone's strength in relation to axial compression and tension. Bone modeling and remodeling processes regulate the amount and distribution of bone within a cross section. Cortical area increases by periosteal (outer bone surface) deposition of new bone at the point where maximum bone strain occurs (farthest from the neutral plane where strain is equal to zero) or by reduction of the rate of bone resorption of the endosteal (internal) bone surface (Eleazer 2013; Lazenby 1990a; 1990b; Ruff et al. 1994).

The complexity of mechanical loading of bone most often involves a combination of compressive and tensile strains which cause bending (Rubin and Lanyon 1982). The distribution of bone material about the neutral axis of bone thus reflects its proportional resistance to bending and torsional stress about an axis. Second moments of area (I_x, I_y, I_{max}, and I_{min}) are used to measure resistance to bending or rigidity in the anatomical anteroposterior (AP) plane (I_x), the mediolateral (ML) plane (I_y), and the maximum and minimum bending rigidity depending on its location within the cross-section (I_{max} and I_{min}). The angle theta (θ) is used to express the location of maximum bending rigidity (I_{max}) in relation to the anatomical axes I_x and I_y (Ruff and Hayes 1983). Bone's torsional strength is calculated as the polar moment of area (J), or the sum of two respective second moments of area (Ruff and Hayes 1983). This measure is widely used as a strength measure and considered to be a good overall indicator of rigidity (Eleazer 2013). Recent studies use other measures of bending strength such as section moduli (Z) (Ruff 2002), but the current study limits the review and choice of measures to those previously discussed to simplify comparisons. The most commonly used mechanical measures for cross-sectional geometry (CSG) studies are defined in Table 5.1 and adapted from the following studies (Carlson et al. 2007; Ruff 1992; Stock and Pfieffer 2004).

Anthropologists have frequently used studies of CSG to address questions surrounding the transition from hunting and gathering or foraging to agricultural subsistence. Biomechanical studies of skeletal populations over the transition from hunting and gathering to agriculture have demonstrated a general gracilization of the human body, typically attributed to increased sedentism (Pearson 2000; Ruff 1987; Ruff et al. 1984) . A pattern of decrease in dimensions and change in form of the properties of long bone shafts as well as decrease in the rugosity of muscle attachment sites is observed within many of these studies (Larsen 1982; Larsen 1984; Perzigian et al. 1984; Smith et al. 1984). Ruff (1987) demonstrated that cross-sectional form of the femur tends to be less circular (wider in antero-posterior dimension relative to medio-lateral dimension) among more highly mobile groups within these transitional contexts. Conversely, Bridges (1985; 1989) demonstrated the opposite by showing increases in bone strength from Archaic to Mississippian Southeastern populations, especially evident among females. She attributed these findings to the diversity and strenuous nature of tasks associated with agriculture. Likewise, other studies found evidence for variability in skeletal evidence for activity patterns in other North American contexts (Ruff 1994).

More recent biomechanical studies of the transition to agriculture in the Old World and other regions have shown great variation in the development and degree of robusticity achieved among agricultural groups (Cowgill and Hager 2007; Wescott 2006). Findings suggest hunter gatherers are not always characterized by increased robusticity compared to agriculturalists (Carlson et al. 2007; Sladek et al. 2006). Stock and Pfieffer (2001) found great variability among groups of hunter gatherers and foragers in degree and location of robusticity depending upon marine versus terrestrial resource bases.

Shackelford (2007) provided evidence linking structural variation to increased sedentism, climatic conditions, and changing resource exploitation. These studies demonstrate the complexities associated with inferring habitual behavior from the bones and the need to consider the role of environment, lifestyle, ecological factors, and cultural influences on behavior.

Sexual Dimorphism and Activity Patterns

The changes in CSG, especially for the femur, associated with the transition to agriculture are demonstrated to have been more pronounced upon males than females, suggesting that males experienced greater alteration in types of physical activity (Larsen 1995; Ruff 1987; Wescott 2006). The effect of this, based on assessment of ratios of bending strength or *I* values, is shown in many studies to have reduced the degree of sexual dimorphism, bringing the males closer to females, presumably due to increased sedentism for both sexes stemming from the reduction in the need for long range resource procurement and hunting (Larsen and Ruff 1994; Ruff 1987;1992; 1994). Patterns of asymmetry of the upper limbs, especially the humerus, within and between sexes are important in this area of inquiry and associations of asymmetry resulting from habitual one sided activity patterns (i.e. spear and bow and arrow use as well as bilateral activities such as mortar and pestle grinding have frequently been made (Bridges 1985; 1989; Brues 1959; Ruff 1992; 1994). The consensus for assessments of population and sex differences in behavior for the upper limb is that they are difficult to assess due to the multifunctional usage of the arms compared to the legs (Bridges 1989; Pomeroy and Zakrzewski 2009; Ruff and Larsen 2001; Stirland 1993).

Sexual divisions of labor among past populations continue to be of great interest to anthropologists in biomechanical analyses and it is clear that the complexities of assessing standardized sex differences have yet to be fully understood. Comparisons between sexes are made based on comparisons of mean values for strength within cross sections of the limbs. Recent statistical examination of mean values of humeral strength comparatively assessed measures of bending strength (*I*) and torsional strength (*J*) between the sexes among foragers and farmers in the American Southwest and found the greatest relative upper body strength and least asymmetry among women farmers, suggesting their heightened role in the grinding and processing of maize (Ogilvie and Hilton 2011). This study was informed by ethnographic evidence including Kiva murals depicting activities by sex. Sexual dimorphism assessment using CSG properties of upper and lower limbs for Australian Aboriginal populations demonstrated equally high levels of mobility, based on lower limb congruencies in properties, but cautioned the rush to interpret differences in upper limb mean values of strength due to age-related differences in remodeling between sexes, diversity of tasks and known habitual activities, sampling error, and a lack of experimental data on mechanical loading for the upper limbs (Carlson et al. 2007). Pomeroy and Zakrzewski (2009) express similar concerns about the intricacies involved in assessing sexual differences in activity from external bone dimensions of robusticity indices. They also note the role of social differentiation and economic specialization within groups in creating variation in activity patterns.

Review of methodology for anthropological studies

Several non-destructive means have been proposed for obtaining images of the cross-sectional properties of long bones. Ruff and Hayes (1982) recognized the need for non-invasive means to be used for the study of archaeological skeletal remains and ethical and other concerns have since moved away from direct sectioning. The ellipse model method (EMM) uses biplanar radiographs to create an image of a long bone diaphysis (Trinkaus and Ruff 1989). The latex cast method (LCM) achieves better results by combining latex casting of the subperiosteal contour of the cross section with biplanar radiographs, producing an accurate mold of the outer dimensions of the bone (Stock 2002). These outer dimensions are crucial due to the fact that the most critical dimension for assessing long bone strength from cross-section is the region most distant from the centroid of the bone (O'Neill and Ruff 2004). Computed tomography (CT) scan images are the optimal method for accuracy and ease of use, provided the means are available (O'Neill and Ruff 2004). CT imaging provides a true image of both the subperiosteal and endosteal contours of the bone, thus achieving a true cross-section. Images derived from any of these methods are typically digitized using tracing or software programs such as SCION image (http://www.scioncorp.com) and then imported into a version of the SLICE program (Nagurka and Hayes 1980) which calculates standard CSG properties (Carlson 2005; Carlson et al. 2007). Image J software used with Moment Macro software also permits easy and efficient derivation of cross-sectional images and properties and is used in the current study (http://imagej.nih.gov/ij/; http://www.hopkinsmedicine.org/fae/downloads/MomentMacroJ_v1_4.txt; Warfel 1997).

Body Size Standardization

In order to assess the effects of human behavior on the skeleton, it is first necessary to control or standardize for the effects of body size and shape on skeletal structure (Ruff 2000; Ruff et al. 1993). This is because cross-sectional shape is related to bone length and less directly to the size and body mass of the individual. Body size and shape vary widely among human populations. Ties to climatic adaptations and clinal variation have been well demonstrated for prehistoric populations (Holliday 1999; Katzmarzyk and Leonard 1998; Ruff et al. 1994; Trinkaus 1981). This is diminished in modern populations but its effects are still obvious (Katzmarzyk and Leonard 1998). In light of these issues, neither bone length nor body mass alone offers a reliable assessment of bending strength in the limbs. Bending rigidity is most accurately predicted by an approximation of the bending moment created by the product of bone mass and bone length (Shackelford 2007).

Various methods have been proposed for estimating body size and mass and, in many studies, they are selected based on the nature of the sample or preservation conditions. Two commonly-used methods are the estimation of body mass from femoral head diameter (Auerbach and Ruff 2004) or from stature/bi-iliac breadth (STBIB) (Auerbach and Ruff 2004; Grine et al. 1995). A surprising but convenient finding for anthropological analyses is that the mechanical scaling of the bending and torsional strength of upper and lower limb bones tends to be very similar despite the fact that the upper limb bones are not load-bearing (Ruff 2000). Ruff and others (Ruff 2000; Ruff et al. 1993) developed means for accounting for body size in limb strength by expressing cross-sectional area and polar moments of area products to powers of magnitude based on separate formulae.

Assessment of Bilateral Asymmetry

Humeral asymmetry in biomechanical studies is calculated fairly simply as the difference between the larger and smaller side, divided by the smaller side value, and expressed as a percentage (Trinkaus et al. 1994). Under this relationship, zero values indicate bilateral symmetry. Humeral asymmetry values are typically determined for bone length, cortical area, and polar moment of area (Ledger et al. 2000).

Statistical Analysis of Cross-Sectional Geometric Properties

Statistical approaches to comparative analysis of cross-sectional properties within and between samples typically use two way analysis of variance (ANOVA) to evaluate differences in body size and body shape as well as to evaluate mean ratios of properties between samples, subsistence groups and sex groups (Ogilvie and Hilton 2011; Shackelford 2007; Sladek et al. 2006). Numerous statistical tests, including post hoc tests such as least significant difference (LSD) are employed within these types of biomechanical studies in order to permit the comparison of multiple sample means with regard to cross-sectional indices, and to account for error and imprecision in factors such as body shape and size within comparison. A detailed treatment is not feasible here as methods will be applied in this study based on the nature of comparisons and composition of the comparative samples.

Criticisms of Cross-Sectional Geometry and Biomechanical Studies

Varied forms of criticism have been leveled against the interpretation of biomechanical stress from CSG. A brief summary of these critiques is presented here. Perhaps the most serious critique is an attack on the application of the biomechanical beam model to inferring long bone loading histories as being drastically oversimplified and failing to account for the eccentricities of forces that are applied to bones in real life. CSG properties may not reflect *in vivo* stresses due to lack of correlation between the beam model which measures stresses from the centroid of the bone and the true nature of neutral axes which do not necessarily pass through the centroid. This research is based on experimental sheep studies (Lieberman et al. 2004). Human experimental studies are lacking and difficult to perform, but research within fields of medicine, orthopedics, kinesiology, physical therapy and exercise sciences offer hope for increased understandings of bone functional adaptation.

Other research has implicated genetic growth factors as having greater control over cross-sectional properties than behavior (Lovejoy et al. 2003). Studies of the ontogeny and development of cross-sectional properties and robusticity are few (Cowgill and Hager 2007). Additionally, the assessment of sexual dimorphism and behavior using biomechanics is severely complicated by genetic, physiological, hormonal, and behavioral differences between the sexes, and their manifestation in the skeleton. These factors may affect the biomechanical response to loading (Ruff and Hayes 1983; Stock and Pfieffer 2004). Stock's research suggests that proximal elements such as the humerus and femur, so often used to infer biomechanical adaptation, may not be the bones that are most reflective of behavioral differences between groups. In fact, proximal elements may correlate more strongly to behavior (Stock 2006).

Pomeroy and Zakrzewski (2009) imply that many studies tend to compartmentalize changes in subsistence and activity and behavior within human groups. They take Wescott (2006) to task for not recognizing the variation and degree of subjectivity inherent to archaeological assessments of past behavior. Similarly, regarding activity changes along major changes in subsistence, they may not occur smoothly or quickly as some studies imply (Bridges et al. 2000). Despite the issues of variability and subjectivity in behavioral interpretations from biomechanical studies, the general consensus is that CSG properties do hold great interpretive potential for assessing past behavior.

Nutritional status is a concern within CSG studies due to the effects of deprivation on cortical bone. Chronic childhood malnutrition can result in reduced adult stature and reduced long bone length (Eveleth and Tanner 1990). Likewise, endosteal absorption of cortical bone can occur due to malnutrition, especially during pregnancy, and affect the maintenance of cortical bone (Huss-Ashmore et al. 1982; Martin et al. 1987). Declines in percent cortical area (PCA) have been linked to undernutrition (Huss-Ashmore et al. 1982; VanGerven et al. 1985). Most of these effects are more measures of childhood stress and are typically resolved prior to adulthood with phenomena such as catch-up growth (Goodman 1998). The linkages between growth, nutrition, and remodeling, however, are complex, making it difficult to sort out the effects of nutritional stress from normal growth phenomena.

Table 6.1 Cross-Sectional Geometric Measures Used in Anthropology. Adapted from (Ruff 1992; Stock and Pfieffer 2004) and (Carlson et al. 2007).

Symbol	Definition	Mechanical Relevance
TA	total cross-sectional area	expressed in mm^2
MA	medullary area	endosteal area ($mm^{2)}$
CA	cortical area	axial compressive/tensile strength
%CA	percent cortical area	relative cortical thickness around the entire cross-section
I_{max}	maximum second moment of area	maximum bending strength
I_{min}	minimum second moment of area	minimum bending strength
I_{max}/I_{min}	diaphyseal circularity index	ratio of max/min bending strengths/ shape of a cross-section
I_x/I_y	diaphyseal circularity index	ratio of antero-posterior to medio-lateral bending strength
J	polar second moment of area	torsional strength of a cross section

CHAPTER 7

COMPARATIVE CROSS-SECTIONAL GEOMETRY STUDY

This chapter begins by presenting and describing the comparative samples used in the CT-scan based comparative CSG study of the Hagley Plantation and Newton Plantation skeletal samples. The Hagley sample of long bones is derived from the commingling approach detailed in Chapter 5. The Newton sample consists of a subset of individuals (n= 16) from Shuler's (2005) skeletal sample from burials excavated during the 1997 and 1998 seasons at Newton Plantation. I also include a subsample of long bones (n= 26) from a commingled portion of skeletal remains (MNI= 24) excavated from Mound 2 at Newton during the same seasons of fieldwork. Following the description of the respective samples, this chapter describes in detail the methods used to collect the CSG data. Finally, this section explains the statistical methods used to test the expectations for the two enslaved groups and then provides results and generalized discussion of the comparisons by bone. Chapter 8 then provides further discussion of these findings within a biohistorical context by addressing each of the three hypotheses proposed in Chapter 1.

Materials and Methods

The complete combined CT-scan study skeletal sample from Hagley and Newton Plantations consisted of 203 bones. Although this study relies solely on biomechanical interpretation from long bones, several skulls were also scanned for purposes of assessment of pathology for future studies. Table 7.1 presents the total elements from which CT scan data was collected. Access and permission for nondestructive analysis of the Newton Plantation skeletal material was granted by the Barbados Museum and facilitated by Dr. Kristrina Shuler of Auburn University Department of Sociology, Anthropology, and Social Work. Dr. Shuler facilitated access to the collection and assisted in coordinating and facilitating transportation of the skeletal remains to Auburn University College of Veterinary Medicine for CT imaging.

All of the bones used in this study were scanned at Auburn University College of Veterinary Medicine, Department of Clinical Sciences, Radiology Section between June 1 and June 8, 2012, under the supervision of Professor John Hathcock, DVM, Radiology Section Chief. Radiology Technician Terrell Lynch performed all of the CT scans. Prior to CT imaging, osteometric data for both samples relevant to this study were collected according to standard protocols (Buikstra and Ubelaker 1994). During this process, CT scan locations were marked with pencil on the bones according to standardized locations. These included 40 percent and 35 percent of length from distal epiphysis for the humerus (to avoid the deltoid tuberosity), midshaft for the radius and ulna, subtrochanter and midshaft for the femur, and midshaft for the tibia as defined in similar studies (Ruff 2000:271-72; Stock and Shaw 2007:414).

For CT-scanning, the long bones were oriented in relation to the sagittal and coronal planes following procedures and diagrams derived from Ruff and Hayes (1983) and Ruff (2002). Bones were positioned and leveled on clear polycarbonate sheets using modeling clay. Following this positioning procedure, the anteroposterior (AP) and mediolateral (ML) breadths of each marked CT-scan location were measured in mm using digital calipers. These measures were recorded by bone for later use in scaling of CT images through comparison with the scale provided with the CT image files.

Scanning was performed using a General Electric CT/I Scanner with x-ray source voltage 120 kVp, field of view (FOV) 10 cm, and an image output size of 512 x 512 pixels. The machine scanned 1 mm slices from each bone sample. Following scanning, the CT-images were exported to DVD format for analysis. CT images were viewed and exported from Soundeklin E-Film Lite Software (2008) Merge Healthcare, following determination of optimal window level and width settings for the images from each archaeological context. Ruff and Leo (1986) describe methods for determining optimal window settings for CT of modern and archaeological bone based on attenuation of x-ray settings for type of tissue or material under study. CT numbers are expressed in relation to water using the constant (H) or Hounsfield Scale. Recommended CT window settings for modern bone based on average density are 800 H "window center" and 600 H "window width" (Ruff and Leo 1986:187), while window center levels for archaeological bone which has lost material will be typically around 300 H and higher with better preservation (Ruff, personal communication, 2012).

This study determined window settings based on comparison of a CT slice image of a damaged bone from the Hagley sample (postmortem fracture of the shaft) at varying settings with a physical transverse section of the bone at the scan location obtained by sawing the bone. The best correspondence of CT window settings and physical measurements of the cross-section slice occurred at settings "W300" and "L500". These settings were tested versus external caliper measurements of the slices for Newton and found to be acceptable. They were thus used for the export of all of the study's CT images. The scale from the E-Film Lite software was found to correspond well to external caliper measurements of the specimens. Figure 7.1 provides an example of exported CT images from the Hagley Plantation sample.

Derivation of Cross-sectional properties

In order to derive cross-sectional measures, CT images were exported from the CT software and converted to TIFF files. These files were imported into Image J software, downloaded from (http://imagej.nih.gov/ij/). Images with taphonomic damage and intrusive limestone sediment (as was the case for Newton's material) required correction and removal of defects and material, which was accomplished using the software's drawing tools. Cross-sectional properties were derived using the plug-in macro "Moment Macro" which calculates cross-sectional properties based on pixel count for scaled images under the assumption of an elliptical cross section (Warfel 1997), accessed online at:

http://www.hopkinsmedicine.org/fae/downloads/MomentMacroJ_v1_4.txt).

Cross-sectional properties were then imported into a Microsoft Excel file for statistical analysis.

Choice of cross-sectional measures

This study employed some of the most commonly-used measures for CSG properties in order to test hypotheses regarding labor and activity in comparative context between the two skeletal samples. Issues of commingling and preservation were considered in choosing these measures and the limitations of testing are discussed in the following section.

The CSG measures used (previously defined in Chapter 6) include cross-sectional or cortical area (CA), a measure of axial compressive and tensile strength, I_x and I_y (second moments of area about the x and y axes which correlate with bending strength or rigidity in the AP and ML planes), I_{max} and I_{min} (maximum and minimum second moments of area (correlates of maximum and minimum bending strength or rigidity in a beam cross-section, and the value J (the polar second moment of area, a correlate of torsional strength of a cross section). The ratios I_x/I_y and I_{max}/I_{min} are also derived in this study. These ratios are used, respectively, to describe the shape of cross sections of bone in relation to AP to ML bending strength and in relation to maximum and minimum bending strengths, wherever they are located within the cross section. As such, these measures both describe biomechanically-relevant gauges of cross-sectional shape. Both of these ratios are often employed as 'mobility indices' by anthropologists and used for inference regarding the types of locomotion and cumulative effects of skeletal response to locomotor behavior within past populations (Bridges 1989; Holt 2003; Ruff 1987; Stock and Pfieffer 2001; Wescott 2014).

As biomechanical measures require standardization for body size and shape, the measures of CA, I, and J for lower limbs are only applied to comparisons between discrete or reassociated individuals within which body size can be estimated. This study chose a method for body mass estimation based on femoral head breadth since the femoral head was available for measurement within most individuals within both samples who were amenable to lower limb biomechanical analysis. Preservation prohibited the association and/or measurement of the innominate within most of these individuals, ruling out the use of formulae that employ pelvic breadth (Ruff 2000). Ruff and colleagues' (1991) formula for estimation of body mass based on femoral head breadth (FHB) was chosen due to its ease of implementation within these sample constraints and because their sample included a sizeable African American component. Auerbach and Ruff (2004) recommended this method based on error rate testing, with its sex-specific formulae for application to skeletal samples which fall between the extremes of human body size, i.e. not exceptionally small or large individuals. The formulae are defined as follows:

$$BM = (2.741 * FH - 54.9) * .90 \text{ (males)}$$

$$BM = (2.426 * FH - 35.1) * .90 \text{ (females)}$$

$$BM = (2.160 * FH - 24.8) * .90 \text{ (combined sex)}$$

The combined sex formula is applied in the current study for standardization of CSG measures for individuals of indeterminate sex (Ruff et al. 1991). Partially reassociated skeletons from Hagley are compared to individuals from Newton using these CSG measures, as means of estimating body mass are possible when femora are present and measureable. For the commingled portions of the two samples for which body mass cannot be measured, comparative analysis is limited to appropriate raw measures of biomechanical shape such as I_x/I_y. Estimated BMI for the Hagley and Newton samples is presented in Figure 7.2. Mean measures for BMI are listed later in Table 7.6 for statistical analysis.

Sample Considerations for Commingling

Tables 7.2 and 7.3 represent the Hagley Plantation sample by individual and skeletal element, as resolved by the multiple-method reassociation conducted in Chapter 5. The makeup of this sample reflects the difficulty and limitations that the commingling approach faced in making confident associations between upper and lower limbs. Seven of the 18 partially-reassociated individuals have humeri in association with femora. This presented challenges for the selection of the body-size standardization method for upper limb comparisons. In order to achieve an acceptable sample size for humerus comparisons which maximized the number of humeri determined to be from unique individuals, the study had to select from non-repeated elements from the unassociated portion of the sample. Ideally, the strength measures (CA, I, and J) would be standardized to account for the effects of body mass using the same methods described previously for the femoral head. Given this situation, the independent upper limb sample must be size-standardized by a different method than that employed for the lower bones (Ruff et al. 1991). Within these comparisons, CSG properties of the humeri are therefore size-standardized using powers of bone length, as recommended by Ruff et al. (1993). Using this method, humeral cross-sectional area (CA) is standardized by dividing by bone length^3 multiplied by 10^8 and cross-sectional moments of area (I and J) are divided by bone length$^{5.33}$ multiplied by 10^{12}. Upper limb comparisons between the two samples in this chapter are thus performed with upper limbs considered as an independent sample in order to avoid elements that may represent the same individual in the upper limb context, as commingling could not be effectively resolved.

Sex determination for Hagley (listed in Table 7.2) was based on features of the innominate using components of the Phenice (1969) method in cases where these bones were present within reassociated individuals, maximum diameter of the femoral head (Condon et al. 1998), proximal epiphysis breadth of the tibia (Symes and Jantz 1983), and vertical diameter of the humerus (France 1983). Condon et al.'s (1998) section points for the femur head were chosen for consistency because they are based on an African American sample, and were used by Shuler (2005) for sex determination at Newton. Sex composition of the Newton sample as derived by Shuler (2005) is presented in table 7.4 which also provides the CT-scanned biomechanical sample by individual and element. Table 7.5 represents the commingled portion of the Newton Plantation sample.

The condition and context of both Newton and Hagley Plantation's skeletal remains pose difficulties for sex and age determination. Shuler (2005) faced complications due to preservation which affected her ability to estimate both of these biological profile components. Thus, a large portion of the Newton individuals studied here (n=8/16, 50%) are of indeterminate sex. Several of these individuals displayed female morphological features of the skull and pelvis, but had femoral head measures in the male range and overall were skeletally robust. CT image data was also collected for several subadults within the Newton sample (Burials 7, 24, and 42). They are not included in the comparative CSG analysis. Shuler's mean age at death and mortality curves were presented in Chapter 2 for reference.

Hagley's sample created similar challenges due to both fragmentation and commingling. As mentioned previously, sex was estimated for the Hagley sample when possible using the innominate. This bone, however, was only reassociated to individuals successfully during the commingling approach in 7 of 18 cases. Furthermore, only 5 of these 7 individuals had innominates intact enough to provide age estimates based on the auricular surface. These estimates were presented in Chapter 2 (Table 2.1).

The overall lack of age indicators suggested that age should be considered broadly in this comparative study. It is widely known that age has an effect on the morphology of long bone diaphyses due to physiology, loss of cortical bone, and changing biomechanical factors (Garn 1969; Ruff and Hayes 1983; Pearson and Lieberman 2004). Due to these complications, I made the decision to compare the adult portion of these two samples in their entirety to each other as populations for CSG measures without conducting separate comparisons by sex and age categories. I make the assumption that the comparisons of these mean measures will be informative due to the fact that the historic evidence suggests that both men and women of a wide age range (often to advanced age), were involved to a degree in similar labor schedules (Handler 1978:72-73; Weston 1864). Additionally, shape and strength measures can be expected, to an extent, to reflect the labor strains that these individuals endured during the onset of their participation in their respective labor regimes, most likely during childhood and adolescence. Studies indicate that bones achieve their approximate adult cross-sectional shape during childhood and continue to respond throughout life in more subtle changes of dimensions in response to activity (Cowgill et al. 2010; Wescott 2006).

Given the decision to evaluate the adult portions only, I exclude several subadults from comparison as previously mentioned. Furthermore, I justify the comparisons of the whole samples due to the fact that relative bone strength measures, controlled for body size, should still be meaningful in comparing labor differentials between these economies. Likewise, age or pathology-related factors such as changes in bone cross-sectional area (CA) due to bone loss of differential etiology, will prove useful by context, in making inference to the demographic and health variables which are operative within each sample.

This study is limited to the comparison of standard measures of bone strength and shape. Osteometric data collection was hampered by fragmentation and poor preservation of epiphyses to a degree within both samples. This made determination of maximum length of the long bones problematical. Studies of biomechanical measures derived from cross-sectional properties of bone designed to examine past activity and behavior (via skeletal response to mechanical loading) require controls for the effects of body shape and mass, as they impose their own mechanical load on limb bones (Ruff 2000). Measures of maximum length for both upper and lower limbs are required for considerations of allometric scaling and body shape and mass effects (Ruff 2000; Ruff et al. 1993). In order to obtain estimates of maximum length as well as necessary locations for CT-scan (i.e. midshafts) for damaged bones, this study used seriation and alignment of landmarks on damaged bones with those of similarly sized complete bones. To do this, all bones within each of the two samples were sorted or seriated by relative length (shortest to longest). Incomplete specimens were aligned next to similarly sized intact bones on an osteometric board by features of diaphyseal architecture, curvature, and shaft landmarks (i.e. the neck and trochanters for the femur).

This approach permitted reasonable alignment of the metaphyseal regions of the bone in most cases and facilitated the derivation of an estimated maximum length informed by the general metric and morphological variation present within each osteological sample. Additionally, within both samples, in order to increase femur sample size, femur ML was estimated based on tibia length. In order to do this, I derived means for both Newton and Hagley for tibia ML/femur ML based on all those individuals within each sample who had one of each element intact. Newton's mean for this measure was 0.818 (N=4, SD 0.025) and Hagley's was 0.837 (N=10, SD 0.031). The consistency of this measure was considered adequate for prediction of femur ML and was applied in two cases at Newton (Burials 25 and 27) and two cases at Hagley (Individuals 7 and 14).

As many other studies, especially those within paleoanthropology, rely on estimation for the determination of body size and shape due to the effects of preservation and fossilization (see Grine et al. 1995; Trinkaus et al. 1998; Trinkaus and Ruff 1999:410), these approaches were felt to be justified. Additionally, research has found population similarities in relative linear dimensions of long bones within the skeleton as well as relationships between articular size and length (Auerbach and Ruff 2004). If the study were limited to complete specimens only, sample sizes would be inadequate.

It is unfortunate that Hagley Plantation's reassociation was not more complete, as it may have permitted the assessment of bilateral asymmetry in upper and lower limbs via biomechanical measures which could serve as comparative data for Newton. Sample size is, however, inadequate for performing an assessment of bilateral limb asymmetry within and between the two samples. Assessment of bilateral asymmetry within Newton's sample may be the subject of a future study.

Results of Strength and Shape Comparisons

This study compares Hagley and Newton Plantation's CSG data using the non-parametric Wilcoxon/Mann-Whitney U Test. I selected this test to compare the two samples for estimated BMI, shape, and strength measures since the test is a powerful means of comparing ordinal scale distributions for significance between smaller samples sizes (Shennan 1997). The current samples, as exemplified by histograms for Hagley and Newton's I_x/I_y ratios for the tibia (Figures 7.3 and 7.4) do not all approximate normal distributions, display some skewing, and reflect the effects of small sample size. The Wilcoxon Rank/Mann-Whitney U Test is appropriate for these conditions and does not require equal sample sizes for comparisons. Rank orderings and mean ranks permit comparison of the two samples for each measure and p values provide measures of statistical significance. Statistical calculations were performed using a Mann-Whitney U Calculator accessed online at: http://vassarstats.net/utest.html, in conjunction with Microsoft Excel tables for each measure by element. The results of all comparisons between Hagley and Newton by bone are presented in Tables 7.6, 7.7, and 7.8.

Estimated Body Mass

Estimated body mass for the Newton Plantation sample is larger on average than Hagley Plantation. This difference is statistically significant ($p=0.0122$). Although the sample comparisons here are done in a combined-sex approach due to problematic sex assessment and sample size, the effects of sexual dimorphism should not be a major influence here. Both samples contain more males than females with a percentage of individuals of indeterminate sex as estimated in the current study for Hagley and for Newton by Shuler (2005).

The Humerus

For the humerus, size standardized measures of cortical area (CA) are greater for Newton and approach statistical significance ($p=0.052$). All second moments of area and the polar moment of area (I_x, I_y, I_{max}, I_{min}, and J) are larger on average for Newton although none of these differences are statistically significant. The AP bending strength measure I_x does approach statistical significance ($p= 0.084$). The humeri in both samples are almost equivalent on average in terms of cross-sectional shape as indicated by the ratios I_x/I_y and I_{max}/I_{min}.

The Radius

Although radial data were collected, preservation and inability to reassociate at Hagley mean that these bones are not considered in this study. Sample size is inadequate.

The Ulna

The ulnae are larger on average in Newton's sample for CA but the difference is not significant. The ratio I_x/I_y reveals that Hagley's ulnae are slightly greater in antero-posterior dimensions relative to medio-lateral dimensions. Unfortunately, preservation and loss of epiphyses, as well as the inability to associate this bone to other limb bones or individuals at Hagley, prevented the derivation of size-standardized CSG measures for the ulna. Based on general examination of the cross-sectional images, however, Newton ulnae appear to have greater bone mass in both antero-posterior and medial-lateral dimensions, appearing generally more circular.

The Femur

For the femur midshaft, Newton exceeds Hagley for all strength measures, but none of these differences are statistically significant. Newton's measure for I_x/I_y also approaches greater circularity for the cross section in comparing measures I_x/I_y and I_{max}/I_{min} for the two samples. The femur comparisons at the subtrochanteric level are more remarkable. This anatomical location is the only site within the comparative study where Hagley's sample exceeds Newton's for a mean measure of strength. The second moment of area I_x for bending strength in the AP plane at Hagley exceeds that measure for Newton, although the difference is not statistically significant. Shape differences related to this strength measure are apparent, however, and are characteristically different between the samples. The ratios I_x/I_y ($p=0.042$) and I_{max}/I_{min} ($p=0.006$) differ statistically significantly between the two contexts. Newton's subtrochanteric region appears AP flattened or platymeric with a much higher ratio of ML bending strength to AP strength.

The Tibia

For the tibia, CA is larger for Newton, the difference is statistically significantly ($p= 0.0197$). It is important to note that Newton's tibia sample for which CA and second moments could be standardized is very small ($n= 6$), and this comparison should be viewed with caution. The measure J approaches statistical significance for difference between the samples at the 0.05 level ($p= 0.059$). Newton's mean J value exceeds that of

Hagley. Newton's values for I_x (p= 0.0594), I_y (p= 0.0869), I_{max} (p= 0.0869), and I_{min} (p= 0.1038) also all exceed Hagley's values and approach statistical significance. The ratio I_x/I_y approaches statistically-significant difference at the 0.01 level (p= 0.015) and indicates the Newton populations' tibia are AP elongated compared to those of Hagley's population. The shape measures are probably the most meaningful for population comparison as acceptable sample size was attained. Due to the contribution of greater values for second moments of area and maximum and minimum second moments, this suggests greater robusticity, rather than medio-lateral flattening of the bone, but again, sample size for second moment measures is small.

Conclusion

The CSG study finds clear statistically significant differences for shape and strength measures between the two samples for limbs. Newton, on average, represents a sample of individuals of larger average body mass with inherently stronger lower limbs. Comparisons of the humerus between the samples reveal near significant difference for CA and overall greater strength measures. These findings are presented preliminarily here but will be discussed in detail for their significance in terms of labor and biocultural context in the next chapter. Chapter 8 will address each of the hypotheses outlined in Chapter 2 using the results derived here for the CSG comparisons.

Figure 7.1 CT Slice Images from Hagley Plantation Skeletal Sample, Right Humerus (Top) and Left Femur (Bottom).

Table 7.1 Total Skeletal Sample for CT Scans from Hagley Plantation.

Skeletal Element	Hagley Plantation	Newton Plantation
Skull	5	1
Humerus	17	24
Radius	11	19
Ulna	13	21
Femur	25	24
Tibia	*22*	21
Total	93	110

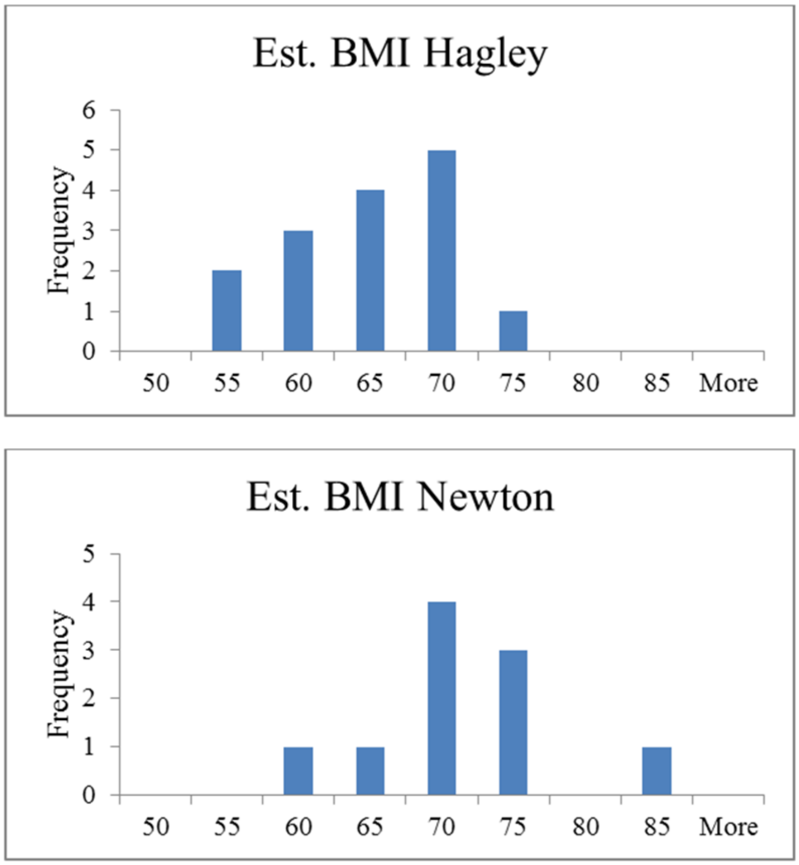


Figure 7.2 Estimated BMI (kg) for Hagley and Newton Plantation.

Table 7.2 Hagley Plantation CT Sample for CSG Study, Reassociated Individuals and Paired Unassociated Elements.

		Humerus		Radius		Ulna		Femur		Tibia		Innominate	
Individual	Sex	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1	Male		115					196	210			327	
2	Male	131	120					207	184	230	248	176	170
3	Female							188	215	234		172	330
4	IND	123	119					197	212	241			
5	IND	319	118					193	216		259		
6	Male							189	218	236	247		178
7	Female	124						200	211		258		
8	IND	126	112					204		240	244		
9	Male							191		238	245		
10	Female	320	122					199		232	246	328	332
11	IND		317					192	214	243	253		
12	Female	116	111							254	260		
13	IND							205		233	338		
14	Female								213	255	261		
15	Male	316							179		252	169	173
16	Male	130						195		237			
17	Male							198		239			
18	Male		318						217		251		163
Paired						148	158						
Elements						151	155						
						150	153						

Table 7.3 Hagley Plantation CT Sample, Unassociated Skeletal Elements.

	Humerus		Radius		Ulna		Femur		Tibia		Innominate	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Unassociated		114						183	231			
Elements	121						194		235			
	132						203		242			
	135							209		250		
		115					333			256		
					149							
						152						
						154						
						156						
						157						
						321						
						322						
			137									
				138								
				139								
				140								
			141									
			144									
				146								
				147								

Table 7.4 Newton Plantation CT Sample by Burial Number and Element.

		Humerus		Radius		Ulna		Femur		Tibia	
Burial #	Sex	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
7	SUB	*	*					*			
8	Male	*	*	*	*	*	*				*
9	IND							*			
20	Male	*	*	*	*		*	*			
22	Male	*	*	*	*	*	*		*	*	
24	SUB							*			*
25	IND			*		*	*		*		*
27	Male	*	*	*	*	*	*	*		*	
29	Female		*	*	*	*	*		*		*
38	Male	*	*	*	*	*	*	*		*	
42	SUB	*						*		*	
47	Male	*	*	*	*	*	*		*		
48	Male	*	*		*	*	*		*		*
52	IND	*	*	*		*			*	*	
54	IND	*		*	*	*	*	*		*	
56	IND		*	*	*	*	*	*			*

Table 7.5 Newton Plantation CT Sample, Commingled Portion.

	Humerus		Radius		Ulna		Femur		Tibia	
Commingled	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1	*						*		*	*
2	*						*		*	*
3	*						*			*
4	*						*			*
5	*						*			*
6	*						*			
7	*						*			
8	*						*			
9	*						*			
10	*									

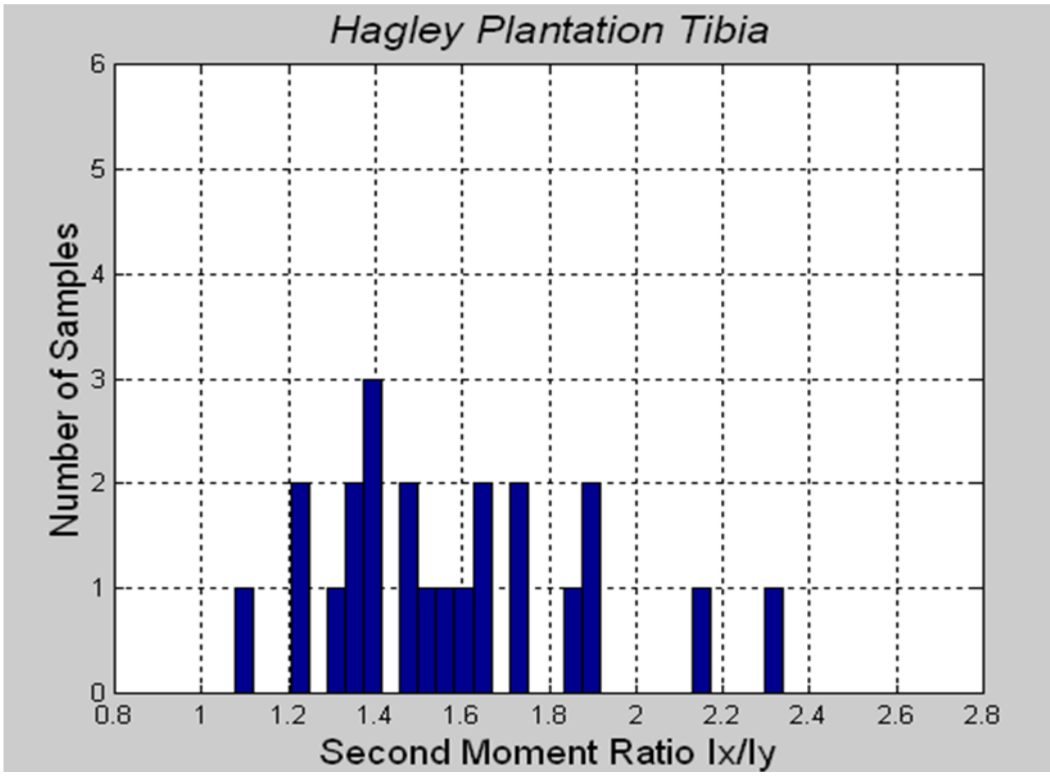


Figure 7.3 Histogram for Distribution of Tibia Shape Measure I_x/I_y at Hagley.

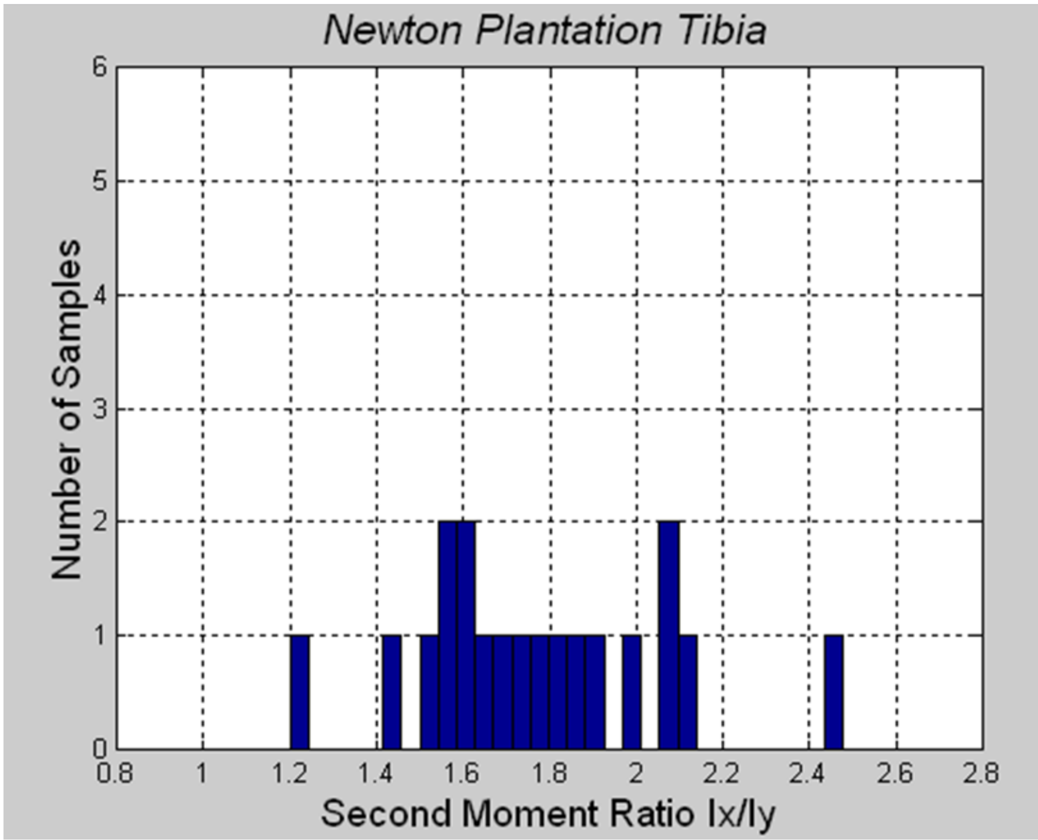


Figure 7.4 Histogram for Distribution of Tibia Shape Measure I_x/I_y at Newton.

Table 7.6 Descriptive Statistics and Results for Wilcoxon/Mann-Whitney U Test for Estimated BMI and Upper Limb CSG Measures.

	N Hagley/Newton	Mean/SD Hagley	Mean/SD Newton	Mean Ranks Hagley	Newton	Ua	z	P1	P2
BMI	14/10	63.27/6.89	68.94/6.38	9.7	16.4	109	-2.25	0.0122	0.244
Humerus									
CA STD	17/10	549.67 / 166.85	646.59 / 100.00	12.1	17.3	118	-1.63	0.0516	0.1031
J STD	17/10	505.47 / 220.52	603.89 / 170.38	12.5	16.6	111	-1.28	0.1003	0.2005
I_x	17/10	281.61 / 123.35	339.10 / 96.49	12.4	16.8	113	-1.38	0.0838	0.1676
I_y	17/10	223.86 / 100.14	264.79 / 76.80	12.6	16.4	109	-1.18	0.119	0.238
I_{max}	17/10	290.19 / 130.68	346.56 / 102.86	12.5	16.6	111	-1.28	0.1003	0.2005
I_{min}	17/10	215.27 / 93.79	257.33 / 71.83	12.5	16.6	111	-1.28	0.1003	0.2005
I_{max}/I_{min}	17/10	1.36 / 0.19	1.35 / 0.17	13.8	14.4	89	-0.18	0.4286	0.8572
I_x/I_y	17/10	1.28 / 0.20	1.29 / 0.13	13.8	14.3	88	-0.13	0.4483	0.8966
Ulna									
CA	13/20	90.84/25.57	101.56/17.04	15.1	18.2	154.5	-0.88	0.1894	0.3789
I_x/I_y	13/20	1.10/0.22	1.01/0.24	18.6	16	109	0.76	0.2236	0.4473

Table 7.7 Descriptive Statistics and Results for Wilcoxon/Mann-Whitney U Test for Femur CSG Measures.

	N Hagley/Newton	Mean/SD Hagley	Mean/SD Newton	Mean Ranks Hagley	Newton	Ua	z	P1	P2
Femur (MID)									
CA STD	17/10	49.51/13.35	54.09/8.70	13.1	15.5	100	-0.73	0.2327	0.4654
J STD	17/10	5531.6/2159.5	6124.9/1491.8	13.1	15.5	100	-0.73	0.2327	0.4654
I_x	17/10	2831.5/1075.4	3138.5/850.85	13	15.7	102	-0.83	0.2033	0.4065
I_y	17/10	2700.1/1139	2986.4/745.24	13.2	15.3	98	-0.63	0.2643	0.5287
I_{max}	17/10	3183.3/1340.4	3404.4/836.48	13.3	15.2	97	-0.58	0.281	0.5619
I_{min}	17/10	2348.3/863.97	2720.4/666.41	12.8	16	105	-0.98	0.1635	0.3271
I_{max}/I_{min}	17/10	1.35/0.20	1.26/0.10	15.2	11.9	64	1.03	0.1515	0.303
I_x/I_y	24/23	1.09/0.20	1.01/0.24	22.1	25.8	320	-0.93	0.1762	0.3524
Femur (SUB)									
CA STD	14/10	51.97/14.86	52.48/8.55	12.5	12.5	70	0.03	0.488	0.9761
J STD	14/10	7403.56/2890.31	7925.24/2054.92	12	13.2	77	-0.38	0.352	0.7039
I_x	14/10	3256.02/1293.07	3201.91/898.13	12.4	12.6	71	-0.03	0.488	0.9761
I_y	14/10	4147.54/1695.28	4723.33/1263.95	11.3	14.2	87	-0.97	0.166	0.332
I_{max}	14/10	4336.33/1666.42	4922.01/1293.86	11.4	14	85	-0.85	0.1977	0.3953
I_{min}	14/10	3067.23/1265.09	3003.23/826.63	12.2	12.9	74	-0.2	0.4207	0.8415
I_{max}/I_{min}	14/10	1.43/0.16	1.67/0.27	9.4	16.8	113	-2.49	**0.0064**	0.0128
I_x/I_y	14/10	0.80/0.15	0.68/0.14	14.6	9.5	40	1.73	**0.0418**	0.0836

Table 7.8 Descriptive Statistics and Results for Wilcoxon/Mann-Whitney U Test for Tibia CSG Measures.

	N Hagley/Newton	Mean/SD Hagley	Mean/SD Newton	Mean Ranks Hagley	Mean Ranks Newton	Ua	z	P1	P2
Tibia									
CA STD	11/6	50.8 / 8.5	61.0 / 11.3	7.1	12.5	54	-2.06	**0.0197**	0.0394
J STD	11/6	5113/1076	6791/2254	7.5	11.7	49	-1.56	0.0594	0.1188
Ix	11/6	3152/789.9	4416/1365	7.5	11.7	49	-1.56	0.0594	0.1188
Iy	11/6	1961/384.7	2375/968.4	7.7	11.3	47	-1.36	0.0869	0.1738
Imax	11/6	3459/808.8	4691/1605	7.7	11.3	47	-1.36	0.0869	0.1738
Imin	11/6	1654/316.5	2101/668.9	7.8	11.2	46	-1.26	0.1038	0.2077
Imax/Imin	23/19	2.1/0.32	2.3/0.21	20.9	22.3	233	-0.35	0.3632	0.7263
Ix/Iy	23/19	1.62/0.31	1.92/0.34	17.7	26.1	305	-2.17	**0.015**	0.03

CHAPTER 8

DISCUSSION OF RESULTS IN A BIOHISTORICAL FRAMEWORK

Based on the overall comparisons of measures of bone strength and bone shape for these two plantation groups presented in Chapter 7, the evidence supports the view that enslaved sugar producers (as represented by Newton Plantation's remains) experienced a greater cumulative labor burden based on skeletal functional adaptation than the rice producers of Hagley Plantation. Given the shorter lives of the Barbadian slaves, as indicated by mean age at death and mortality measures, the historical conception that sugar slaves were "worked to death" appears to be borne out. The enslaved rice producers examined in this study appear to have labored hard under compromised health conditions, but lived longer and do not manifest the degree of skeletal response to labor strains on the group level that characterizes the sugar slaves. Despite this overall finding, there are a number of complex factors (social, biological, environmental, and political) that likely contribute to these differing profiles which will be addressed in this chapter. In the first section, I briefly discuss the results of the multiple method pXRF commingling study for their biocultural significance. The next section presents the hypotheses outlined in Chapter 1 and briefly addresses the findings for them individually.

Following that, I provide a discussion, situated within a biocultural and political-economic perspective, of the findings of the study geared towards explaining the skeletal strength measures with consideration of the differing structures of the two slave economies. In this discussion, I consider the environmental, historical and political context of the two sites, their respective disease and nutrition environments, the culture and lifestyles of the enslaved, the motivations of planters and their imposed structures of social and labor control, and the means of production and relevant technologies involved within the two systems.

Biocultural Approach

In this dissertation, I consider indicators of skeletal functional adaptation, relative measures of bone strength and shape derived from their cross-sections, as a response to forced labor within two contexts, rice task labor and sugar gang labor, in hopes of addressing historical perceptions of their relative severity. Within the comparative study of these two distinct slavery regimes, I address social, cultural, and political factors as potential determinants of the proximate conditions that contributed to the formation of these individuals' skeletal morphology. In doing this, I attempt to link the local contexts for these two plantation skeletal samples to their larger regional and global connections. I consider patterning of CSG measures with respect to the historical and cultural record and other corollary evidence for past health patterns within enslaved populations. In this manner, I create an implicit framework geared toward seeking understanding of historical contingencies on past human biology. I follow two salient points presented by Goodman and Leatherman (1998) in their framing of a political-economic and ecological biocultural model, a means of bridging biology and culture. The first is that "understanding biological responses… requires understanding local history" and the second tenet is that "Humans create their environment and at the same time are created by their environment, an insight that goes back to Frederick Douglass." (Blakey 1998:388; Goodman and Leatherman 1998:20). These points are especially relevant for sugar and rice production. I argue that these two economies created unique local biologies by both the human toll related to social control and forced labor, and, with respect to the unparalleled impact and alteration that these two economies had on their environments. Rice planters themselves even debated and expressed their concerns about the impact on health, environment, and the enslaved caused by their artificial modification of the landscape (Chaplin 1992:30-31). In this chapter, I will integrate the findings with the historical and political-economic contexts of these two economies.

Biocultural Significance of pXRF results

The elemental aspects of the commingling study presented in this dissertation have biocultural implications for diet, origins, cultural practices, and possible medicinal treatment within the unique context of rice plantation culture. I will briefly summarize the findings and discuss possible explanations in this section with the caveat that it may be impossible to disentangle the elemental signatures and their respective causes (biogenic and diagenetic) given the methods used and the limitations of the skeletal sample. The end result of the commingling approach operationalized here, however, is positive in that it did succeed in creating a sample that was much more amenable to biomechanical comparative study than if examined by individual element without appropriate controls.

The fact that Sr and Pb were the best elements for sorting these remains is not a surprise and almost certainly reflects, to a degree, individual dietary differences as well as possible origins of the enslaved. Although rice plantations are perceived as unique and somewhat culturally bounded entities during the antebellum period, the presence of slaves born in Africa, the Caribbean, and other regions of the south persisted through the slavery era (Joyner 1984:173; Shugerman 2002). Whitten (1977) examined the economic motivations of the rice planters in consideration of medical care for the enslaved focusing on the large plantations of the rice-growing counties in South Carolina, to include those of Plowden C. J. Weston. He demonstrated the changing priorities in light of demographic performance and profitability of rice and cotton, suggesting that the rice planters may have had as much interest in sale and interregional trade of slaves as in rice production. Dusinberre (2000) also examined the interregional sale and trade of slaves by the Weston and Allston families. It is thus expected that there should be differing Sr signatures within the sample. The degree of reliance or individual preference for seafood, meats, and plant based foods also presents a context for differing Sr content within the Hagley sample. Rathbun (1987) suggested Sr elemental findings from Remley Plantation, Charleston were possibly reflective of a more plant-based diet with rare animal protein. Individual difference in bone Pb elemental counts, as suggested by the results of this study, are consistent with those findings for other South Carolina plantation contexts, namely the likelihood of exposure to Pb based on occupational exposure to lead-lined cookware or drinking ware, or due to ingestion from contaminated alcoholic beverages (Crist 1990; Rathbun 1987:250).

The findings in the present study with regard to elements which failed to be of utility in sorting commingled remains due to overlap in their measures, are also informative. Metals such as Cu and Fe displayed high degrees of overlap and variation within and between individuals in this study and likely reflect the presence of cultural practices such as burial patterns. Crist (1990) attributed this to burial in shrouds which were held together using copper pins. This pattern is historically documented for other areas of North America through the colonial and antebellum periods (Noel Hume 1976). As indicated by brown metallic staining at Hagley, nails and other iron artifacts suggest that coffins may have been used among the burials St. Mary's Chapel cemetery. No preserved wood or identifiable hardware was recovered with the remains.

An unexpected finding from the elemental analysis was the potential that mercury (Hg) demonstrated in clustering. Despite overlap in signatures, Hg displayed close clustering within the bones of individuals (Figure 8.1). Individual number 6 displays no detectable Hg, many cluster in the mid range, and one individual (1) is a high outlier for Hg/Ca. Zuckerman's (2010) study used pXRF to detect Hg among seventeenth to nineteenth century English skeletal samples, for the purpose of examining medicinal use of mercury for the treatment of syphilis, establishing the method's ability to detect trace amounts of the metal within buried human remains. Recent work by Rasmussen et al. (2013) found evidence that Hg was uniformly distributed in compact bone of an individual who was treated medicinally with mercuric compounds. The clear differential clustering in my study, coupled with the absence of evidence for Hg in large quantity within the soil suggest endogenous exposure of some individuals to mercuric medicinal treatments.

Calomel, a solution derived from chloride of mercury, was used widely in the nineteenth century, especially within the plantation economies of the south, as a purgative and anti-venereal medication among many other uses (Swiderski 2008:XIV-XV). Its use is documented during yellow fever outbreaks in Charleston, SC (Swiderski 2008:56). Both mercurial ointment and calomel are listed within the plantation journal for the Weston family's plantations from 1802 to 1820 (Weston 1764-1855). Plowden C.J. Weston directly refers to calomel in his "Rules and Management for the Plantation" in which the overseer is "particularly warned not to give strong medicines, such as calomel… Strong medicines should be left to the Doctor…" (Weston cited in Collins 1865:109) (Appendix A). It is likely, in Hagley Plantation's context that the elemental signatures of mercuric treatments are preserved in the skeleton.

Discussion of CSG Hypotheses

Hypothesis 1.

Based on historical narratives, demography, and slave import records, Newton Plantation's enslaved should reveal a sample of individuals who were possibly selected for their body size and musculature within the context of planter preference for sugar labor. They should be larger than Hagley rice plantation's enslaved in measures of body size, cortical area of bone, and relative measures of bone strength.

Hypothesis 1, Findings. The findings of this study's overall population comparison provide support for this hypothesis in that the overall estimated body mass is greater for Newton's individuals than Hagley's individuals. This population difference is statistically significant and may suggest selection for their participation in sugar plantation labor. The population comparison finds that Newton's enslaved are also comparatively larger than Hagley's enslaved for size-standardized cortical area, for all bones, however the only skeletal element where this difference approaches statistical significance is the humerus ($p= 0.052$). Newton is greater for all standardized measures of bending strength except for AP bending strength (I_x) and minimum bending strength of the femur subtrochanter. The only strength measure differences that approach statistical significance are those for torsional strength (J) of the tibia, for which Newton is greater ($p= 0.059$) and similarly for AP bending strength (I_x) for the tibia ($p= 0.059$).

Hypothesis 2.

2A. Relative to body size, I expect, despite the notion of more autonomy within working conditions for rice task agriculture, that both of these groups will exhibit relatively strong bones compared to a base line and be similar in bone strength measures to each other. Both groups were faced with heavy disease burdens and possible nutritional inadequacy, however, which may have placed limiting factors on their expression of bone functional adaptation, placing them in similar biocultural contexts.

2B. Alternatively, the fact that Hagley Plantation's enslaved appear to have lived longer on average, may mean that they show greater expression of labor-related bone strength increase. Implicit to this hypothesis is the possibility that Newton's individuals may be more compromised by nutritional and health insults- corroborating the conception of being "worked to death".

Hypothesis 2, Findings. The results of the population comparison conform most closely to Hypothesis 2A. The only baseline CSG data that were felt to be applicable were those of Ledger et al.'s (2000) comparative study of CSG properties of the humerus and tibia among probable enslaved 18th century South African laborers (Cobern sample), a modern South African labor class sample, and a group of Later Stone Age African hunter-gatherers. The femur was not examined in the Ledger et al. study. Tables 8.1 and 8.2 place Hagley and Newton Plantation's size standardized samples for humeri and tibiae in comparative context with these samples and figures 8.2 through 8.6 display them in bar graphs by measure. Newton has the largest value for standardized CA of the humerus, as well as the second largest for CA of the tibia, only surpassed by Ledger's highly mobile hunter gatherer population. Hagley's males fall beneath Newton and all of the other samples except the modern working class sample, which they slightly surpass, for CA of the humerus. For CA of the tibia, Hagley's males are on par with the Cobern sample, barely exceed the modern workers, and fall well beneath Newton and hunter-gatherers. Hagley and Newton both fall below Cobern and modern workers in South Africa for ML bending strength of the humerus (I_y), but are on par (Hagley) or above (Newton) these samples for AP bending strength (I_x). Newton approaches Cobern for torsional strength of the humerus (J), while Hagley's value is lower and on par with modern workers, but exceeding hunter gatherers. Newton and the hunter gatherers are remarkable for exceeding all of the other groups for AP bending strength (I_x) and torsional strength (J). The two samples fall short of Cobern but exceed Hagley for ML bending strength (I_y) of the tibia.

The findings of greatest relevance to the current study are represented in bar graphs for the humerus and tibial measures. Figure 8.2 compares standardized CA for the humerus probably reflects, to a degree, relatively smaller body size for Hagley's enslaved. Figure 8.3 for I_x reflects greater AP bending strength for the enslaved samples versus those who were not enslaved. Figure 8.4, displaying I_y for the humerus suggests greater ML bending strength among urban laborers and slaves compared to those involved in agricultural labor (Hagley and Newton). Figure 8.5 portrays I_x for the tibia and is of interest in that Newton's enslaved are on par with the hunter gatherers for a probable mobility measure. Figure 8.6 places Newton as roughly equivalent in torsional strength (J) to the hunter gatherer sample.

Table 8.3 places Newton and Hagley's sample in comparative context with Ruff's (1999) data for shape ratio (I_x/I_y) for the femur midshaft among agricultural and hunter gatherer populations. The comparison suggests that Newton and Hagley Plantation generally fit the accepted pattern for greater circularity of the midshaft associated with agricultural subsistence patterns. These population means also reflect sexual dimorphism within Newton and Hagley.

All of these groups in the preceding comparison were involved in either labor or long distance travel for subsistence purposes, and as a result seem to have differently apportioned relative strengths of bone which appear to reflect functional adaptation to differing work contexts. Overall, the skeletal and historical evidence supports them all being relatively strong due to the muscular and underlying bony response to heavy workload. The three questions initially proposed (Chapter 1) beneath Hypothesis 2 are now considered in discussion of Hypothesis 3 as they are deemed to be closely related to findings that came from addressing Hypothesis 2.

Hypothesis 3.

Due to the fact that both of these groups were involved in heavy but diverse labor in terms of occupations within each economy, variations in relative strength and shape of the skeletal elements under study within and between these samples should be present and indicative to some degree of differential labor strains. The following questions will be addressed within Hypothesis 3:

1) Does the skeletal evidence correlate with documented tasks and divisions of labor? If not, how do we account for the discrepancies?
2) Studies of slave skeletal remains in urban and industrial contexts such as Catoctin Furnace (Kelley and Angel 1983), and Cape Town, South Africa (Ledger et al. 2000) suggest evidence for a considerable degree of sexual dimorphism in limb strength, suggesting clear sexual divisions of labor.
3) Do the skeletal remains within the rice and sugar plantation economies reflect differences in CSG properties that reflect differential labor patterns and sexual division of labor?

Hypothesis 3, Findings and Discussion

In attempting to address Hypothesis 3, to assess sexual dimorphism in upper and lower limb strength and shape, my study is severely limited by sample size and preservation. Rather than conduct statistical analysis involving such small samples of female slaves for both sites, I chose to plot relevant strength measures for the samples as a whole in hopes of demonstrating patterns by sex within and between samples. I plotted standardized CA versus J as the most representative overall measures for population bone strengths. Immediately, a consistent portion of Hagley's female sample along with one male, stood out from all the rest as low outliers from the entire study sample. These are the individuals that I considered omitting earlier due to bone weight, but made the decision to leave in for their potential to contribute to cross-sectional shape measures as well as the potential for them to be informative about the population's nutritional and health status.

Although I do not assess Percent Cortical Area (PCA) in this study, it is obvious from their CT Images, that these bones have extensive endosteal loss due to bone resorption, and also exhibit macroscopic porosity. The figures are informative, having obvious implications for health and nutrition status for Hagley. Osteopenia and poor maintenance of cortical bone due to health and nutritional stress have been a characteristic finding within other studies of nineteenth century African Americans (Martin et al. 1987; Rankin-Hill 1997). Figures 8.7, 8.8, and 8.9 present scatter-plots of Newton and Hagley's individuals by element for CA versus J for the humerus, the femur subtrochanter, and for the femur midshaft respectively. No individuals are repeated, and these representations reflect to the best degree possible, the complete portion of each sample for which body size standardization could be implemented. CA and J are obviously correlated measures due to the inherent relationships between the amount of bone in a cross-section, and general rigidity or strength. The tight linear relationship of the cluster for the femoral midshaft is consistent with findings that this is a major location of load bearing bending stress in the body. For humeral CA and J measures, a relatively looser correlation is apparent in the plot, and appears consistent with the fact that this bone is not load-bearing and may respond differentially to imposed loadings (Eleazer 2013). Sexual dimorphism and probable labor related relative strength differences are probably apparent here, but would be impossible to tease out without a larger sample with better sex controls. The subtrochanteric femur is interesting as it displays almost the degree of variation apparent for the humerus. This is consistent with findings that this measure may be linked to body size and shape variation (Stock 2006).

Interestingly, this region of the femur has been cited as an anatomical region which likely reflects differences in subsistence economy, more so than mobility as other lower limb measures may reflect (Larsen 1997). This measure is discussed further along with the significant differences in the tibia in the following pages.

The clustering apparent in the previously-discussed plots provides evidence that Hagley's males were in fact as strong or stronger in relative measures than the majority of Newton's population. I next made the decision to remove the low outliers for CA and J as well as female components and the majority of the indeterminate sex individuals and undertake a comparison of males of prime age, those exhibiting strong bones based on gross weight, relatively little degenerative change, and no obvious pathology. The results are presented in a Mann-Whitney U Test (Tables 8.4 and 8.5). This comparison removed the statistical effects of low outliers from the comparisons of Hagley and Newton, resulting in the reversal of virtually all ranks of strength measure in favor of Hagley's males for both the humerus and the femur. Obviously sampling effect is still apparent, but these findings suggest a more complex picture. The overall results remain similar. There are no statistically significant differences between the samples for the humerus, and the only significant differences are found in the subtrochanteric region of the femur. This finding is more supportive of Hypothesis 2B, suggesting that Hagley's males perhaps had more cumulative experience in heavy labor, probably due to living longer.

Considering some of the previously-described problematic effects of sample size and sex determination, I consider that the scatter plots of CA versus J by element are the best means of observing pattern that reflects division of labor between and within these two plantation contexts. Tabulation and sorting of Plowden C.J. Westons's Will (Weston 1864) (transcribed by Wright 2009) reveal a pattern that is informative for my results. Weston's will provides a list entitled "Negroes belonging to Hagley Plantation, Estate of Plowden C. J. Weston, 1864" (Appendix B). The document lists 185 slaves for Hagley by name and age. It provides listed occupation for 111 adolescents and adults. Approximately 29 percent (n= 32) of the enslaved are prime hands (all female). Roughly 11 percent (n= 12) of the enslaved are "Half Hands" likewise apparently all female. Approximately 23 percent of the enslaved (all male) are "Ditchers" (n=25) and 31.5 percent of the enslaved (n= 35) are involved in specialized tasks such as cattle and sheep minding, sewing, nursing, house servitude, cooking, midwifery, carpentry, fishing, and gardening. For males, 20 slaves (approximately 18 percent) have occupations pertaining to agriculture that do not list them as "Ditchers".

The degree of variation apparent in the clustering of relative bone strengths convincingly approximates these types of breakdown in occupation. Males possess the relative strength clustering to suggest their participation in the most arduous aspects of field labor for Hagley. This is not possible to assess at Newton, due to the small sample size for females. Totalling “Prime Hands”, “Half Hands”, and “Ditchers” for Hagley reveals that 69 percent of the population participated in agricultural labor. The clustering of CA versus J for the humerus is limited by small sample size for females at Hagley, but the pattern, nonetheless suggests differentials in relative arm strength with males having both greater standardized CA and greater torsional strength for the bone. The female outlier is noteworthy, as this humerus displays as strong and dense bone on cross section as most of the male sample. It clearly reflects a woman involved in heavy upper arm labor.

The pattern of differential clustering with males having greater values for both CA and J is borne out in general within both the humerus and the femur for Hagley’s slaves. I think it clearly reflects evidence for bone strength differences that reflect sexual division of labor. In the plots, those of indeterminate sex consistently occupy an intermediate cluster, suggesting they probably represent a percentage of male and female individuals. The pattern is similar for Newton Plantation in that those of indeterminate sex and a single identified female cluster intermediately and lower respectively for both values. Thus, sexual division of labor appears to be present, but cannot be adequately quantified due to sample limitations.

Findings for the Lower Limbs

The significant differences between Hagley and Newton Plantation’s enslaved lie almost entirely within the lower limbs. For the femur, statistical significant differences were seen in both the whole group comparison and the prime age male comparison.

Mann-Whitney U-Test results (Table 8.5) for the subtrochanteric region reveal that the prime male comparison reflects significant difference more based on bone strength measures rather than based on shape differences as suggested in the overall group comparison. Figure 8.10 shows CT images of the subtrochanteric region from Hagley and Newton which approximate the mean shape measures which displayed statistically significant difference within the overall group comparison. The apparent shape difference is minimized in the male comparison, but strength measures are significantly different. Hagley's males present significantly greater bending rigidity in all planes as well as greater torsional strength in the subtrochanteric femur compared to Newton's males.

The morphology of the subtrochanteric region of the femur has been investigated with respect to the metric phenomenon of platymeria or the platymeric index (PI). Variations in expression of its shape have been attributed to a number of influences, including sex (Bass 2005; Ruff 1987, Brown 2006), genetic difference between groups (Gill et al. 1990; 2001; Miller 1995; Wescott 2006), body shape (Ruff et al. 2006; Stock 2006; Shaw and Stock 2011) and activity (Cole 1994; Kiesewetter 2006; Larsen 1997), especially flattening (platymeria) due to possible increases in sedentism across population transitions.

Dutt (2012) recently assessed the morphology of the proximal femur within the context of investigating activity, sex, and health among a population of Bronze Age agricultural and agropastoralist inhabitants of the Arabian Peninsula. She found clear evidence for differential habitual use of muscle groups reflected on the proximal femur among this mobile population who engaged in a heavy labor pertaining to farming, herding, and fishing among other subsistence activities, but expressed caution and the need for considering corollary evidence such as archaeological data in order to infer exact activities. She observed trends in her skeletal sample that suggested the proximal femur varied in shape, did not appear to be under strong genetic control, and did not closely associate with sex, suggesting possible association with differential activities.

The results of my study provide convincing evidence that the strength differences are activity-related because they associate with known regimes of activity- work in rice fields. The subtrochanteric region is close in proximity to the intertrochanteric line, the attachment for the iliofemoral ligament. This is one of the strongest ligaments in the body and subject to a variety of dynamic strains due to its association with the capsular ligament and the femoral acetabular joint (Gray 1995:242). Bony changes in this region likely reflect increased strain in the hip region. I do not quantify or assess musculoskeletal stress markers (MSM) in the present study, but it is notable that the presence of MSM or hypertrophy of this landmark characterizes many of Hagley's male slaves (Figure 8.11). This skeletal change is present in 8 of 14 male femora used in the biomechanical study. It is not apparent in the female portion of the Hagley sample. It is reasonable to conclude that the occupation of ditching, coupled with the historically and ethnographically-documented modes of fieldwork in the inundated rice fields have contributed to these skeletal properties. The enslaved at Hagley toiled in the deep pluff mud along the Waccamaw River, an environment that imposes obvious restrictions and increased burden for mobility as well as occupational hazards. The skilled maintenance of heavy equipment such as the rice trunks within these environs was a constant requirement. Regulation of the flooding of fields, weeding, and harvesting were incredibly painstaking and regimented (Tuten 2010).

Asian Rice: A Modern Occupational Analogy

The modern Asian occupational health literature provides compelling evidence for the unique health and occupational hazards faced by rice workers. Many aspects of rice agriculture, as exemplified by Nepal, are done in the same way in which they were by the nineteenth century labor of enslaved workers on the Waccamaw Neck tidal rice plantations. Modern rice workers are exposed to repetitive motion and postural requirements that create musculoskeletal disorders as well as environmental factors and insect vectors which contribute to skin, respiratory, and parasitic disease (Joshi and Phil 2002:111). Although levels of mechanization vary throughout the modern rice-producing regions, many locales require that laborers construct dikes and levees to hold water for inundation of fields. Aspects of the control of weeds and pests are still undertaken exhaustively by hand in some regions, and the demands of the harvest still include hand cutting and carrying of rice stalk bundles (2002:112). Barefoot labor in inundated fields exposes workers to parasites and the intensive labor schedules expose workers to repetitive stress injuries due to overuse of muscles, poor posture, and joint stress (2002:113).

The contemporary musculoskeletal and biomechanical signatures of rice labor which hold the most relevance to my findings for Hagley, include research pertaining to ergonomics and musculoskeletal disorders. A study of the musculoskeletal injuries of Thai rice farm workers by Karukunchit and colleagues (2014), reveals extensive occupational stress brought on by the atypical biomechanics associated with the cultivation and harvesting of rice, namely prolonged walking, standing, stooping, bending, and repetitive work done abnormal postural stances. The imposed hip, knee, and foot strains result in frequent diagnoses of tibial torsion, anterior pelvic tilt, femoral antetorsion, knee hyperextension and knee varus. Maintenance and harvesting exposes workers to both hard ground surface work and wet, slippery surface hazards (Karukunchit et al. 2014:77-79).

Findings for the Tibia

The statistical differences in the tibia between the samples are interesting and present interpretive difficulties. Historically, both of these contexts are seen as relatively bounded communities. Weston's enslaved traveled on boats, with supervision, and traveled on foot between plantations, with appropriate authorization and pass tickets (Joyner 1984). I think the overall morphology of the tibia for Hagley's enslaved reflects a relatively lower degree of mobility. A relatively low I_x value compared with Newton and the hunter gatherer sample reveals reduced mobility, more similar to the modern sample (Figure 8.5).

Newton's statistically significant differences for the tibia, as presented in Chapter 7 (Table 7.8) reveal greater strength and AP elongation. However, these are small sample sizes, meaning caution is necessary in interpreting these comparisons. Nevertheless, Newton's tibia is AP- elongated, a finding often linked to increased mobility (Stock 2006; Marchi 2008). They appear more platycnemic based on shape ratios, but do not display comparatively reduced ML rigidity. Figure 8.12 illustrates a Hagley and a

Newton tibia which approximate the mean measures for shape in the overall sample. There is no apparent historical reason to consider that Newton's enslaved would be more mobile than Hagley's given the strictness of the sugar codes (Dunn 1973). Recent focus on the household economies of Barbados (Handler and Wallman 2014) hints at mobility. The thriving market economy of the island would have entailed inter-plantation travel and transportation of goods, crafts, and produce. Likewise, fishing, if permitted by the planter, would have given slaves good reason to travel frequently to the coast. Newton is only a few kilometers from the beach, but intervening cliffs present terrain obstacles for negotiation. The land around Newton is high and only gently undulating, but nonetheless, is distinct from the flat lowlands surrounding the Waccamaw Neck plantations. Newton may present increased mobility due to some of these factors.

Consideration of pathology is also important in this interpretation. I selected Newton's tibia for scanning based on gross assessment for lack of pathology, but I cannot rule out the possibility that appositional bone formation on some of Newton's tibiae are not pathological in nature. While not grossly visible, the residual or initial effects of bony changes of vitamin deficiencies such as Rickets or the initial response to treponemal disease such as syphilis or yaws may be manifest in some of these cross-sections. Shuler's (2005) analysis revealed evidence for some of these specific conditions, and recent work with Newton's remains revealed a high prevalence of periosteal lesions, especially affecting the lower limbs (Shuler 2011).

Two of Newton's burials (burials 8 and 27) (Figure 8.13) display remarkable apportionment of bone mass in the tibia in both the anterior and posterior directions, combined with overdevelopment of the interosseous crest. This morphology is not approached within Hagley's sample and, I speculate, must be indicative of combined effects of mobility and field labor. The interosseous crest of the tibia serves as attachment for the interosseous membrane which encases the musculature of the lower leg. Modern athletes who exhibit hypertrophy of these muscle groups are involved in activities which involve plantar flexion and walking on incline among other activities, such as bicycling (Harris, personal communication 2016). The labor of the sugar harvest at Newton likely involved carrying heavy burdens such as cut sugar cane over undulating topography, a possible cause for skeletal response. Other explanations for increased mobility include specialist labor roles, or that some individuals traveled between plantations for social, religious, or other reasons.

In summary of the hypotheses proposed, the evidence clearly suggests evidence for labor differentials and also for strength differences that reflect on the whole the type of labor they participated in as well as the environment of cultivation. Labor and mobility within a swamp environment of tidal rice agriculture has likely influenced the morphology of the femur at Hagley, giving them relatively stronger bones than those of Newton for this portion of the lower limb. Newton's tibial measures suggest increased mobility and probably reflect increased mobility with heavy burdens, as ethnographically documented for the sugar cane harvest (Handler 1965). The findings in general suggest differential labor strains for these two economies.

Political Economy, Health, and Labor

The general profiles of the wealthiest Waccamaw rice planters as represented by the Allston and Weston families, among others, are of men of considerable inherited wealth who had either familial attachment to rice agriculture or an awareness of the great potential profit of the enterprise (Chaplain 1992; Dusinberre 2000:286-287). They were shrewd capitalists and remained deeply and intimately involved in managerial aspects of agriculture, sometimes to the detriment of their own health, given the health hazards of the rice region and size of their landholdings coupled with the amount of travel involved between residences. They were deeply devoted to their plantations, yet unable to reside on them during the malarial summers. Among these wealthy entrepreneurs, men such as Robert Allston and Plowden C.J. Weston may have been unique in that they remained as closely involved as possible year-round, having summer residences on Pawleys Island and relatively close inland towns such as Conway, South Carolina (Dusinberre 2000:311; Collins 1865). Other wealthy rice planters remained either remained “wholly non-resident” or spent as much as half of the year as far away as Charleston, Appalachia, or even Europe (Dusinberre 2000:311). As such, many plantations were left for much of the year in the control of white overseers, many of whom had reputations for cruelty and abuse of power. Severe corporal punishment, torture, and even capital punishment are historically documented for the Waccamaw rice region (Dusinberre 2000).

Plowden C.J. Weston is remembered for his “Rules and Management for the Plantation” (Weston, cited in Collins 1865:104-116)(Appendix A.). These and period accounts including slave narratives are cited by numerous sources as indication that Weston was among the most humane of the Waccamaw rice planters (Collins 1865; Devereux 1973; Dusinberre 2000; Joyner 1984). According to the “Distribution of Slaves in All Saints’ Parish by Plantation, 1860” (cited in Joyner 1984:19), Weston held

334 slaves (196 male and 138 female) in his three adjoining plantations, Hagley, Weehawka, and True Blue.

Weston's rules convey a paternalistic concern for the overseer "MOST DISTINCTLY to understand that his first object is to be, under all circumstances, the care and well-being of the negroes." It lists in detail the "Schedule of Allowance" for food and rations for workers, children, the sick and the elderly, describes allowances for Christmas and holidays, and delineates work schedules. The daily task is indicated as being a nine hour work day for the "meanest full hand… working industriously". Half-task work was done on Saturday, with Sunday off as well as the Christian holidays.

Weston frequently wrote and spoke in defense of slavery with direct reference to the inherent inferiority of the negro which made them well-suited to the institution of slavery, but, ironically, he and his wife Emily also illegally taught some slaves to read (Devereux 1973). Weston sent his well-known enslaved carpenter Renty Tucker to England for apprentice training. Weston also built a chapel for his slaves. The Rev. Alexander Glennie ministered and served to provide Christian education to the enslaved at St. Mary's Chapel where the skeletal remains were recovered (Joyner 1984). Implicit in the wealthy Waccamaw planters' worldview, and possibly divergent from regions such as sugar, depending on time period, was the view that enslaved African Americans were in fact human. The means of social control were much different than those employed within the sugar economy as historically described (Dunn 1973). They were seen as chattel and investment, but within many of the complex relationships of the period, also maintained their own distinct social identities through complex familial and kinship networks, knowledge and trade skills, and resistance to planter-imposed work structures

(Bell 2010). Planters and slaves disputed the nature and quantity of imposed tasks and slaves often exercised power to redefine labor terms based on protest or negotiation (Chaplain 1992; Morgan 1982).

Interpretation of the demography of antebellum Georgetown is varied. Ricards and Blackburn suggest the Georgetown slave census may indicate low fertility probably due to imbalance in sex ratios and high child mortality. Whitten's (1977) opinion is that the gaps in the census for the Waccamaw Georgetown area represent the selling of young slaves, rather than the possibility of epidemics of fever (Ricards and Blackburn (1975). Francis Marion Weston, Plowden Weston's father, owned slaves who were among the older mean-age groups for the Waccamaw planters (mean age 24.38 years) (Ricards and Blackburn 1975: 217). Plowden Weston probably continued in his family tradition with his exhibited concern for medical care and rationing for the sick as well as time for rest and recovery. Plowden Weston, however, did, according to historic documentation sell 100 to possibly 180 slaves from his Laurel Hill Plantation in 1856 (Collins 1865; Dusinberre 2000), in effect severing family and kinship ties, sending the slaves west.

The skeletal remains from St. Mary's Chapel corroborate the concern for maintaining the labor force via slave health care. The presence of clear bone loss in three (2 female and one male) of the 18 assembled individuals at Hagley is suggestive of osteoporosis, obviously a function of age, but probably reflecting the combined effects of chronic illness such as malaria and febrile illness, possible protein deficiency, and illness-related immobility. I do not suspect severe malnutrition to be the cause given Weston's wealth, the dietary allowances described in his "rules", and his humane reputation. Figure 8.14 shows a probable osteoporotic femur and a humerus from the Hagley skeletal remains. Weston's "rules" and other sources indicate the necessity for sick persons of "lying in" and the presence of a "hospital". Numerous planters kept detailed records of work days lost to illness (Whitten 1977). Given the prevalence of tuberculosis, and the description of the immobility that characterized Plowden Weston's own death from the disease in 1864 (Devereux 1973:120), it is quite possible that failing health among the slaves led to extended bed-ridden periods prior to death. Hagley's skeletal sample, biased as noted towards the larger bones, displays little evidence to corroborate the disease other than the presence of several rib fragments which display woven bone plaques or periosteal reaction of their surfaces similar to those described by Pfieffer (1991).

Considering the overall findings, and then the male section comparisons, I conclude that the demographic profile and evidence from male strength measures backs up the idea that for tidal rice, at least among planters like Weston, the motivations of planters were multifold. Their concerns for population health and birth increase served to maximize the participation in the labor force and foster profits from rice production and slave sales. The skeletal findings for age at death mirror aspects of the slave inventory recorded in Weston's will by showing evidence for an older workforce compared to that of Newton based on skeletal findings and historical evidence. As important as planter motivations are to these outcomes, however, is the agency and self-determination of the enslaved in determining their own labor and lifestyle. The ability of slaves in South Carolina to negotiate their own labor routines and social networks may have been the primary driver of their ability to survive given the conditions they faced.

Unfortunately, the documentary record and chronology for the burials from Newton are not known. We cannot examine the motivations and economic concerns of the planters directly but can infer from the record of the period (at least for a large portion of the seventeenth and eighteenth centuries) that planters did not invest greatly in health care or the well-being of the enslaved, due to the low cost of replacement (Kiple 1984; Higman 1984; Sheridan 1985). Shuler's findings for health at Newton corroborate great life stresses endured due to scarce resources and overcrowding. Environmental hazards such as hurricanes, frequent epidemics, and the impact of psychosocial stress due to varied forms of abuse perpetuated by overseers, especially within the context of absentee British planters, took a severe toll on population health (Shuler 2005; Shuler 2011). Shuler and others state that the cost of replacement in much of the time period for Newton would have been low enough that planters often worked slaves without concern for their well-being.

Handler's review of the Newton documentary record indicates that Newton was one of the larger Barbadian plantations during the prosperous 1670's and that its original owner, Samuel Newton was among the "most eminent planters in Barbados" (Handler 1978:62). The plantation remained in the family following Newton's death, but underwent periods of absentee ownership. The plantation varied in size over the slavery period but remained large, on the order of 400 to 500 acres throughout most of its 175 year existence (1978:65-66). Period accounts and skeletal evidence for Newton and Barbados in general suggest dietary inadequacy of plantation provisions, probably not offset in full by the slaves own household production activities (Corruccini et al. 1987; Handler 1978:88-89; Shuler 2005). Labor structures for Newton and Barbados were discussed in Chapter 2 (see pages 36 to 38), and are not presented again here. Social relationships and slave status are notably complex within the Caribbean also, but the English were notorious for being the most "heavyhanded with their liberties over slaves" (Stinchcombe 1995:141). Barbadian planters debated the well-being of bondsmen primarily out of concern for the maintenance of the system through interest in natural increase and profits (Handler 1978:83).

I conclude this discussion with an opinion that the findings suggest intriguing differentials between these two economies which reflect labor structure, social control, and general health patterns. These differences are manifested in skeletal evidence, which is informative about the lifestyles of the enslaved within these economies, especially when multiple lines of evidence are considered. These bone strength data can be merged with other lines of data, including biological and archival evidence, in order to further our understanding of health during slavery.

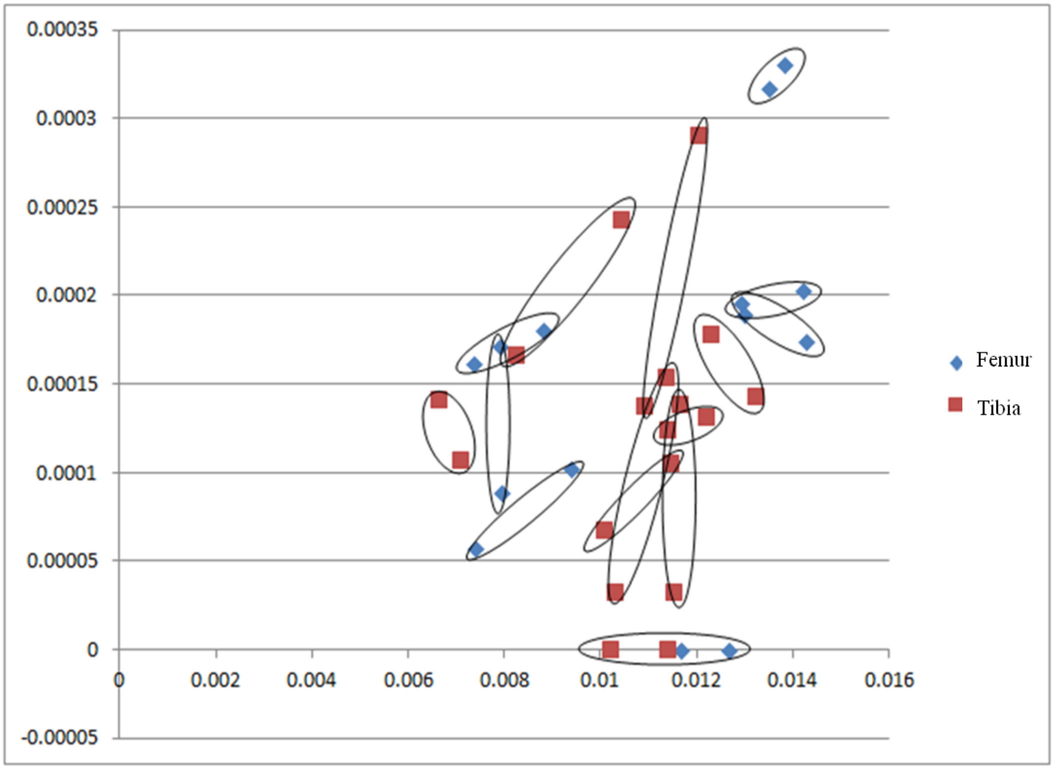


Figure 8.1 Clustering of Test Individuals for Ratios Sr/Ca versus Hg/Ca in paired lower limb elements at Hagley Plantation.

Table 8.1 Size-standardized Mean CSG Values for the Humerus (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

	N	CA (mm)	Ix (mm)	Iy (mm)	J (mm)	Imax/Imin
Hagley Enslaved	12	579 +/- 160	312 +/- 120	246 +/- 98	558 +/- 215	1.4 +/- 0.2
Newton Enslaved	8	659 +/- 86	352 /- 98	273 +/- 76	625 +/- 171	1.4 +/- 0.2
Cobern Enslaved	32	629 +/- 118	309 +/- 121	334 +/- 139	647 +/- 250	1.6 +/- 0.2
Modern	36	573 +/- 129	289 +/- 97	307 +/- 94	592 +/- 184	1.5 +/- 0.2
Hunter Gatherers	30	616 +/- 123	250 +/- 110	228 +/- 81	478 +/- 182	1.5 +/- 0.2

Table 8.2 Size-standardized Mean CSG Values for the Tibia (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

	N	CA (mm)	Ix (mm)	Iy (mm)	J (mm)	Imax/Imin
Hagley Enslaved	6	545 +/- 68	327 +/-104	189 +/- 24	517 +/- 124	2.1 +/- 0.3
Newton Enslaved	5	604 +/- 117	418 +/- 171	213 +/- 46	631 +/-214	2.2 +/- 0.2
Cobern Enslaved	25	535 +/- 135	311 +/- 123	248 +/- 111	559 +/- 208	2.5 +/- 0.6
Modern	23	512 +/- 95	298 +/- 77	226 +/- 60	524 +/- 129	2.2 +/- 0.4
Hunter Gatherers	29	641 +/- 101	417 +/- 126	220 +/- 59	637 +/- 167	2.7 +/- 0.5

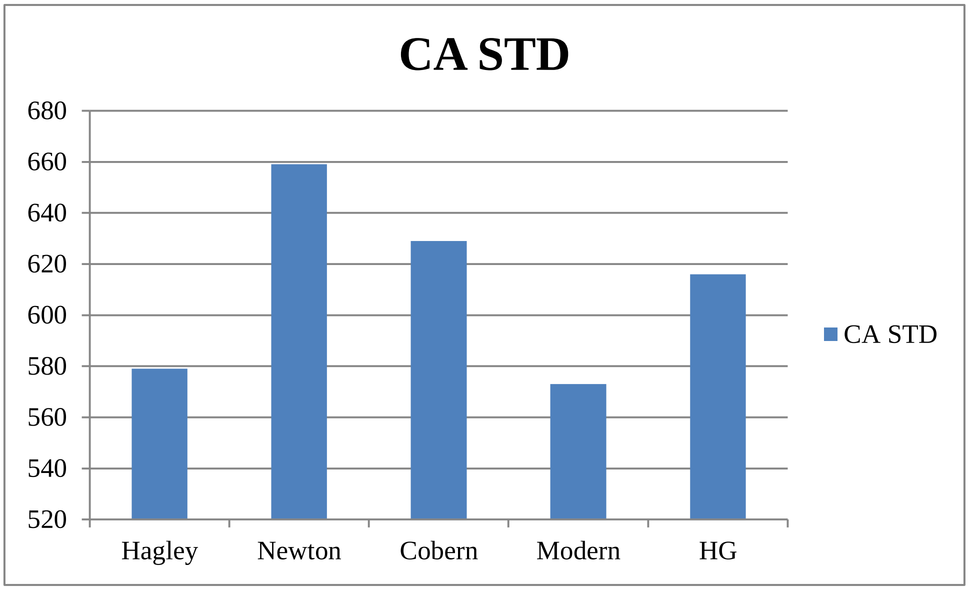


Figure 8.2 Size-Standardized Cortical Area (CA) for the Humerus (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

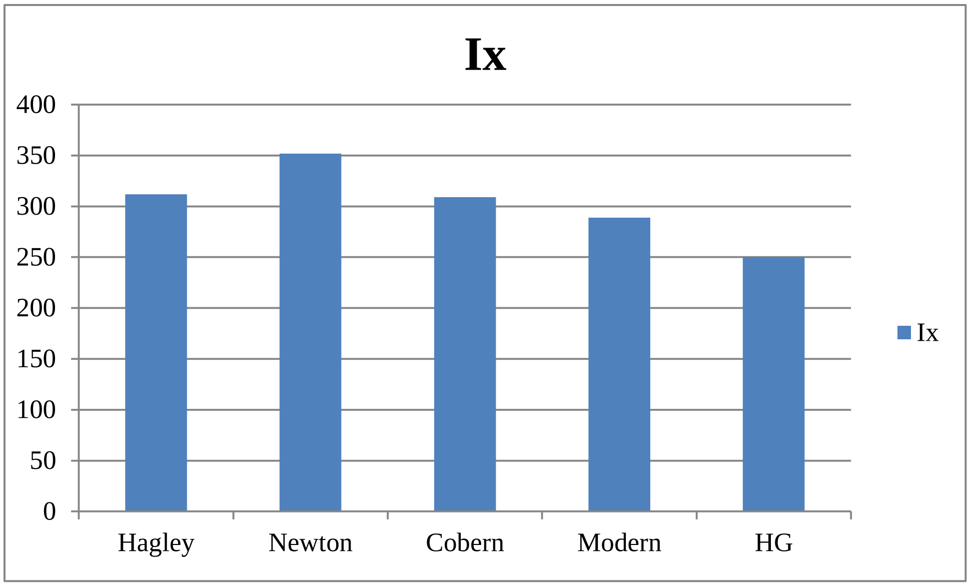


Figure 8.3 Size-Standardized Second Moment of Area I_x for the Humerus (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

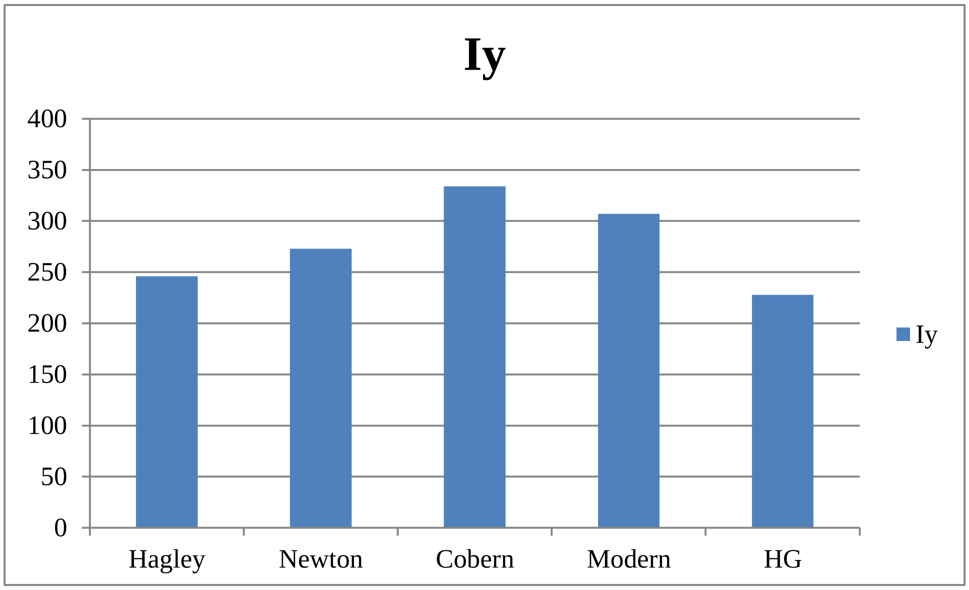


Figure 8.4 Size-Standardized Second Moment of Area I_y for the Humerus (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

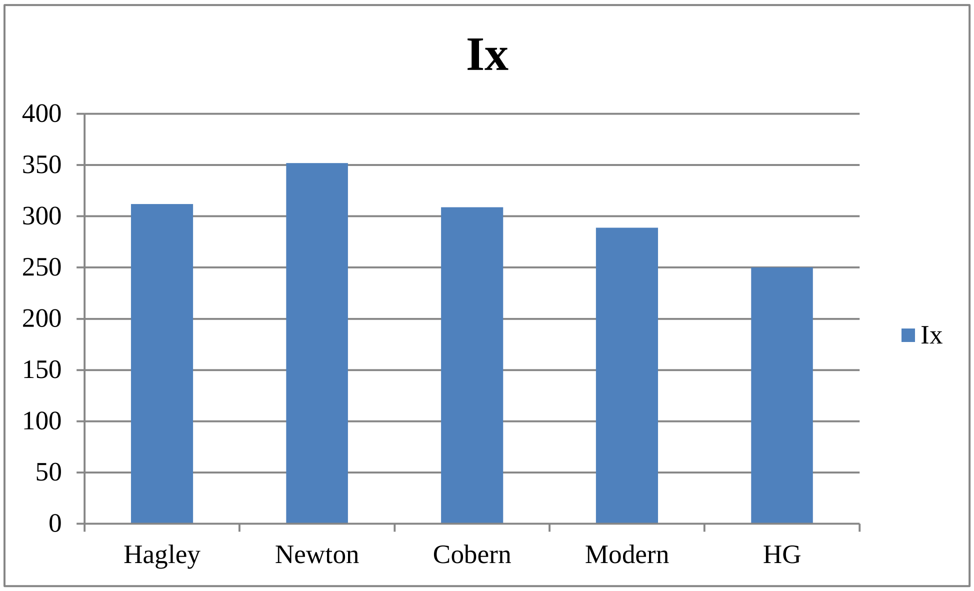


Figure 8.5 Size-Standardized Second Moment of Area I_x for the Tibia (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000

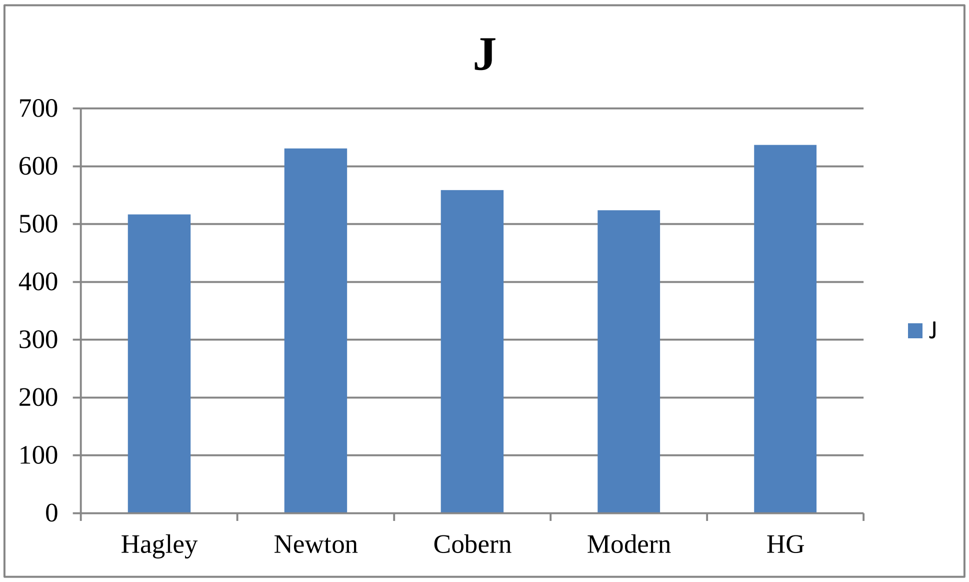


Figure 8.6 Size-Standardized Second Polar Moment of Area J for the Tibia (Males) with Hagley and Newton Plantations Compared to Data from Ledger et al. 2000.

Table 8.3 Comparison of Shape Ratio I_x/I_y with Hagley and Newton Plantation's Enslaved Compared to Prehistoric Native American Hunter Gatherers and Agriculturalists, Data from Ruff 1999.

Sample	Male	Female
Georgia Coast HG	1.28	1.16
Georgia Coast AG	1.08	1.03
Stillwater HG	1.26	0.98
Southern Plains AG	1.74	1.29
Hagley Enslaved	1.06	1.1
Newton Enslaved	1.12	1.06

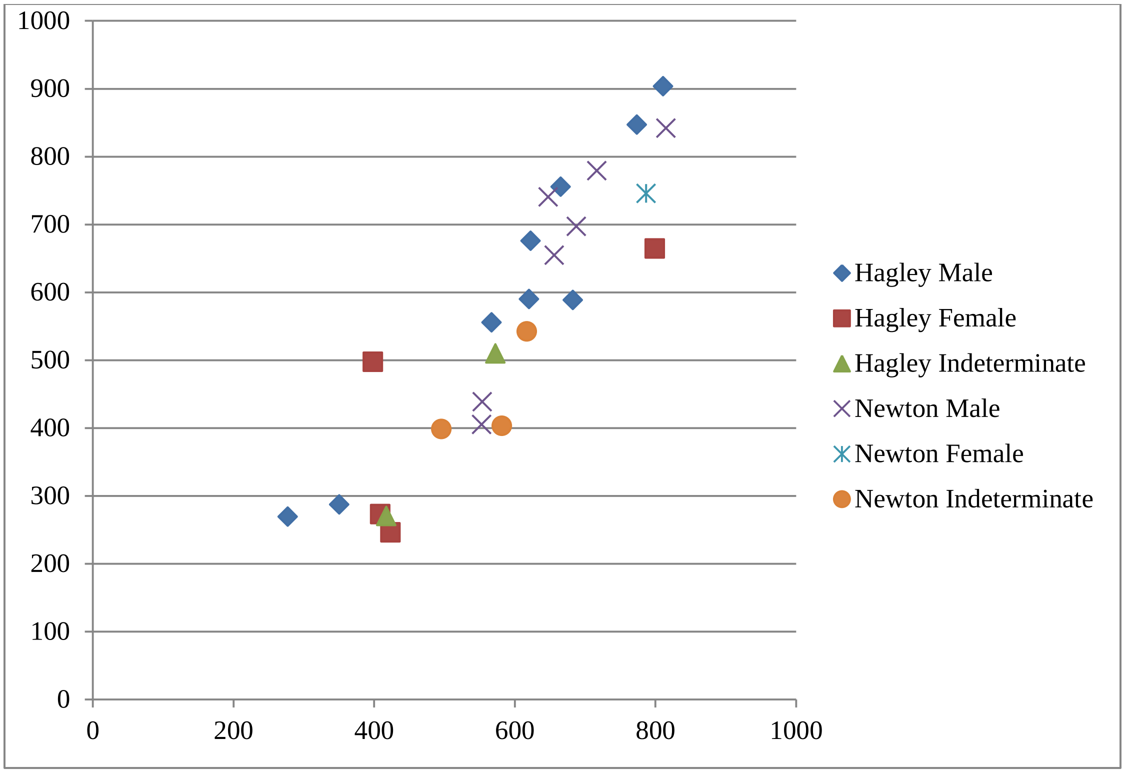


Figure 8.7 Humeral 40 Percent Shaft CT Slice Data for Standardized CA versus J by Estimated Sex for Hagley and Newton Plantation Samples.

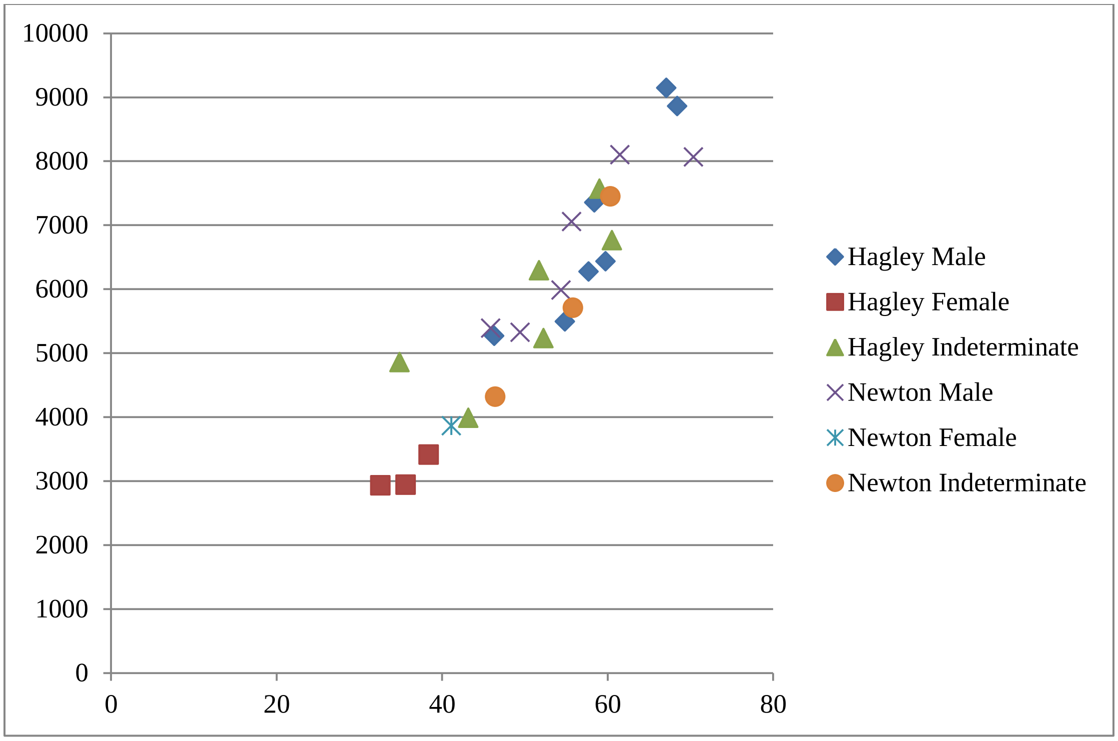


Figure 8.8 Femoral Midshaft CT Slice Data for Standardized CA versus J by Estimated Sex for Hagley and Newton Plantation Samples.

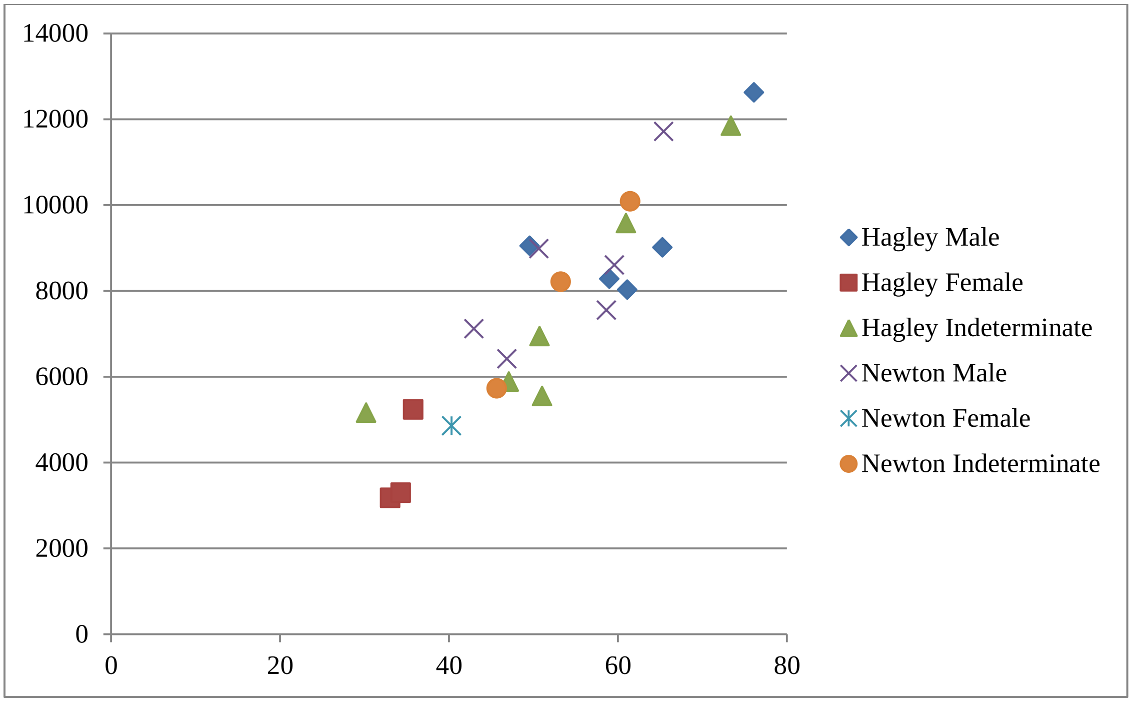


Figure 8.9 Femoral Subtrochanteric CT Slice Data for Standardized CA versus J by Estimated Sex for Hagley and Newton Plantation Samples.

Table 8.4 Descriptive Statistics and Results for Wilcoxon/Mann-Whitney U Test for Humerus Comparisons for Male Subsamples between Hagley and Newton Plantations.

Humerus	N Hagley/Newton	Mean/SD Hagley	Mean/SD Newton	Mean Ranks Hagley	Mean Ranks Newton	Ua	z	P1	P2
CA STD	7/7	677.54 / 87.36	661.52 / 92.07	7.7	7.3	23	0.13	0.4483	0.8966
J STD	7/7	702.02 / 136.65	650.61 / 167.68	8	7	21	0.38	0.352	0.7039
Ix	7/7	385.38 / 91.13	367.24 / 94.89	7.7	7.3	23	0.13	0.4483	0.8966
Iy	7/7	316.64 / 47.34	283.37 / 75.85	8.6	6.4	17	0.89	0.1867	0.3735
Imax	7/7	402.05 / 99.69	378.00 / 102.32	7.9	7.1	22	0.26	0.3974	0.7949
Imin	7/7	299.97 / 44.22	272.61 / 70.03	8.3	6.7	19	0.64	0.2611	0.5222
Imax/Imin	7/7	1.33 / 0.21	1.39 / 0.17	6.4	8.6	32	-0.89	0.1867	0.3735
Ix/Iy	7/7	1.21 / 0.13	1.30 / 0.12	6	9	35	-1.28	0.1003	0.2005

Table 8.5 Descriptive Statistics and Results for Wilcoxon/Mann-Whitney U Test for Femur Comparisons for Male Subsamples between Hagley and Newton Plantations.

		N	Mean/ SD	Mean/ SD	Mean Ranks					
		Hagley/Newton	Hagley	Newton	Hagley	Newton	Ua	z	P1	P2
Femur (MID)	CA STD	9/7	58.14 / 6.90	56.15 / 8.02	9.2	7.6	25	0.64	0.2611	0.5222
	J STD	9/7	6965.81 / 1375.04	6516.72 / 1212.40	9.2	7.6	25	0.64	0.2611	0.5222
	Ix	9/7	3559.11 / 697.81	3335.05 / 638.35	9	7.9	27	0.42	0.3372	0.6745
	Iy	9/7	3406.70 / 762.87	3181.67 / 718.00	9.2	7.6	25	0.64	0.2611	0.5222
	Imax	9/7	4015.73 / 1035.91	3623.04 / 677.18	9.2	7.6	25	0.64	0.2611	0.5222
	Imin	9/7	2950.08 / 404.67	2893.68 / 544.62	9	7.9	27	0.42	0.3372	0.6745
	Imax/Imin	9/7	1.35 / 0.24	1.25 / 0.06	9.1	7.7	26	0.53	0.2981	0.5961
	Ix/Iy	9/7	1.06 / 0.14	1.07 / 0.20	8.2	8.9	34	-0.21	0.4168	0.8337
Femur (SUB)	CA STD	14/10	63.63 / 9.01	53.92 / 7.84	9.6	5.4	10	1.79	**0.0367**	0.0735
	J STD	14/10	9772.36 / 1773.13	8368.56 / 1717.81	9.6	5.4	10	1.79	**0.0367**	0.0735
	Ix	14/10	4243.89 / 884.38	3450.05 / 662.12	9.4	5.6	11	1.66	**0.0485**	0.0969
	Iy	14/10	5528.47 / 1139.19	4918.51 / 1190.11	8.6	6.4	17	0.89	0.1867	0.3735
	Imax	14/10	5737.82 / 929.58	5179.60 / 1205.84	8.9	6.1	15	1.15	0.1251	0.2501
	Imin	14/10	4034.54 / 944.95	3188.97 / 590.62	9.4	5.6	11	1.66	**0.0485**	0.0969
	Imax/Imin	14/10	1.45 / 0.21	1.63 / 0.23	5.9	9.1	36	-1.41	0.0793	0.1585
	Ix/Iy	14/10	0.78 / 0.17	0.72 / 0.14	8.4	6.6	18	0.77	0.2207	0.4413

Figure 8.10 CT Slice Image of Femoral Subtrochanteric Location for Hagley Plantation Male (Left) and Newton Plantation Male (Right).

Figure 8.11 Left Femur from Hagley Plantation Male Displaying Marked Muscoloskeletal Stress Marker of Intertrochanteric Line.

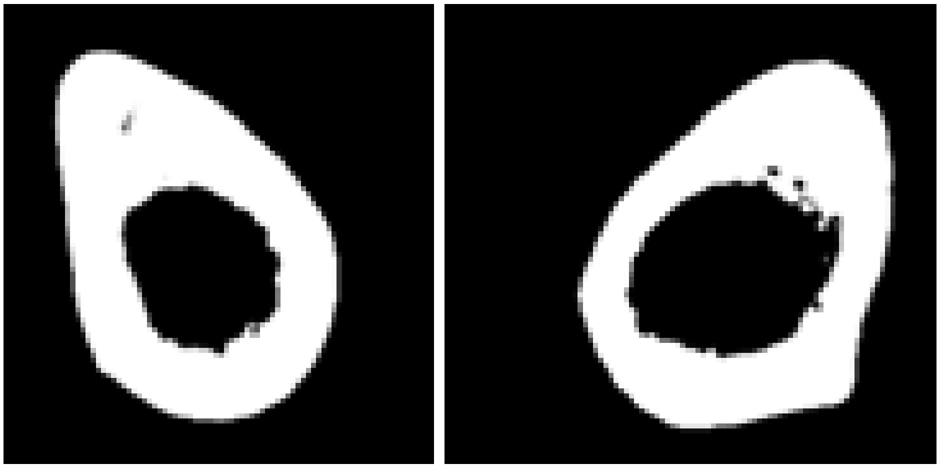


Figure 8.12 CT Slice Image of Tibial Midshaft from a Male Right Tibia from Newton Plantation (Left) and from a Male Left Tibia from Hagley Plantation (Right).

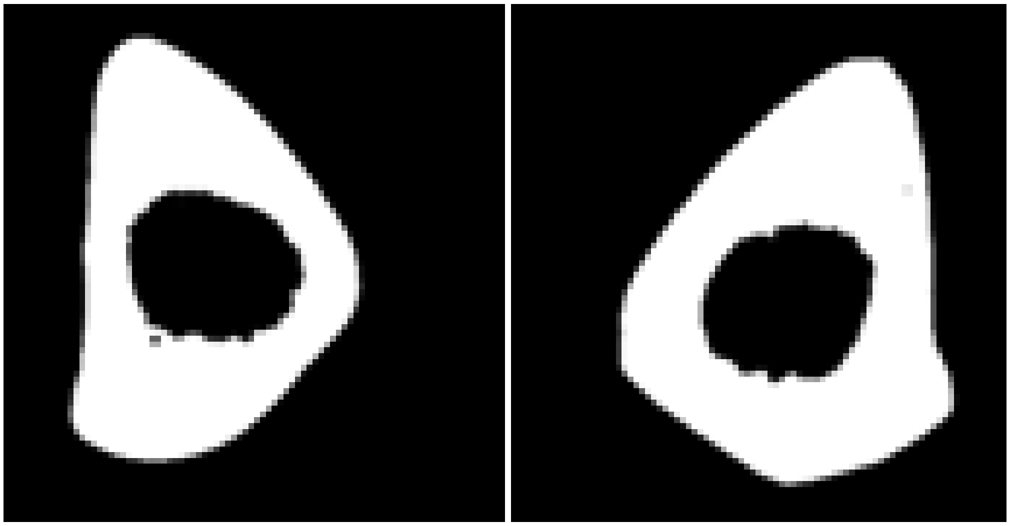


Figure 8.13 CT Slice Image from the Tibial Midshaft from Two Male Individuals from Newton Plantation (Right and Left Bones, Respectively).

Figure 8.14. Probable Osteoporosis of a Humerus (Left) and a Femur Midshaft (Right) from Hagley Plantation.

CHAPTER 9

CONCLUSION

In conclusion, this study has succeeded in meeting the goals I proposed in Chapter 1. The approach to commingling of skeletal remains in both of these skeletal populations was overcome, in part, and fostered the ability to derive skeletal samples that were amenable to comparative study. I tested several hypotheses with the CSG data and was able to answer questions about the character of labor for these two contexts based on significant differences between the two enslaved groups.

Hagley and Newton Plantations represent interesting case studies for the interpretive complexity of cross-sectional properties within anthropology. Both of these plantation economies involved early onset of participation in heavy labor and both faced extreme stress due to social factors, environmental factors, documented nutritional compromise, and heavy disease burden. The variables at work in determining the CSG properties within these samples are thus intricately tethered and perhaps difficult to separate. Despite these challenges, my study has demonstrated population differences in relative bone strength and shape which reflect participation in the unique aspects of labor of these two economies. Consideration of the skeletal measures of strength in relation to the historical record and skeletally-derived demographies has also been informative.

The bioarchaeological comparison of the profile of these skeletal populations supports the historical conception that Sugar slaves were “worked to death” compared the demographic outcomes of other plantation economies, and, I believe is discordant with the historical conception that rice task labor offered autonomy that may have lessened the labor burden on the enslaved. Both of the groups labored under conditions we can barely imagine today.

The two historical contexts are different, I acknowledge, with Newton’s skeletal remains probably being from the colonial period and Hagley’s most likely from the antebellum era although dates of death and cemetery use remain unknown. This should not matter, I argue, because the two economies both participated in manual labor regimes. Mechanization played a role in both, with processing and preparation of their respective crops, but field labor remained a key characteristic. Due to the fact that these populations were similarly compromised, their respective bone strength measures should be a valid means of comparing the labor stresses they endured.

I chose to compare these two sites and skeletal samples in order to gain insight into how labor differentials affect the health and lifestyles of the enslaved within differing economies and differing structures of labor organization (gang and task). The comparison of sugar and rice production has been suggested before by historians because the two economies were distinct from other forms of slavery. Carney (1996) viewed both rice and sugar within the context of pre-capitalist seasonal agricultural labor with shared British origins, and seasonal rounds of intense labor performed by relatively enclosed populations and employing chattel slavery. She and others followed up on scholarly challenges such as those proposed by Wood (1974), Littlefield (1981), Morgan (1982) and others to continue asking questions about rice slavery in order to quantify and understand the nature of production within the rice plantation economy with consideration of its transatlantic and African-derived roots and technologies, its changing character through colonial and antebellum time based on sociopolitical factors and technological advance, and its unique cultural and social relations (Bell 2010; Carney 1996; Chaplain 1992; Porcher 2014; Tuten 2010).

Eleazer (2013) recently investigated the interaction of mechanical loading and metabolic stress on cortical bone morphology with the goal of testing common anthropological assumptions from CSG studies. Her findings provided insight suggesting that anthropological interpretations of subsistence activities face complications and limitations due to their "inability to address the interaction between mechanics and metabolism" (2013:44). As reviewed in Chapter 3, both contexts, rice and sugar slavery faced similar challenges due to the effects of febrile illness, frequent epidemics, overcrowding, and the introduction of new pathogens and parasites via the slave trade (Craton 1991; Fogel 1989; Handler and Corruccini 1983; Patterson 1989). Both of these economies present similar but equally "peculiar" and characteristic disease profiles (Craton 1991; Higman 1976; Patterson 1989).

Coupled with the effects of protein-deficiency, these health variables present synergistic mechanisms for growth and development limitation and host resistance (Genovese 1967; Gibbs et al. 1980; Steckel 1986a). Additionally, the fact that long bone cross-sectional properties reflect an "aggregation of continuous modifications to cortical structure" that occur across the lifespan (Eleazer 2013:45) may make it very difficult to link patterns of skeletal change to specific activities. Complicated patterning of CSG properties may also result due to cultural variability in activity patterns, especially across childhood and adolescence (Pearson and Lieberman 2004). This study overcomes some of these factors by comparing two economies that both engaged in arduous labor involving repetitive agricultural tasks from childhood, throughout their lives, under conditions of nutritional and disease stress.

The ways in which the lower limbs differ between Hagley and Newton Plantations, in my assessment, reflect interesting features of skeletal functional adaptation brought on in part by the cumulative effects of a lifetime of enslaved labor. CT images and CSG measures reflect differences that suggest multi-directional appositional bone response making these bones display relative strength differences in a variety of dimensions. AP flattening of the femur combined with AP elongation of the tibia, which characterizes Newton on average, might seem contradictory if considered in terms of simple mobility index or by shape. This is an area of active critical evaluation for anthropological interpretation of CSG measures (Carlson and Marchi 2014). The body of evidence that demonstrates skeletal response to the environment is growing steadily but many questions remain unanswered. As themes within Carlson and Marchi's (2014) book sugest, it is informative to look at measures for the whole lower limb, as different bones and the anatomical locations typically studied within bones are likely to be measuring different aspects of our behavior. Single bone measures for mobility and behavior should not be used alone, but in conjunction with other measures within the skeleton and in conjunction with the historical and material record of human behavior, in order to infer past human activity.

I present three images (Figure 9.1) in order to demonstrate the differentials under investigation in current scholarship, namely the variable response to loading and habitual activity by different bones, within the same limb. The images from Newton and Hagley's enslaved illustrate the variability in alignment of principle axes along these bones (i.e. proximal femur, mid femur, and mid tibia). The top image is the left femur and tibia from a Newton Plantation male of likely Barbadian birth. The middle image is the right femur and tibia of a female slave from Newton, likely to be African-born based on isotopic evidence (Schroeder et al. 2009). The bottom image is the right femur and tibia of a male slave from Hagley. Sample parameters did not permit the selection of whole lower limb images for more similar individuals, but these choices illustrate the diversity bone geometry and cross-sectional properties present within the two contexts.

It is unfortunate that the study did not present a more reliable means of assessing sexual division of labor. Sexual division of labor and gendered agricultural knowledge are central tenets to understanding the diasporic connections and transfer of technology between rice culture in Africa and rice culture in the American south (Berlin and Morgan 1993; Wood 1974; Littlefield 1981). Perhaps improved understandings of bone functional adaptation and further developments in the ability to resolve commingling will permit the use of these data in conjunction with new information in the future in order to address the salient questions about the unique rice economy and its impact on the biology of the enslaved.

The effects of enslaved labor on children are also of particular interest. Both Hagley and Newton Plantation lacked a sufficient sample size of child and adolescent skeletal remains to infer much about growth, development, and timing of labor force entry. From the historical evidence, children labored in the sugar gangs from an early age (Dunn 1973) according to documentary research, and ethnographic studies document their involvement in heavy agricultural work such as planting, harvesting, and irrigation ditch maintenance (Handler 1965). Hander's (1978:33) research suggests children were involved in the labor force beginning at age 5 or 6 and sometimes even younger, with a share which "increased in scope and arduousness" with age.

For North American contexts, including rice agriculture, the entry into field labor for children is often cited as one of the factors that offset the effects of an unhealthful childhood characterized by early weaning, stunted growth, birth defects, and protein-calorie malnutrition, permitting catch-up growth (Fogel 1989; Rathbun and Steckel 2002; Steckel 1986b). Weston's will demonstrates that 13.5 percent of his labor force (n= 15) was within the age bracket of 13 to 18 years old in 1864. Occupations are not listed for any slave younger than 13 in the document. It is clear, however, that growing and developing adolescents were involved in labor as indication of their occupation primarily as "half hands" are listed. Delayed entry into field labor, may be a factor in the health and labor profiles presented in the comparisons of these two plantation contexts. The rice planters' awareness of the extreme health challenges faced by infants and children in the rice plantations, however, may have necessitated that children avoid participation in the workforce until later age.

The last question I pose in this dissertation pertains to African birth and the possibility of a childhood not involved in enslaved labor. All of Hagley Plantation's individuals were likely born into slavery, but Newton's were not. Does African birth retain a signature that can be recognized due to the possibility of being born into a radically different social structure? The final figures represent Hagley, the African-born portion of the Newton biomechanical sample (N= 3), and Newton's Barbadian-born enslaved for torsional strength of the femur at the subtrochanter (J) (Figure 9.2), torsional strength of the humerus (Figure 9.3), and for the shape ration I_x/I_y at the femur subtrochanter (Figure 9.4). While the data presented in these figures is in no way conclusive, the lack of overlap for femoral J between Newton's island-born and three likely Africans at the subtrochanter is especially suggestive of a difference in life experience during these individuals' developing years. The histograms that follow (Figures 9.5 and 9.6) demonstrate that one of the African-born individuals has clear and distinctive outlying measures for femoral subtrochanteric strength apportionment and shape.

It is my hope that these data and studies of this kind will continue and serve to further our understanding of the life stresses of slavery experienced within the African Diaspora by adding to the growing body of biohistorical data from the Americas.

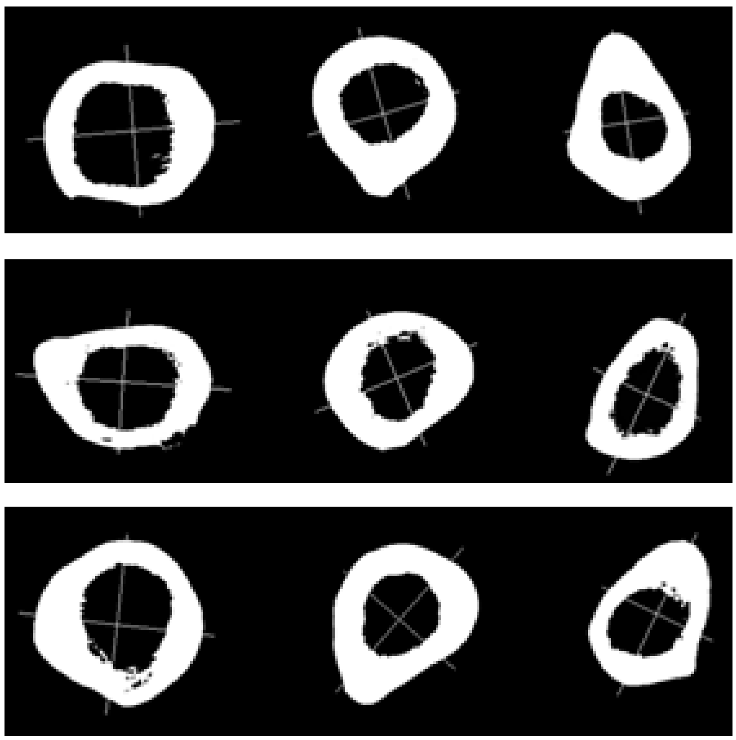


Figure 9.1 Lower Limbs from the CSG Study: A Male from Newton (Top), An African-Born Female from Newton (Middle), and a Male from Hagley (Bottom).

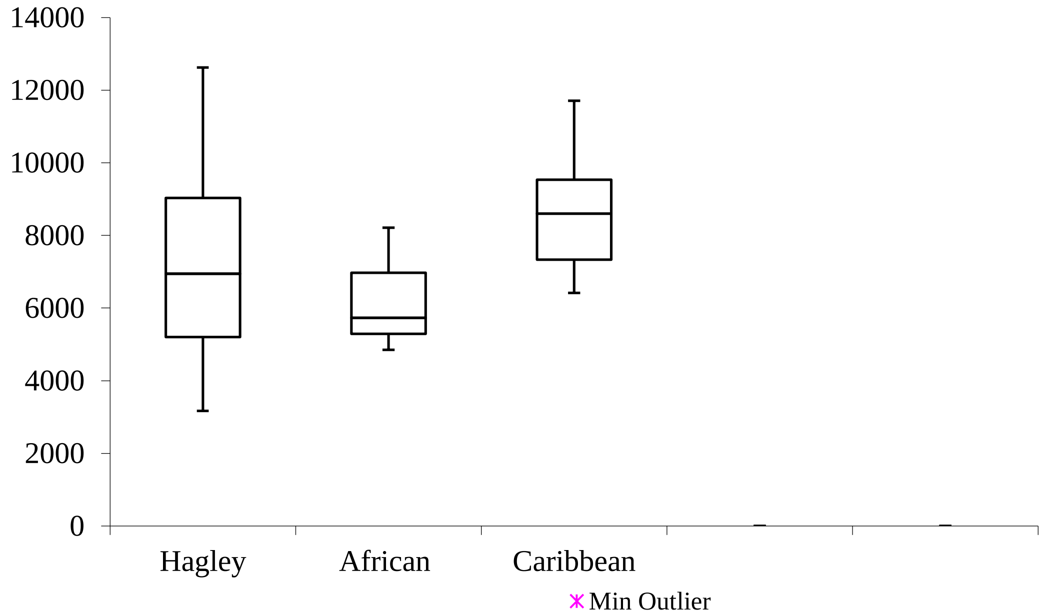


Figure 9.2 Boxplot showing the Distribution of Femoral Subtrochanteric J for Hagley, African-Born Newton, and Newton Groups.

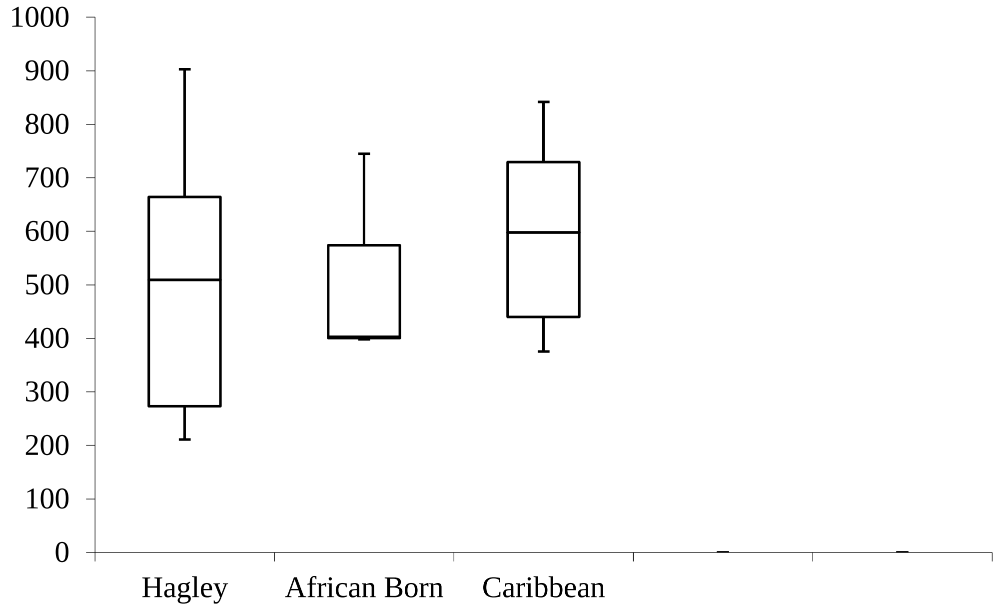


Figure 9.3 Boxplot showing the Distribution of Humeral J for Hagley, African-Born Newton, and Newton Groups.

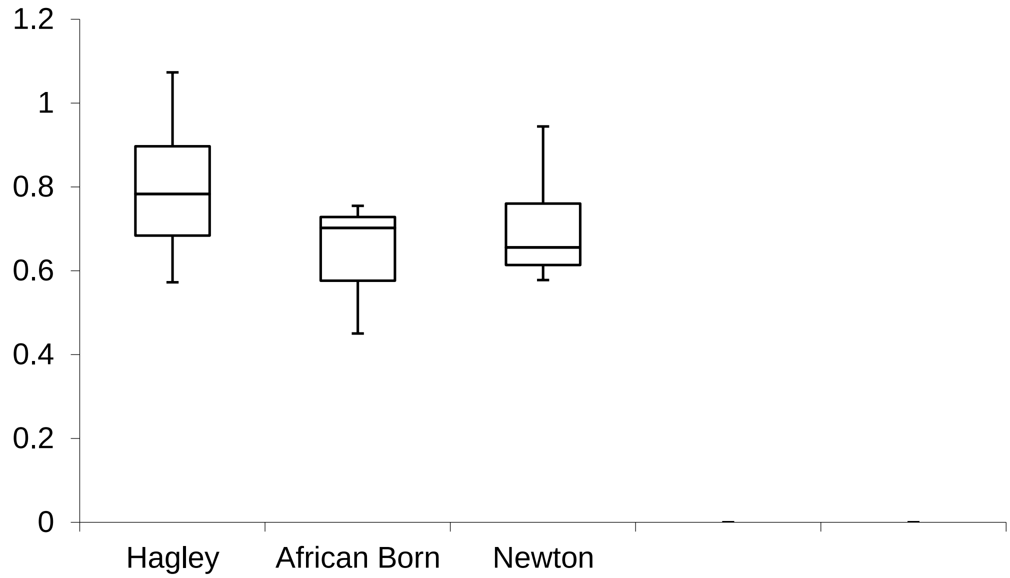


Figure 9.4 Boxplot showing the Distribution of Femoral Subtrochanteric Ix/Iy for Hagley, African-Born Newton, and Newton Groups.

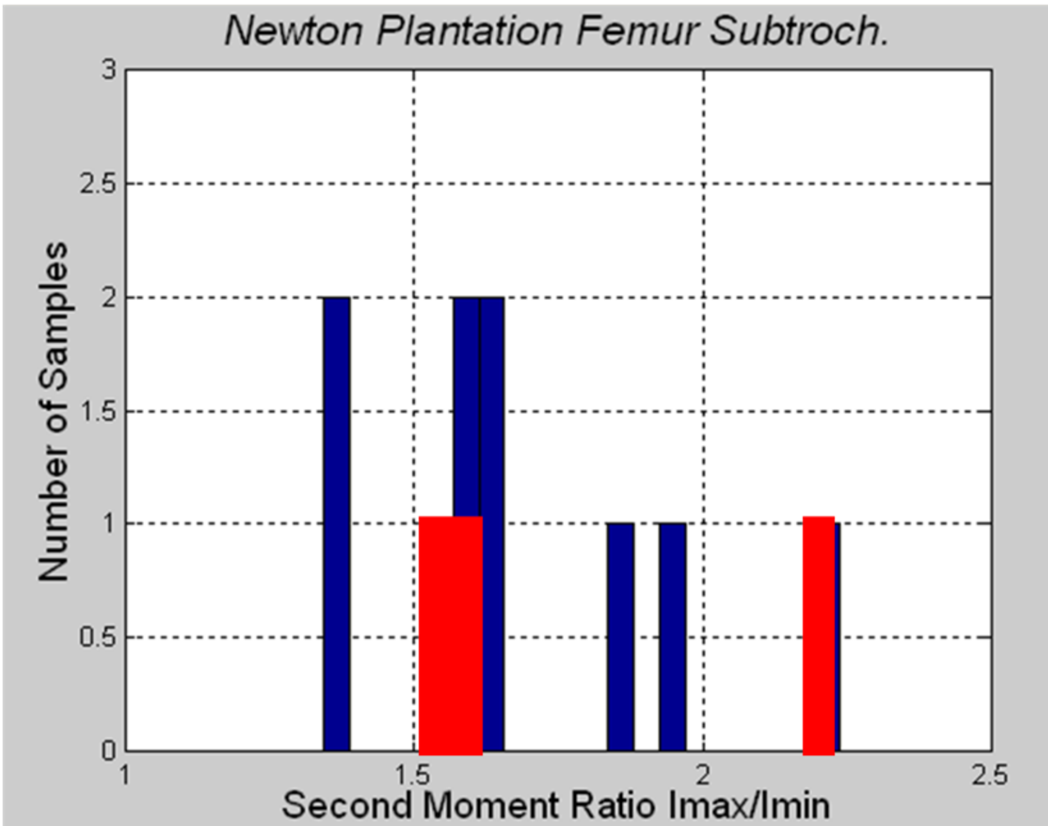


Figure 9.5 Histogram of Imax/Imin for Newton Sample Showing African-Born Individuals in Red.

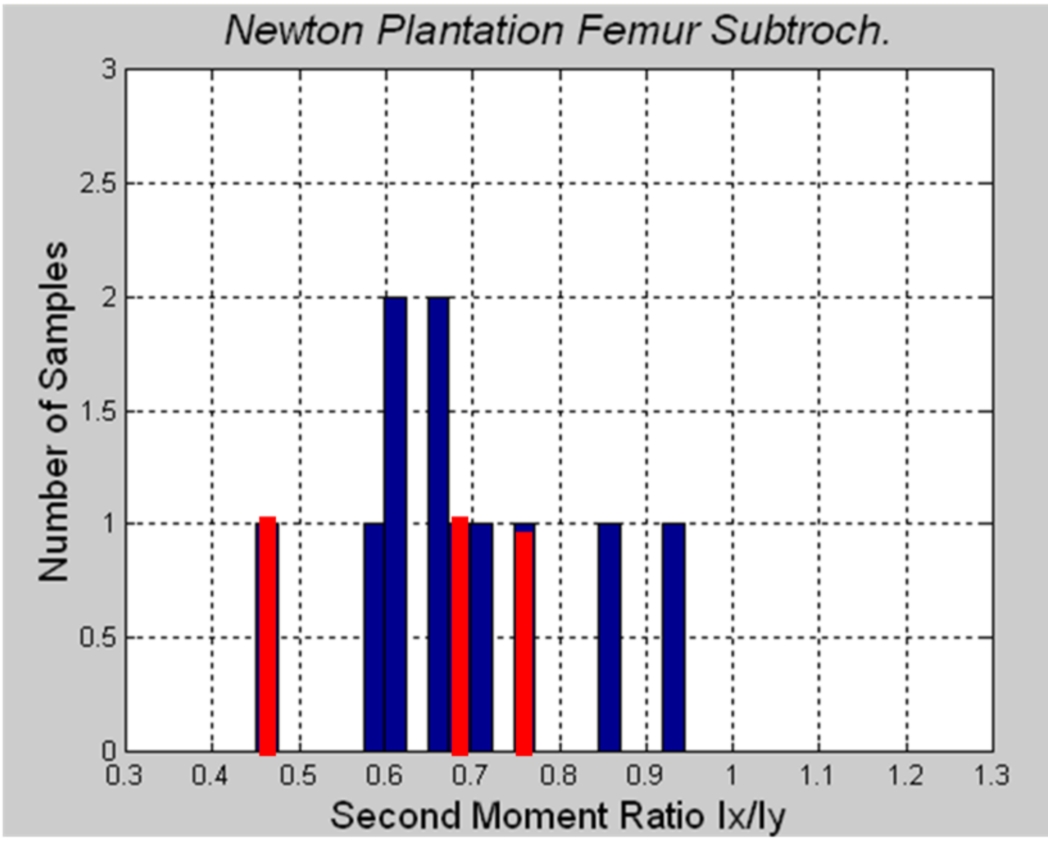


Figure 9.6 Histogram of Ix/Iy for Newton Sample Showing African-Born Individuals in Red.

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APPENDIX A

RULES AND MANAGEMENT FOR THE PLANTATION.

THE Proprietor, in the first place, wishes the Overseer MOST DISTINCTLY to understand that his first object is to be, under all circumstances, the care and well being of the negroes. The Proprietor is always ready to excuse such errors as may proceed from want of judgment; but he never can or will excuse any cruelty, severity, or want of care towards the negroes. For the well being, however, of the negroes, it is absolutely necessary to maintain obedience, order, and discipline; to see that the tasks are punctually and carefully performed, and to conduct the business steadily and firmly, without weakness on the one hand, or harshness on the other. For such ends the following regulations have been instituted:

LISTS—TICKETS.—The names of all the men are to be called over every Sunday morning and evening, from which none are to be absent but those who are sick, or have tickets. When there is evening Church, those who attend are to be excused from answering. At evening list, every negro must be clean and well washed. No one is to be absent from the place without a ticket, which is always to be given to such as ask it, and have behaved well. All persons coming from the Proprietor's other places should show their tickets to the Overseer, who should sign his name on the back; those going off the plantation should bring back their tickets signed. The Overseer is every now and then to go round at night and call at the houses, so as to ascertain whether their inmates are at home

ALLOWANCE—FOOD.—Great care should be taken that the negroes should never have less than their regular allowance: in all cases of doubt, it should be given in favour of the largest quantity. The measures should not be *struck,* but rather heaped up over. None but provisions of the best quality should be used. If any is discovered to be damaged, the Proprietor, if at hand, is to be immediately informed; if absent, the damaged article is to be destroyed. The corn should be carefully winnowed before grinding. The small rice is apt to become sour: as soon as this is perceived it should be given out every meal until finished, or until it becomes too sour to use, when it should be destroyed.

Allowances are to be given out according to the following schedule. None of the allowances given out in the big pot are to be taken from the cook until after they are cooked, nor to be taken home by the people.

SCHEDULE OF ALLOWANCE.

DAILY (SUNDAYS EXCEPTED.)

During Potato-time.

To each person doing any work, ... 4 qts.

To each child at the negro-houses .. .. .. 2 qts.

During Grits-time.

To the cook for public-pot, for every person doing any work, 1 qt.

To the child's cook, for each child at negro-houses, .. 1 pt.

Salt to cook for public pot, .. •. .. .. 1 pt.

Salt to child's cook, ... i pt. Ore *every Tuesday and Friday throughout the year.*

To cook for public-pot, for whole gang of workers, trades-) Meat men, drivers, &c, ... j 30 lbs.

To child's cook for all the children, ... 15 lbs.

Ore *every Tuesday and Friday from April 1st to October 1st.*

To the plantation cook for each person doing any work, | Small Rice instead of the pint of grits, ...) 1 pt.

To the child's cook, for each child instead of the i pt.) , . of grits \ 4 pt

To plantation cook for the whole gang of j Peas; quantity dependworkers, tradesmen, drivers, &c, \ ing on produce.

Every Thursday throughout the year. To the child's cook, for all the children, Molasses, 2 qts.

Weekly Allowance throughout the year.—To be given out every Saturday afternoon.

To each person doing any work, ... Flour, 3 qts.

To each child at negro-houses, ... 3 pts.

To each person who has behaved well, and has not) 2 Fish or

been sick during the week To each nurse

To head-carpenter; to head-miller;

To head-cooper; to head-ploughman;

To watchman ; to trunk-minders;

To drivers; to mule-minder;

To hog-minder; to cattle-minder; and

To every superannuated person, ..

Monthly Allowance.—Ore *the 1st of every month,*

To each person doing any work, and each superannuated)

1 pt. Molasses. 4 Fish or 14 pt. Molasses.

3 Fish,

or

14 pt. Molasses

each.

Christmas Allowance.

To each person doing any work, and each superannuated person, To each child at negro-houses,

1 Fresh Meat, 3 lbs. Salt do., 3 lbs. Molasses, 1 qt. Small Rice. 4 qts. Salt, 4 bushel. *)* Fresh Meat, Hlbs. f Salt Meat, *1{* lbs. *i* Molasses, 1 pt.) Small Rice, 2 qts.

Additional Allowance.

Every day when rice is sown or harvested, to the cook,) Meat, 40 lbs. for the whole gang of workers in the field, j Peas, as above.

No allowances or presents, besides the above, are on any consideration to be made—except for sick people, as specified further on.

WORK, HOLIDAYS, &C —No work of any sort or kind is to be permitted to be done by negroes on Good Friday, or Christmas day, or on any Sunday, except going for a Doctor, or nursing sick persons; any work of this kind done on any of these days is to be reported to the Proprietor, who will pay for it. The two days following Christmas day; the first Saturdays after finishing threshing, planting, hoeing, and harvest, are also to be holidays, on which the people may work for themselves. Only half task is to be done on every Saturday, except during planting and harvest, and those who have misbehaved or been lying up during the week. A task is as much work as the meanest full hand can do in nine hours, working industriously. The Driver is each morning to point out to each hand their task, and this task is *never* to be increased, and no work is to be done over task except under the *most urgent necessity;* which over-work is to be reported to the Proprietor, who will pay for it. No negro is to be put into a task which they cannot finish with tolerable ease. It is a bad plan to punish for not finishing task; it is subversive of discipline to leave tasks unfinished, and contrary to justice to punish for what cannot be done. *In nothing does a good manager so much excel a bad, as in being able to discern what a hand is capable of doing, and in never attempting to make him do more.*

No negro is to leave his task until the driver has examined and approved it, he is then to be permitted immediately to go home; and the hands are to be encouraged to finish their tasks as early as possible, so as to have time to work for themselves. Every negro, except the sickly ones and those with suckling children, (who are to be allowed half an hour,) are to be on board the flat by sunrise. One driver is to go down to the flat early, the other to remain behind and bring on all the people with him. He will be responsible for all coming down. The barn-yard bell will be rung by the watchman half an hour before sunrise.

PUNISHMENTS.—It is desirable to allow 24 hours to elapse between the discovery of the offence, and the punishment. No punishment is to exceed 15 lashes: In cases where the Overseer supposes a severer punishment necessary, he must apply to the Proprietor, or to

Esq., in case of the Proprietor's absence from the neighbourhood. Confinement *(not* in the stocks) is to be preferred to whipping: but the stoppage of Saturday's allowance, and doing whole task on Saturday, will suffice to prevent ordinary offences. Special care must be taken to prevent any *indecency* in punishing women. No Driver, or other negro, is to be allowed to punish any person in any way, except by order of the Overseer, and in his presence.

FLATS, BOATS, &C—All the flats, except those in immediate use, should be kept under cover, and sheltered from the sun. Every boat must be locked up every evening, and the keys taken to the Overseer. No negro will be allowed to keep a boat.

SICKNESS.—All sick persons are to stay in the hospital night and day, from the time they first complain to the time they are able to go to work again. The nurses are to be responsible for the sick not leaving the house, and for the cleanliness of the bedding, utensils, &c. The nurses are never to be allowed to give any medicine, without the orders of the Overseer or Doctor. A. woman, beside the plantation nurse, must be put to nurse all persons seriously ill. In all cases *at all* serious the Doctor is to be sent for, and his orders are to be strictly attended to: no alteration is to be made in the treatment he directs. Lying-in women are to be attended by the midwife as long as is necessary, and by a woman put to nurse them for a fortnight. They will remain at the negro houses for four weeks, and then will work two weeks on the highland. In some cases, however, it is necessary to allow them to lie up longer. The health of many women has been entirely ruined by want of care in this particular. Women are sometimes in such a state as to render it unfit for them to work in water; the Overseer should take care of them at these times. The pregnant women are always to do *some* work up to the time of their confinement,, if it is only walking into the field and staying there. If they are sick, they are to go the hospital, and stay there until it is pretty certain their time is near.

Nourishing food is to be provided for those who are getting better. The Overseer will keep an account of the articles he purchases for this purpose, during the Proprietor's absence, which he will settle for as soon as he returns.

BLEEDING IS UNDER ALL CIRCUMSTANCES STRICTLY PROHIBITED, EXCEPT BY ORDER OF THE DOCTOR.-—THE Overseer is particularly warned not to give strong medicines, such as .calomel, or tartar emetic: simple remedies such as flax-seed tea, mint-water, *No.* 6, magnesia, &c, are sufficient for most cases, and do less harm. Strong medicines should be left to the Doctor; and since the Proprietor never grudges a Doctor's bill, however large, he has a right to 'expect that the Overseer shall always send for the Doctor when a serious case occurs. Dr. _____ is the Physician of the place. When he is absent, Dr. . Great care must be taken to prevent persons from lying up when there is nothing or little the matter with them. Such must be turned out immediately; and those somewhat sick can do lighter work, which encourages industry. Nothing is so subversive of discipline, or so unjust, as to allow people to sham, for this causes the welldisposed to do the work of the lazy.

LIVE STOCK.—One man is to be put to take care of all the oxen; he will do only half-task ploughing, and will be responsible for them. The Overseer must see them well provided with straw, tailing, and coarse flour. The ploughing and carting tasks will be regulated by the appearance of the oxen. It is better to be a fortnight later in work, and have the cattle in good order, than to kill any of them.

Mules should also be under the care of one person *all the year round*, who shall be responsible for them. Their ordinary food shall be flour and tailing cut up, and during hard work, corn; crab grass cut up, with straw and flour, is also good food. In summer they must be turned out on the marsh, when not it use. No mule must ever be worked with a gall: on the first appearance of one, the man in charge must inform the Overseer. It must be recollected, *that it is easy to keep an animal once fat in good condition, but extremely difficult to get one into condition who is worked down.*

The harness, chains, yokes, ploughs, &c, should always be kept under cover, as well as the carts and waggons. The stable and ox-houses should be cleaned out every week, and the oxen and mules cleaned down every evening. No animal can do well, whose skin is covered with dirt.

THRESHING, &C.—MACHINERY.—The mill is to be closed in time to allow the whole yard to be cleaned up by sunset. The Proprietor considers an Overseer who leaves any straw or tailing during the night within 300 yards of the mill, as unfit to be trusted with the care of valuable property. He should keep a constant and vigilant inspection on the machinery, to see that no part of it heats; he should also stay in the yard whilst threshing, and not leave the keys to the drivers. As soon as the people come in, in the morning, the barn-yard doors should be locked, and not be opened again until work is over, except to admit the meals, and the suckling children. As soon as any thing goes wrong in the mill, or other machinery, Mr. should be informed of it.

DUTIES OF OFFICIALS.

DRIVERS are, under the Overseer, to maintain discipline and order on the place. They are to be responsible for the quiet of the negro-houses, for the proper performance of tasks, for bringing out the people early in the morning, and generally for the immediate inspection of such things as the Overseer only generally superintends. *For other duties of Drivers, see article* WORK.

WATCHMEN are to be responsible for the safety of the buildings, boats, flats, and fences, and that no cattle or hogs come inside the place. If he perceives any buildings or fences out of repair, or if he hears of any robberies or trespasses, he must immediately give the Overseer notice. He must help to kill hogs and beeves.

TRUNK-MINDERS undertake the whole care of the trunks, under the Proprietor's and Overseer's directions. Each has a boat to himself, which he must on no account let any body else use.

NURSES are to take care of the sick, and to be responsible for the fulfilment of the orders of the Overseer, or Doctor, (if he be in attendance.) The food of the sick will be under their charge. They are expected to keep the hospital floors, bedding, blankets,

utensils, &c, in perfect cleanliness. Wood should be allowed them. Their assistants should be entirely under their control. When the Proprietor and Overseer are absent, and a serious case occurs, the nurse is to send for the Doctor.

YARD WATCHMAN is responsible for the crop in the yard, and for the barns.

COOKS take every day the provisions for all the people, the sick only excepted, *(see article Allowance.)* The Overseer is particularly requested to see that they cook cleanly and well. One Cook cooks on the Island; the other on the Main, for the carpenters, millers, highland hands, &c.

The child's Cook cooks for the children at the negrohouses; she ought to be particularly looked after, so that the children should not eat anything unwholesome.

MISCELLANEOUS OBSERVATIONS.

THE Proprietor wishes particularly to impress on the Overseer the criterions by which he will judge of his usefulness and capacity. *First*—by the general well being of the negroes; their cleanly appearance, respectful manners, active and vigorous obedience; their completion of their tasks well and early; the small amount of punishment; the excess of births over deaths; the small number of persons in hospital, and the health of the children. *Secondly*—the condition and fatness of the cattle and mules; the good repair of all the fences and buildings, harness, boats, flats, and ploughs; more particularly the good order of the banks and trunks, and the freedom of the fields from grass and volunteer. *Thirdly*—the amount and quality of the rice and provision crops. The overseer will fill up the printed forms sent to him every week, from which the Proprietor will obtain most of the facts he desires, to form the estimate mentioned above.

The Overseer is expressly prohibited from three things, viz.: bleeding, giving spirits to any negro without a Doctor's order, and letting any negro on the place have, or keep any gun, powder, or shot.

When carpenters work is wanted, the Overseer must apply in writing to Mr. Miller.

When the Overseer wishes to leave the plantation for more than a few hours, he must inform the Proprietor, (if he is in the Parish.)

Whenever a negro is taken seriously ill, or any epidemic makes its appearance, or any death or serious accident occurs, the Proprietor (if in the Parish) must be immediately informed, as well as of any serious insubordination or breach of discipline.

No gardens, fowl-houses, or hog-pens, are allowed near the house; a space will be fenced out for these purposes, and they will be under the charge of the watchman.

No trees are to be cut down within 200 yards on each side of the houses.

Women with six children alive at any *one* time, are allowed all Saturday to themselves.

Fighting, particularly amongst women, and obscene or abusive language, is to be always rigorously punished.

During the summer, fresh spring water must be carried every day on the Island. Any body found drinking ditch or river water must be punished.

Finally.—The Proprietor hopes the Overseer will remember that a system of *strict justice* is necessary to good management. No person should ever be allowed to break a law without being punished, nor any person punished who has not broken a well known law. Every person should be made perfectly to understand what they are punished for, and should be made to perceive that they axe not punished in anger, or through caprice. All abusive language or violence of demeanor should be avoided: they reduce the man who uses them with a level with the negro, and are hardly ever forgotten by those to whom they are addressed.

W. Hagley, 1859.

APPENDIX B

WILL OF PLOWDEN C.J. WESTON

Weston, P.C.J.

Weston, Emily F Executrix

Filed: February 6, 1864

[1. Document written on lined paper, last will and testament of PCJ Weston]

The State of South Carolina

Horry District

I, Plowden Charles Jennet Weston of All Saints Parish in the State aforesaid do make publish and declare this present writing executed in Duplicate as and for my last Will and Testament, hereby revoking all former and other Wills by me, at anytime, heretofore made.......

It is my Will and I do hereby direct that all my just debts funeral and Testimentary expenses be fully paid and satisfied.........

I give bequeath and devise unto my dearly beloved wife Emily Frances Weston my entire property and Estate real and personal of whatever the same may consist and in whatever country situated and being.......

I do hereby nominate constitute and appoint my said wife Emily Frances Weston and William Clement Drake Esdaile Esquire of Burley Manor, Hants, England, Executrix and Executor of this my Will.....

In witness whereof I the said Plowden Charles Jennett Weston, in the presence of the persons whose names are hereunto subscribed as Witnesses have set my hand and seal this thirtieth day of October Anno Domini Eighteen Hundred and Sixty Three to this my last Will and Testament, in duplicate form with the intention of sending the exact counterpart hereof to England for safekeeping in consequence of the hostilities which now exist between the Confederate States and the United States of America....

[original signature] Plowden Charles Jennett Weston

Signed Sealed published and declared by the said Plowden Charles Jennett Weston, as and for his last WIll and Testament in our presence, who in his presence, and in the presence of each other, and at his request, have subscribed our names as Witnesses...

[original signatures]

Elizth Collins Haselbury Somerset

Wm P Porter Georgetown SC

Jos T Walsh of Conwayboro, S.C.

[2. continuing on same lined paper, different hand]

South Carolina

Horry District

By J. A. Thompson Ordinary H. D.

Whereas I have first received from E. Waterman Esq. Ordinary of Georgetown District, a special power to prove the last Will and Testament of Plowden C.J. Weston in common form. Therefore Personally appeared before me Jos. T. Walsh who being duly sworn on the Holy Evangelist of Almighty God, doth make oath and say that he was present and saw Plowden C.J. Weston sign, Seal, publish pronounce and declare the within instrument of writing to be and contain his last will and Testament. That he the said Plowden C.J. Weston was then of sane and disposing mind memory and understanding to the best of this deponents knowledge and belief, and that he the said Jos T. Walsh together with Elizabeth Collins and Wm P Porter signed their names as witnesses thereto, at the request of the Testator in his presence and in the presence of each other.

[original signature] Jos T Walsh

Sworn to before me

February 12th 1864

J. A. Thompson

ord’y H. D.

I do solemnly swear that this writing contains the true last Will of the within named Plowden C.J. Weston Deceased, so far as I know or believe, and that I will well and truly execute the same by paying first the debts and then the Legacies contained in the said Will, as far as the goods and chattels will thereunto extend and the Law charge me, and that I will make a true and perfect Inventory of all such Goods and chattels so help me God.

[original signature] Emily F. Weston

Sworn to

Feby 12th 1864

J.A. Thompson

ord’y H.D.

[3. unlined page with seal, different hand]

State of South Carolina

Georgetown District

By Eleaser Waterman, Esq. Ordinary for Georgetown district

To J. A. Thompson, Esquire, Ordinary for Horry district

I, Eleaser Waterman, ordinary as aforesaid having full confidence in the integrity, cure, circumspection, and fidelity of you the said J. A. Thompson, Ordinary forthe district of Horry, do hereby authorize you to have proved, in common form, the enclosed Will of Plowden C. J. Weston, late of All Saints Parish, in this district deceased by having one of the subscribing witnesses take and subscribe the usual oath in such cases, that you have the said probate written on the opposite page of this paper in which the will is written.

That you also, in having the will so proved, administer to Mrs Emily Frances Weston the usual oath as Executrix, and then hand to her the usual Letters Testamentary as Executrix, which oath have also expressed in writing on the following page containing the original will, and [words obscured by seal]dimus so executed, with your actings and doings return to one[words obscured by seal]bation or disallowance.[Words obscured by seal]der my hand and seal of Office at sixth day of February, on ethousand eight hundred and sixty-four and fourth of the Independence of the Confederate

States of America

[Seal]

[signature, same hand as letter] E. Waterman, Ordinary

[4. Lined paper, turned sideways; appears to be the outside fold of the will:]

#448

The Last Will & Testament of Plowden C.J. Weston of All Saints Parish

State of South Carolina recorded 2/4/53 Will Book D, page 434

[5. Certificate, printed words shown here in italics, handwritten additions in bold text:]

Warrant of Appraisement for Executors

Printed and sold by A. J. Burke, 40 Broad St

The State of South-Carolina

Georgetown*[was Charleston, crossed out] District*

By **Eleaser Waterman***, Esquire, Ordinary*

These are to authorise and empower you, or any three or four of you, whose names

are hereunder written, to appear to all such parts and places within this State, as you shall

be directed unto by **Emily Frances Weston**

Executrix named in the last Will and Testament of

Plowden C. J. Weston

late of **All Saints Parish**

deceased, wheresoever and of the Goods and Chattels of the said deceased are or do

remain within the said parts and places, and which shall be shown unto you by the *said* **Emily Frances Weston**

and there view and appraise all and every the said Goods and Chattels, being first sworn

on the Holy Evangelists of Almighty God, to make a true and perfect inventory and

appraisement thereof, and to cause the same to be returned under your hands, or any
three

or four of you, to the said

Emily Frances Weston

on or before the **thirteenth** *day of* **April** *now next ensuing.*

Dated the **thirteenth** *day of* **February** *Anno Domini* **1864**

and in the **eighty-eighth** *year of American Independence*

E. Waterman, Ordinary

To

Francis Weston

Charles Alston Sr.

J. R. Sparkman

J W LaBruce

or any three or four of them

Ordinary's Office

Recorded, Book,

Page

[next page, same document?]

MEMORANDUM

This **Eighteenth** *day of* **March 1864**

Personally appeared before me **Francis W Heriot** *Esquire,*

one of the Justices assigned to keep the Peace in **Georgetown** *District,*

Francis Weston , Charles Alston Jr.

J R Sparkman and J W LaBruce

being **Four** *of the appraisers appointed to appraise the Goods and Chattels*

of **Plowden C. J Weston**

deceased: Who being duly sworn, made oath, that they would make a just and true

appraisement of all and singular the Goods and Chattels of

Plowden C. J Weston

deceased, as shall be produced by **Emily Frances Weston**

the Executrix

of the Estate of the said **P C J Weston**

deceased, and that they would return the same certified under

their hands, unto the said **Emily Frances Weston**

within the times prescribed by law.

Frs W Heriot Magistrate

Francis Weston

Charles Alston Sr

Ja R Sparkman

J W LaBruce

6. Negroes belonging to Hagley Plantation. Estate of Plowden C. J. Weston 1864.

	age	
Antony	43	driver
Tenah	38	prime hand
Hannah	18	half hand
Martha	15	half hand
Samuel	13	half hand
Willoughby	24	prime hand
Baby	2	
Little Anthony	16	half hand
Abraham	15	stable boy
Abel	27	sheep minder
August	21	ditcher
Betsey	20	prime hand
Ben	19	Ditcher
Billy	35	Ditcher
Betty	35	prime hand
Cain	36	ploughman & ditcher
Clarinda	35	prime hand
Carolina	38	watchman & cowminder
George	15	
Quanco	10	
Willard	8	
Quasheba	4	
Baby	2	
Cato	40	ditcher
Mary	35	child's nurse
Simon	19	lead plough
Cudjoe	29	ditcher
Daniel	38	ditcher
Mary	37	half hand
Dick	21	ditcher
Flander	25	Carpenter
Ceely	24	workwoman(sickly)
Baby	2	
Fortune	20	ditcher & carter
Friday	33	ditcher
Clarinda	30	prime hand
Joshua	7	
Caroline	1	

James	35	ditcher
Frank	11	
Chloe	12	
Sandy	9	
Napoleon	5	
Molly	2	
Joe	40	ditcher
John	21	ditcher & ploughman
S John	30	ditcher
Rose	8	
Delia	6	
Agrippa	3	
Charles	1	
Johnno	50	Gardener
Dolly	53	1/4 hand
H Johnny	32	ditcher
Lavinia	30	prime hand
T U Johnny	35	Trunk Minder
Rachel	35	prime hand
Milly	15	half hand
Richard	12	
Jack	10	
Cretia	19	prime hand
Baby	1	
W Johnny	45	watchman
Sal	45	Child's Cook
Peter	10	
March	20	ditcher & ploughman
Napoleon	30	ditcher
Sarah	27	prime hand
Ned	56	ditcher
Judy	50	Midwife
Jack	18	lead plough
Neptune	40	ditcher & fisherman
Poonah	35	prime hand
Pemba	1	
Quanco	45	ditcher
Patience	45	weaver
Juba	15	half hand
Blanche	12	
Joshua	6	

C Quanco	50	Cooper & driver
Mousiah	50	head nurse
Pompey	28	Carpenter
Simmon	40	watchman & ditcher
Martha	15	half hand
Kit	12	
Ellen	14	
Israel	10	
Mildred	8	
Mary	8	
Maria	4	
Titus	50	ditcher & carter
Nancy	45	prime hand
Sylvia	17	half hand
Cilla	15	half hand
Yanickey	1	
Hannah	8	
Philip	6	
Tom	28	Carpenter
Nancy	25	prime hand
Becky	4	
Baby	1	
Frank	45	ditcher
Kate	35	prime hand
Susannah	2	
George	5	
Pocahontas	55	Nurse
Toney	70	Superannuated
Yambo	21	ditcher
Will	35	ditcher
Cumsee	30	prime hand
Abraham	4	
Dido	7	
William	30	ditcher & ploughman
Jim	5	
Rachel	1	
Amy	35	overseer’s cook (sickly)
Amelia	35	prime hand
Noah	8	
Harriet	3	
Bess	25	prime hand

Charity	24	prime hand
Joe	6	
Dil	24	prime hand
Baby	2	
Hagar	45	Plantation Cook
Elizabeth	15	half hand
Cornelia	12	
Hannah	30	prime hand
Harriet	28	prime hand
Baby	2	
Laura	34	prime hand
Phoebe	16	half hand
Lucretia	14	
Elvira	10	
Fraser	4	
Sylvy	75	Superannuated
Venus	28	Overseer's nurse
Lony	24	prime hand
Lucinda	28	prime hand
Prince	3	
Baby	1	
Melissa	30	prime hand
Nelson	4	
A Tenah	35	prime hand
Sibley	18	prime hand
Jeremiah	12	
Madison	5	
Baby	2	
Luckey	30	prime hand
Abraham	4	
J Rachel	25	prime hand
Nelly	23	prime hand
Hagar	12	
J Nancy	35	Prime hand
G Nancy	30	prime hand
Sarah	3	
Baby	1	
F Sarah	12	
Jenny	10	
	House servants	
Hector	33	head servant

Jenny	34	house servant
Prince	32	Coachman
Renty	33	Carpenter & house servant
Gabriel	32	Carpenter & footman
Caesar	23	footman
Jack	23	footman
Agrippa	16	groom
Rachel	35	washerwoman
Dolly	38	Sempstress & housemaid
Phillis	33	Cook & sempstress
Josephine	33	Washer & sempstress
Selina	30	housemaid & sempstress
Mary	32	housemaid
Susanna	30	cook
Ben	12	
Gabriel	10	
Peter	8	
Josiah	6	
Julien	4	
Dido	2	
Elizabeth	1	
Alick	4	
Maurice	2	
185 Negroes	at $2000 round	$370,000

Miscellaneous

Library	$30,000
Silver & plated goods	2735
Furniture	3490
Musical Instruments	1200
Linen, glass, & china	1400
Carriages – four	1500
Horses – four- two old	2000
Mules – nine- three old	5400
Cows & calves – thirty three	1650
Oxen – twenty-six	3900
Sheep & lambs – sixty two	620
Poultry – one hundred & forty head	140
5 wagons & 3 carts – eight	800
Axes – forty	
Hoes – eighty “ all much used”	500

Spades - fifty	
Reaphooks - fifteen	
Ploughs – ten – old	100
Cypress plank – 4000 superficial feet	200
Flats – four – old & rotten	400
Small flat – one new	100
Carried forward	$426135

Estate of Plowden C Weston Brought forward $426135

Iron Boat – one six oared	300
- Do - one small leaky	100
Wooden Boat – three – old padling	30
Wine & liquors – 150 dozen	36000
Rough Rice – Jan 1 – 5000 bushels	15000
Corn – 250 bushels	750
Hogs – forty-four	1320
Deposited in Bank March 2	37600
In Factors hands	2000
xx for $799 Confederate 8 per Ct stock	700
	$520435

Francis Weston

Charles Alston Sr

Ja R Sparkman

F W LaBruce

[7. Note on stationery paper, written sideways in margin:]

Mr E Waterman, Ordinary

Georgetown S. C.

Dear Sir,

Since the Appraisement for Hagley was made, I have found a memorandum of my late husband rating his library at $15,000 (fifteen thousand dollars) and I wish to make this correction in the appraisement – also the wine was over-rated in quantity – I have had it counted since coming here & find it 110 doz instead of 150 doz. I will thank you to let me know how I can properly correct the above items. Also please inform me whether I should be expected to keep an account with receipts, of my private expenses, to be presented to the Ordinary at the end of the year, or whether the appraisement already sent in is sufficient. Please direct yr answer to Conwayboro, where I intend returning in a day or two.

Yrs truly

Emily F Weston, Hagley, April 12th