The Influence of Climate on the Obstetrical Dimensions of the Human Bony Pelvis

by

Rachel Leigh Nuger

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ABSTRACT

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The human bony pelvis is thought to be under the influence of several different selective pressures: locomotor constraints imposed by habitual terrestrial bipedalism, obstetric constraints imposed by the birth of large-brained, broad-shouldered neonates, and climatic pressures that have an influence on body breadth, and perhaps pelvic breadth specifically. This dissertation focuses on the latter two selective pressures by investigating the relationship between obstetrics and climate and the subsequent impact that these two pressures may have on pelvic morphology. This study investigated the relationships and degree of variation in pelvic morphology both within and across human populations representing different climatic regimes to determine if there are associations between obstetrics and climate.

Pelvic and long bone measurements from adult human skeletal remains representing diverse climatic regimes were collected. Partial correlation analysis was used to determine the extent of ecogeographical patterning across the samples. Body size was adjusted for using the anteroposterior (AP) femoral head diameter as the covariate in partial correlation analysis. A variety of approaches to quantifying climate were utilized.

The results of this study indicated that in females, the major transverse pelvic obstetrical diameters (the diameters at the plane of the pelvic inlet, midplane, and outlet) were statistically significantly correlated with climate. These results indicated larger obstetrical pelvic dimensions in high latitude/cold climate female individuals and smaller obstetrical pelvic dimensions in low latitude/hotter climate female individuals. The results for anteroposterior (AP) pelvic dimensions were not as consistent, and most AP pelvic obstetrical dimensions were not statistically significantly correlated with climate. Results were similar for males, with the exception of the transverse pelvic inlet which was not correlated with climate, and some additional AP pelvic dimensions that were not significant in females.

These results suggest that there is a statistically significant relationship between transverse obstetrical pelvic diameters in climate. Furthermore, this relationship remains significant even after accounting for individual body size. The transverse pelvic obstetrical dimensions exhibit a greater degree of ecogeographic patterning than AP pelvic obstetrical dimensions, perhaps because of biomechanical constraints, or because AP pelvic diameters are oriented in a superoinferior direction when the pelvis is in anatomical position.

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Dedication

To my aunt, Pamela Elaine Nuger, for introducing me to a love
of books, music, and learning
Thank you

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CHAPTER 1

INTRODUCTION

Some of the most profound changes in hominin evolutionary history are the morphological changes seen in the pelvis. This anatomical region has long been considered to be under the influence of a variety of different selective pressures, in part because it serves multiple functions which each provide different demands and constraints as the pelvis has evolved over time. First, there are the mechanical demands imposed by committed terrestrial bipedalism (Lovejoy 1988; Rose 1991). The human pelvis is characterized by a much shorter, wider, and more flared ilium compared to the great apes. This serves to shorten the torso and bring the body's center of mass closer to the hips, and also provides a greater area of muscle attachment for the gluteus maximus. The gluteus medius and gluteus minimus muscles are attached more laterally on the ilia compared to the great apes, so that these muscles can stabilize the pelvis during weight transmission. The basin-shape of the ilia helps support the abdominal viscera in an upright position.

Second, there are the obstetric constraints imposed by the birth of large-brained, broad-shouldered neonates in a committed terrestrial biped. The same morphological changes that are biomechanically efficient in a biped have led to a pelvis that makes giving birth much more difficult. First, the morphological changes mentioned above have led to a narrower interacetabular distance, which is more efficient for habitual terrestrial bipedalism, but reduces the size of the birth canal overall. Second, the human birth canal is effectively "twisted," meaning it is wider in the transverse or mediolateral (ML) dimension at the plane of the pelvic inlet (the entrance of the birth canal), but wider in the anteroposterior (AP) dimension at the plane of the pelvic midplane and pelvic outlet, the exit of the birth canal (Rosenberg and Trevathan 1996). As a consequence, the fetal head and shoulders must rotate as they navigate the birth canal, whereas in the great apes the fetal head can pass through all three pelvic planes in the same orientation (because in the great apes the long axis of the birth canal remains the same throughout). Compounding these difficulties, the increased encephalization in the genus *Homo* has made fetal navigation through the birth canal even more difficult. The precise role and balance of biomechanical and obstetric selective pressures on the pelvis has been the subject of some debate (Krogman 1951; Washburn 1960; Rak and Arensburg 1987; Weaver 2002).

Finally, it has been proposed (Roberts 1978; Ruff 1994) that climate has an effect of its own on human pelvic morphology, and on biiliac breadth in particular. Ruff (1991, 1994) has found statistically significant positive correlations between latitude and biiliac breadth (the reasons for this will be explained further later on in the chapter). Although biiliac breadth is not a direct measurement of the birth canal, it includes the transverse diameter of the birth canal and it is therefore possible that the same climatic selective pressures may influence the birth canal as well. Given the variety of selective pressures which influence the morphology of the pelvis, my aim is to examine specifically the relationship between obstetrics and climate, and determine the extent to which these two selective pressures may interact with regard to human bony pelvic morphology.

Obstetrical constraints on the human pelvis

The anthropological literature suggests that the spatial constraints imposed on the pelvis by parturition are considerable (Tague and Lovejoy 1986; Trevathan 1987, 1988; Rosenberg and Trevathan 1996; Trevathan and Rosenberg 2000). Fetopelvic disproportion, defined as "failure of the fetus to pass safely through the pelvis on account of mechanical hindrances" (Adadevoh et al. 1989: 243), is one of the most common causes of complications during parturition, frequently leading to stillbirths and maternal death. This is sometimes noted in the literature as "cephalo-pelvic disproportion" which is the same concept, but refers exclusively to the fetal head obstructing the birth canal, whereas fetopelvic disproportion includes the fetal head and shoulders (or any part of the fetus) obstructing the birth canal. In areas where cesarean section is available, fetopelvic disproportion is cited as one of the most common complications requiring the procedure (Jagani et al. 1981; Adadevoh et al. 1989; Tsu 1992; Abitbol et al. 1999; Aisien et al. 2002). Tadesse et al. (1996) cite the major indications for cesarean section in an Ethiopian study as follows: previous cesarean sections + cephalo-pelvic disproportion (32.4%), cephalopelvic disproportion (29.2%), placenta praevia (12.6%), fetal distress (12.3%), severe pre-eclampsia (6.3%), and a few other complications under 6%. The percentages are similar in Abasiattai et al. (2006), who in a Nigerian study cite the reasons for cesarean section in cases of singleton breech as follows: fetopelvic disproportion (28.6%), footlong breech (21.4%), placenta praevia (14.3%), breech + uterine fibroids (7.1%), pre-eclampsia (7.1%), previous cesarean section (7.1%), and then a few other complications under 6%.

In traditional societies, where modern medical services are not available, such disproportions are considered a strong selective agent against women with small pelvic dimensions (Howell 1979; Trevathan 1987; Hill and Hurtado 1996; Yu 1997). In Nigeria, fetopelvic disproportion is considered the largest individual factor in maternal deaths, (27.2%), and in stillbirths, (18.8%) (Kolawole et al. 1978). As evidence for the importance of the actual metrics of the pelvis in preventing fetopelvic disproportion, Stålberg et al. (2006) found that women who underwent an emergency cesarean section due to obstructed labor had a narrower pelvic outlet than a control sample of women that had delivered vaginally.

Maternal and infant mortality are not the only possible complications from parturition; the risk of injury to both mother and infant is also considerable (Oxorn 1980). The incidences of devastating maternal injuries due to obstructed labor, such as vesicovaginal fistulas (a tear between the bladder and vaginal walls) are quite prevalent in countries that lack modern obstetric care (Cottingham and Royston 1991).

The obstetric literature clearly supports the idea that strong selective pressure acts on the pelvic aperture during parturition in present human populations, and it is reasonable to conclude that such a mechanism operated in prehistoric and fossil populations as well (Arriaza et al. 1988; Rosenberg 1988; 1992; Tague 1994; Abitbol 1996; Stone 2000; Malgosa et al. 2004). However, there is an opposing viewpoint, presented by Walrath (2003), that the dangerous aspects of the childbearing process have been overemphasized. Walrath argues that paleoanthropologists have exaggerated the degree of danger and difficulty of childbirth, and that consequently clinicians have adopted a cultural perspective that emphasizes danger derived from the anthropological model. This viewpoint is not adopted here, first because the author does not find it likely that clinicians are influenced to any great extent (if at all) by paleoanthropological depictions of human childbirth. Second, when one examines maternal mortality statistics worldwide, the deaths from childbirth are by no means insignificant. Table 1.1 lists maternal mortality statistics compiled by the World Health Organization (Abou Zahr and Wardlaw 2004). In the table, “MMR” stands for “maternal mortality ratio,” which is the number of deaths occurring per 100,000 live births. These statistics seem to indicate that maternal mortality due to complications from childbirth is not a selective pressure of the past, particularly in developing nations. Also, although the contrast in the table is of maternal mortality in “industrialized” nations versus “developing” nations, it is interesting to note that so many of the countries with the highest infant mortality are countries along the equator, or very close to it (with the exception of Afghanistan). However, as socioeconomic factors (some of the hottest countries are also the poorest) undoubtedly contribute to this pattern, it is not possible to examine current maternal mortality trends further as they might relate to climate.

Table 1.1: Maternal mortality statistics, from Abou Zahr and Wardlaw (2004)

Industrialized Nations			**Developing Countries**		
Country	MMR (Maternal deaths per 100,000 live births)	Lifetime Risk of Maternal Death 1 in	Country	MMR (Maternal deaths per 100,000 live births)	Lifetime Risk of Maternal Death 1 in
Sweden	2	29,800	Sierra Leone	2,000	6
Ireland	5	8,300	Afghanistan	1,900	6
Italy	5	13,900	Malawi	1,800	7
Canada	6	8,700	Angola	1,700	7
Australia	8	5,800	Mali	1,200	10
Germany	8	8,000	Niger	1,600	7
Japan	10	6,000	Tanzania	1,500	10
Great Britain	13	3,800	Ethiopia	850	14
France	17	2,700	D.R. Congo	990	13
Israel	17	1,800	Uganda	880	13
United States	17	2,500	Nigeria	800	18
Cuba	33	1,600	Ghana	540	35
China	56	830	India	540	48
Russian Fed.	67	1,000	Pakistan	500	31
Turkey	70	480	Bangladesh	380	59
Mexico	83	370	Guatemala	240	74

Climate, the pelvis, and the cylindrical model

The physiological explanation for the influence of climate on the pelvis rests with the thermoregulatory and ecogeographical rules first noted by Bergmann (1847; for translation see James 1970) and Allen (1877). Bergmann's Rule states that in widespread, warm-blooded species, populations in cold climates tend to have larger-bodied individuals than populations in warmer climates. A translation of the original text for Bergmann's Rule argues for a model of inter-specific rather than intra-specific variation, as it is translated as "when other factors are constant, the smaller *species* in a *genus* will occur in a warmer climate" (James 1970: 387). It was modifications to Bergmann's Rule by Mayr (1963) that modified Bergmann's Rule to the model of intra-specific variation as we understand it today. Allen's Rule (1877) states that animals tend to have smaller peripheral body parts in colder climates than animals in warmer climates. As Allen was speaking more generally about animal species, "peripheral body parts" refers to bill or wing size in birds, tail length, or limb size/length in a variety of animals. In the context of humans, biological anthropologists have interpreted Allen's Rule in terms of limb proportions, whereby cold climate populations tend to have shorter extremities relative to their height than warm climate populations (Trinkaus 1981; Holliday 1995, 1997a). The patterns associated with both Bergmann's Rule and Allen's Rule are related to the surface area to body mass (SA/BM) ratio, which changes depending on the overall size of an animal. The (SA/BM) ratio decreases as an object (or body) becomes larger. This idea is key in thermoregulatory processes, because a larger body will have a higher ratio of heat production to heat dissipation than a smaller body of the same shape. Therefore, minimizing the SA/BM ratio in a cold climate conserves heat whereas a larger SA/BM ratio in hot environments facilitates heat loss.

The basic tenets of ecogeography hypothesized by Bergmann's Rule and Allen's Rule do explain much of the variation seen in modern human morphology. Studies by anthropologists and human biologists have shown well-documented systematic clines (continuous character variation) in body shape corresponding to climatic gradients, that are generally in support of Bergmann's and Allen's Rule (Roberts 1978; Crognier 1981;

Trinkaus 1981; Holliday 1997b; Katzmarzyk and Leonard 1998; Pearson 2000; Ruff 2002; Weaver 2002). There is some evidence of support for Bergmann's and Allen's Rule in the fossil record as well. Ruff and Walker (1993) argue that the KNM-WT 15000 *H. erectus* skeleton exhibits a tall, narrow body form and high brachial and crural indices, a suite of characteristics that would be considered an adaptation to a tropical, semi-arid environment. There have also been many studies indicating a cold-adapted morphology in Neandertals (Trinkaus 1981; Holliday 1997b; Steegmann et al. 2002; Weaver 2003), although the extent of the cold adaptation has been the subject of some debate (Weaver and Steudel-Numbers 2005).

Ruff (1991, 1994) has taken Bergmann's Rule one step further by emphasizing the importance of body width or breadth as a factor explaining variation in modern human morphology. Ruff has shown correlations between thermoregulation, climate, and pelvic breadth, indicating that populations in colder climates have absolutely wider lower trunks (i.e., biiliac breadths) than populations in warmer climates. Ruff argues that the human body can be modeled as a cylinder, where stature is the "height" of the cylinder and biiliac breadth is the width or "breadth" of the cylinder. Biiliac breadth is taken as the width measurement not only because it is a general body breadth measure, but also because it can be measured in both living humans and human skeletal remains (not because it intrinsically needs to be the "width" calculation). When such a model is applied, it is found that the SA/BM ratio remains constant when the height is changed as long as the width remains constant. However, when the width of the cylinder is changed, the SA/BM ratio is always impacted, where an increase in width produces a decrease in the SA/BM ratio, and a decrease in width causes an increase in the SA/BM ratio. An examination of human pelvic breadth across different climates allows for the opportunity to test the cylindrical model. Although changes in hominin pelvic breadth are not a direct test of Bergmann's Rule, the smaller SA/BM ratio that results from a wider biiliac breadth is based on the underlying thermoregulatory predictions derived from Bergmann's Rule.

However, not all human variation that has been studied is in direct support of Bergmann's Rule. Hiernaux and Froment (1976), found that in sub-Saharan Africa body size and stature did not vary in expectation to Bergmann's Rule, as body weight and stature were positively correlated with increases in temperature. Stinson (1990) found that in South America, weight was significantly correlated with climatic variables in females but not in males.

It is also important to note that Bergmann's and Allen's Rule, while usually good explicators of observed variation, become more complicated when one attempts to examine or measure the adaptation that purports to explain such variation. Steegmann (2007) has noted that from a physiological standpoint, Bergmann's Rule and Allen's Rule need to be evaluated more critically by both human biologists and biological anthropologists. Steegmann examines whether the biogeographic variations noted within humans are actually environmentally adaptive, by producing a "significant functional outcome" (in other words, an adaptation) compared to individuals who do not have such variations. When the potential physiological advantage of a reduced SA/BM ratio under cold conditions is evaluated in terms of core temperature loss, Steegmann argues that the physiological significance of a lower SA/BM ratio is not clearly evident, or at the very least, inconclusive. This could be because individual body composition (the amount of body fat and muscle mass) is a confounding variable, and also because the anthropometric variables under study tend to be very highly correlated with one another. Steegmann's physiological examination of the study of Bergmann's Rule and heat is similarly inconclusive. Interestingly, most studies indicate that body mass is more important than the SA/BM ratio in terms of heat dissipation during active exercise, and a higher body mass is more advantageous than a lower body mass, a vexing contradiction of Bergmann's Rule. When the physiological benefits of Allen's Rule are studied, Steegmann suggests that the reduction of extremity length to trunk height does not have a great physiological impact, because most body heat is not lost through the extremities. Despite the equivocal physiological evidence in support of Bergmann's and Allen's Rules, Steegmann does "suspect that length and diameter of the trunk are the body areas most involved in cold defense" (2007: 224). Within this discourse, I aim to examine the obstetrical pelvis in the context of climate, with the goal of perhaps filling in some of these gaps, and identifying additional adaptive aspects of pelvic morphology which may explain some of the inconsistencies in variation with regard to Bergmann's Rule and the cylindrical model.

The mechanism of birth

The mechanism of birth, defined as the way the fetus "adapts itself to and passes through the maternal pelvis" (Oxorn 1980: 86), is unique in humans compared to other nonhuman primates, and other fossil hominins. Rosenberg and Trevathan (1996) have noted that the mechanism of birth in humans differs from nonhuman primates in two fundamental ways. First, the orientation of the fetal head as it enters the pelvic inlet is different in humans and nonhuman primates. Nonhuman primates face anteriorly or posteriorly, and humans are oriented transversely (such that the suboccipito-bregmatic diameter of the neonate cranium is oriented along the transverse axis of the inlet). Second, the change in orientation of the fetal head as it passes through the birth canal is different, whereby nonhuman primates rotate to a variable degree but emerge facing forward with the head flexed, and human neonates rotate upon entering the pelvic midplane to exit facing backward with the head extended. Human neonates must also flex their head anteriorly before engaging the pelvic inlet. Most importantly, human neonates must rotate when they descend the birth canal because the greatest breadth at the inlet is in the transverse dimension, but the greatest breadth at the midplane and outlet is in the sagittal dimension. When the fetal head reaches the midplane, it encounters bony resistance and rotates internally 45°-90° (depending on whether its position upon entering the inlet is transverse or oblique). The fetal head usually rotates such that the occiput comes to lie near the pubic symphysis, a position known as occiput anterior. However, Walrath (2003) notes that occiput posterior presentations are also common, and are possibly underrepresented in paleoanthropological models of the human birth mechanism.

The mechanism of birth in *Australopithecus*, however, has been proposed to be unique. Tague and Lovejoy (1986) argue based on a reconstruction of A.L. 288-1 (*Australopithecus afarensis*) that the fetal head engaged at the pelvic inlet in the same manner as humans (with the occipito-frontal diameter of the fetal head aligned transversely) but that the fetal head did not rotate as it descended the birth canal. Häusler and Schmid (1995), have a contrasting viewpoint, proposing that in Sts 14

(*Australopithecus africanus*) internal rotation of the fetal head would have occurred when the head passed from the inlet to the midplane. However, Trevathan and Rosenberg (2000) have argued that there must have been some rotation of the fetal shoulders in *Australopithecus* even if there was no rotation of the fetal head.

It is not easy to identify exactly when in the fossil record the transition from the proposed mechanism of birth in australopiths to rotational birth in *H. sapiens* occurred. Ruff (1995) argues that the true pelvis in early *Homo* was also markedly platypelloid, and more similar in shape to australopithecines than modern humans. He hypothesizes that the ML breadth of the pelvis increases to a maximum in early *Homo* and then decreases again in *H. sapiens*. Ruff also posits that AP breadth of the pelvic outlet increases slightly from *Australopithecus* to early *Homo*, and then increases rapidly to *H. sapiens* as rotational birth is established. Ruff's model argues that rotational birth did not occur until relatively late in the evolution of the genus *Homo* (around 0.7 Ma). Rosenberg (1992) presents a similar viewpoint, but see Abitbol (1996), who argues for a rotational birth mechanism in some early fossil hominins.

It is also important to consider the degree of sexual dimorphism in the hominin pelvis. Sexual dimorphism in the human bony pelvis is driven by two underlying factors: the overall larger body size of males relative to females, and the adaptations of the female pelvis to parturition. However, the degree of sexual dimorphism in certain features can vary from population to population (Tague 1986). For the features described below, all figures are in Chapter 2. In general, males, relative to females, tend to be larger in the following features: biiliac breadth (Figure 2.1), true pelvis depth (Figure 2.11), height and breadth of the acetabulae (Figure 2.10), vertical height of the pubis, and overall dimensions of the os coxa such as coxal height, iliac height and maximum iliac breadth (Figure 2.9 for all three). Additionally, iliac flare (the angle of the iliac blade relative to the vertical) tends to be greater in males. Females, relative to males, tend to be larger or wider in the following features: transverse inlet, midplane, and outlet diameters (Figure 2.1), AP midplane and outlet diameters (Figure 2.2), posterior midplane and outlet (Figure 2.5), interacetabular distance, linea terminalis (Figure 2.4), subpubic and sacral angles (Figures 2.7 and 2.8), and the greater sciatic notch (Figure 2.12). Pubic length tends to be longer in females, but the extent of this difference is population dependent (Rosenberg 1986). This summary of sexual dimorphism is based on Rosenberg (1986), Tague (1986), Arsuaga and Carretero (1994), and Weaver (2002). Although the focus of this particular study is not sexual dimorphism in the pelvis, the author is aware of these differences, and will analyze males and females separately where appropriate to remove sex differences as a confounding variable.

While recent studies have examined biiliac breadth across populations in relation to thermoregulation, and other studies (Sibley et al. 1992; Tague 1994; Stone 2000) have examined the impact of obsetrics as a selective pressure, limited research has examined whether the same climatic factors affect the morphology of the obstetrical pelvis (also called the “lower” or “true” pelvis). This study will examine human pelvic morphology in order to analyze the relationships and degree of variation both within and across human populations from different climatic regimes to determine if associations exist between obstetric dimensions and climate.

Obstetrics and climate

There are at least two primary reasons to expect the dimensions of the obstetrical pelvis to vary across populations as a response to climatic factors. First, the work of Roberts (1978) and Ruff (1991, 1994) on biiliac breadth and climate indicates a direct relationship between climate and pelvic breadth, whereby populations in colder climates have wider pelves and populations in warmer climates have narrower pelves, again, as adaptations for efficient thermoregulation. Second, maternal body weight and overall body size (i.e., stature) are thought to be critical determinants of infant size and therefore of birth canal size (Garn and Pesick 1982; Rosenberg 1986; Martorell and González-Cossío 1987; Kirchengast and Hartmann 1998; Kirchengast et al. 1998; Pickett et al. 2000). As populations in higher latitudes (and colder climates) are heavier relative to their stature (Ruff 1994), it follows that females in higher latitudes should give birth to heavier infants (therefore requiring a larger birth canal) than females in lower latitude (warmer climate) populations. As further evidence of the possible interaction of obstetrics and climate, research on living populations across a wide ecogeographical range indicates that there is a strong negative correlation between heat index and birth weight (Wells and Cole 2002). This research suggests that heat-stressed populations may have a smaller obstetrical pelvis for more efficient thermoregulation, which could in turn be leading to a smaller neonate size. It also follows that there would be selection for larger neonates in cold climates, as babies are particularly sensitive to thermal loss (Brace 1988). Thus, there are two types of selection that can result from climate: selection on adult body shape and selection on infant size at birth.

In other words, there are two different underlying reasons to expect associations between obstetrics and climate. The first type of selection is on adult body form, due to the predictions of the cylindrical model (a wider body breadth in colder climates and a narrower body breadth in hotter climates) and how this might relate to thermoregulation. This particular type of selection has been most studied with regard to the false pelvis, as measured by biiliac breadth. However, the possibility of selection related to climate affecting the true pelvis should also be considered, as it is possible that the diameters of the true pelvis could be "dragged along" by selection on the false pelvis. Or, it is possible that this selection pressure is counteracted by locomotor efficiency that would select for a narrower birth canal, with all other things being equal. Second, there is selection on the pelvis due to obstetrical pressures, because larger, heavier females tend to have larger neonates, and smaller, lighter females tend to have smaller neonates. This second type of selection in turn results from two possible sources of selection pressure—selection on adults causing them to be larger and heavier [and hence have larger neonates] and selection on neonatal size, causing selection for larger maternal birth canals. This type of selection would be expected to have the greatest impact on the true pelvis, which is the portion of the pelvis that includes the birth canal, and the smallest dimensions that the fetal head and shoulders must navigate. It is important to note that associations between pelvic dimensions and climate could be present (and be working in the same direction) for all of the aforementioned reasons.

It might not be possible to identify precisely which of the different selection pressures stated above is responsible for association between climate and the dimensions of the true pelvis. Examining associations between the true pelvis dimensions and climate in males will assist in this effort, as males do not have the same obstetric pressures as females, and therefore should exhibit a greater emphasis on climatic and biomechanical selective pressures. However, it also cannot be assumed that males are completely isolated from selection related to obstetrics. The purpose of this study is to first find out if those associations exist between climate and the true pelvis, and then it might be possible to examine the possible reasons why these associations might exist. This study allows for a greater understanding of the selective pressures operating on the hominin bony pelvis, especially the obstetrical dimensions, by examining the interaction of two key selective pressures: obstetrics and climate.

Research questions and hypotheses

This study investigates the relationship between climate and the dimensions of the obstetrical pelvis, with the following goals:

1. To determine whether obstetrical pelvic size and shape dimensions vary with increasing or decreasing latitude and/or temperature.
2. To determine if obstetrical and non-obstetrical pelvic dimensions are correlated with each other.
3. To determine whether the corresponding "obstetrical" pelvic dimensions in males exhibit the same patterns as females.

The main hypothesis to be tested is that females in populations from high latitude/colder climates will require a larger obstetrical pelvis than females in populations from lower latitude/hotter climate populations, because of the selection on adult body form and infant size at birth, as discussed earlier. Although it is never possible to completely "remove" or "eliminate" the effects of body size, the above hypothesis will be tested both with and without "controlling" or "accounting for" the effects of body size. A summary of all of the hypotheses tested in this project are listed in Table 1.2.

Table 1.2: Summary of hypotheses

Hypothesis (H_0)	**Hypothesis (H_A)**
1. Pelvic obstetrical dimensions are not statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)	1. Pelvic obstetrical dimensions are statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)
2. Male pelvic dimensions are not statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)	2. Male pelvic dimensions are statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)
3. Pelvic obstetrical dimensions show no statistically significant correlation(s) with biiliac breadth	3. Pelvic obstetrical dimensions show statistically significant correlation(s) with biiliac breadth
4. Pelvic obstetrical variables in multivariate space are not statistically significantly correlated with climate	4. Pelvic obstetrical variables in multivariate space are statistically significantly correlated with climate

In order to approach these research questions, a large sample (n = 543) of associated pelvic and long bones from adult human postcranial skeletal remains were examined and measured. The methods and materials will be discussed further in Chapter 2 of this work, which contains a discussion of the human skeletal remains chosen for this study. Descriptions of each skeletal sample, along with its temporal and geographic provenience will be presented. This will be followed by a discussion of the measurement protocols and a description (written and illustrative) of all of the measurements collected. Identification of sex is also extremely important for this study, and methods for sex determination of individual specimens will be discussed. Finally, a description of the statistical techniques used to analyze the samples will be presented.

Chapter 3, Univariate Results and Analysis, begins with a discussion of the descriptive statistics for all of the measurements collected. The second section of Chapter 3 investigates the relationship between different measures of climate and the obstetric dimensions of the human pelvis (hypotheses #1 and #2 in Table 1.2). The third section of Chapter 3 analyzes the relationship between biiliac breadth and other transverse and AP obstetrical pelvic dimensions, and investigates whether obstetrical and non-obstetrical pelvic dimensions are correlated with each other (hypothesis #3 in Table 1.2). The final section of Chapter 3 analyzes the long bone measurements that were collected. Brachial and crural indices were calculated in order to test Allen's Rule and examine another source of climatic variation in the postcranial skeleton.

Multivariate Results and Analysis, Chapter 4, presents the results of principal components analysis (PCA) on the variables created from the pelvic measurements collected in this study (hypothesis #4 in Table 1.2). The second portion of this chapter examines the relationship between the principal components extracted and the same measures of climate utilized in the previous chapter. This is done in order to examine the correlation between pelvic size/shape and climate in multivariate space.

Chapter 5, the concluding chapter, will present a summary and discussion of the results presented in Chapters 3 and 4. This chapter revisits the three research questions and four hypotheses presented in the introduction. The implications of these conclusions will be discussed.

CHAPTER 2

MATERIALS AND METHODS

Materials

This chapter introduces the skeletal remains used in this analysis. It will cover how the included skeletal remains were identified and selected for this study. This will be followed by a brief description of each sample population, including sample size, geographic and temporal provenience, and information about the subsistence economy where available. The methods for quantifying climate and the various climatic measures used are covered. I will then discuss the set of pelvic and long bone measurements collected, and conclude with the statistical methods used to analyze the samples.

Adult human postcranial skeletal remains from museum collections in the United States and Europe were used in this analysis. The skeletal remains measured by the author and included in this study are listed in Table 2.1, along with the institutional location of each collection and sample sizes for males and females.

Adult status was determined by complete fusion of all major long bone epiphyses and at least partial fusion of the iliac crest and ischial tuberosity. Age at complete fusion of the iliac crest has a range of 18-23 years, and age at fusion of the ischial tuberosity has a range of 17-25 years (White and Folkens 2000). Adult status was further corroborated by using the Todd (1921a, 1921b) method to assign a phase for the pubic symphysis and the Lovejoy et al. (1985) method to assign a phase for the auricular surface, both utilized from Buikstra and Ubelaker (1994). Although knowledge of a precise age of the individual is not integral to the project, these phases were assigned in order to have additional verification of the mature adult status of the individual. For some of the collections an independent age assessment was available on record.

Sex determination was made using standard osteological techniques, including evaluation of the sciatic notch (Holcomb and Konigsberg 1995; Hager 1996), subpubic angle, preauricular sulcus, and other sexual characteristics found in the pubis (Phenice 1969; Buikstra and Ubelaker 1994). In almost every population studied, there was an independent sex assessment on record, either in publications about the collection or associated with the skeleton. However, a sex assessment was still conducted by the author (when possible, without prior knowledge of the other assessment). In rare cases where the author's sex assessment was not in agreement with the sex assessment on record, another researcher was asked to do an independent sex assessment. In all cases the researcher's independent assessment agreed with the author's and then this sex assessment was used. Ultimately, no individual was removed from the analysis due to indeterminate sex.

Nutrition as a possible factor influencing body size was considered in all analyses. However, the obstetric literature suggests that maternal nutrition does not affect neonatal birth weight except under conditions of extreme nutritional deprivation (Martorell and González-Cossío 1987; Susser 1991). In situations where body size might have been reduced in response to chronic undernutrition, this was accounted for in analyses by comparing pelvic size to overall body size (see "measurements" section). The possibility of vitamin D deficiency was also considered, as such a deficiency may lead to rickets and consequent deformity of the skeleton affecting the lower limbs and os coxae (Serenius et al. 1984; Stuart-MacAdam 1989; Brabin et al. 2002; Hochberg 2003). Although the samples under study were from varying time periods, they were all pre-industrial (with the exception of the Spitalfields collection), which likely minimized the incidence of rickets (Robins 1991). In the case of the Spitalfields collection, there were several cases of rickets, noted most frequently in the bowing of the tibiae but occasionally affecting the sacra (Molleson and Cox 1993). Where there appeared to be evidence of rickets, the individual was not included in the analyses, even if the os coxae and sacrum did not appear to be affected. Individuals were also excluded if there were any bilateral conditions affecting the hip joint (osteoarthritis, eburnation, etc.) that would have prevented accurate measurements of the acetabulae and femoral head.

Data on climate were obtained from climatic tables and atlases (Willmott et al. 1981; Binford 2001). Three measures were used to quantify climate and subdivide the samples for this study: latitude, mean temperature of the coldest month (MTCM), and mean temperature of the warmest month (MTWM). All temperatures are in °C. These approaches are comparable to previous work on ecogeographic patterning (Ruff 1994; Katzmarzyk and Leonard 1998, and references therein). Locality and climatic data for each sample are listed in Table 2.2.

Table 2.1: Populations studied and sample sizes

Population	Institution Where Housed	Male	Female	Total
Alaska (Point Hope)	American Museum of Natural History, New York, New York	55	52	**107**
Denmark (SkælskØr)	The Panum Institute, University of Copenhagen	23	14	**37**
Tierra del Fuego	University of Rome; Natural History Museum of Florence	9	7	**16**
United Kingdom (Spitalfields)	Natural History Museum, London	40	65	**105**
Czech Republic (Budec)	Peabody Museum of Archaeology and Ethnology, Harvard University	6	4	**10**
Bosnia-Herzegovina	Peabody Museum of Archaeology and Ethnology, Harvard University	19	11	**30**
Illinois (Dickson Mounds/Elizabeth Mounds)	The Illinois State Museum, Springfield, IL	8	10	**18**
Lower Nubia (El Shellal)	The Duckworth Collection, Cambridge University, UK	12	14	**26**
Lower Nubia (Sayala)	Naturhistorisches Museum, Vienna	24	26	**50**
Upper Nubia (Kulubnarti)	University of Colorado, Boulder	64	44	**108**
Andaman Islands	Natural History Museum, London	6	2	**8**
Peru (Ancon)	The Field Museum, Chicago, IL	17	11	**28**
			Grand Total	**543**

Table 2.2: Climate data

Population	Latitude	MTCM (ºC)	MTWM (ºC)	Source
Alaska (Point Hope)	68.29 N	-24.08	8.97	Binford (2001)
Denmark (SkælskØr)	55.25 N	-0.05	16.6	Willmott et al. (1981)
Tierra del Fuego	52.28 S	2.1	11.1	Willmott et al. (1981)
United Kingdom (Spitalfields)	51.52 N	3.6	15.4	Willmott et al. (1981)
Czech Republic (Budec)	49.90 N	-1.6	17.4	Willmott et al. (1981)
Bosnia-Herzegovina	42.38 N	8.9	24.7	Willmott et al. (1981)
Illinois (Dickson Mounds/Elizabeth Mounds)	40.35 N	-2.7	24.7	Willmott et al. (1981)
Lower Nubia (El Shellal)	24.05 N	16.8	33.8	Willmott et al. (1981)
Lower Nubia (Sayala)	22.98 N	16.8	33.8	Willmott et al. (1981)
Upper Nubia (Kulubnarti)	19.63 N	23.8	33.9	Willmott et al. (1981)
Andaman Islands	11.67 N	26.04	28.89	Binford (2001)
Peru (Ancon)	11.50 S	21.7	27.3	Willmott et al. (1981)

Description of samples (in order of decreasing latitude)

Point Hope, Alaska

The Point Hope Alaskan skeletal collection is currently housed at the American Museum of Natural History. This collection was excavated by Larsen and Rainey (1948) between 1939-1941, and the remains are associated with the Ipiutak and Tigara cultures. The Ipiutak component dates from 100 B.C.-500 A.D. and the Tigara component dates from 1300-1700 A.D. (Costa 1980; Schwartz et al. 1995). Both groups depended upon traditional Inuit foraging strategies that utilized maritime resources. A sample of 55 males and 52 females (the individuals with the most complete pelvic and long bone elements) was measured for this project.

SkælskØr, Denmark

The skeletal remains from SkælskØr, Denmark, are housed at The Panum Institute at the University of Copenhagen. The remains are from a Carmelite monastery located in SkælskØr, Denmark, that is thought to date to as early as 1418 A.D., and closed in 1532 A.D. (Koch and Lynnerup 2003). The inhabitants of the cemetery are thought to be residents of the monastery, as well as other individuals from the town and surrounding area, who might have preferred the monastic cemetery to the parish church cemetery on the other side of the town. The exact occupation of all of the cemetery inhabitants is not known, but it is thought to consist of either residents of the monastery, or more skilled laborers from the town and surrounding area (N. Lynnerup, personal communication). A sample of 23 males and 14 females was included for this study.

Tierra del Fuego, Patagonia (Argentina/Chile)

The skeletal remains from Tierra del Fuego are housed at the University of Rome, "La Sapienza," and the Natural History Museum of Florence. Most of the individuals included in the analysis are from the Rome sample, as the pelvic remains in the Florence sample did not have long bones (or any other postcranial elements) associated with the pelves. However, both samples are from the same collection, acquired by the Italian explorer Giacomo Bove from a voyage that began in 1866 (Manzi 1988). In terms of the subsistence base for this sample, the archaeological and ethnographic record suggests a strong maritime hunting adaptation, with an emphasis on the hunting of sea mammals, supplemented by marine birds, and almost certainly the collection of mussels at low tide (Borrero 1997). Canoes were also a critical part of the maritime adaptation, as it would be nearly impossible to navigate the channels without them. A sample of 9 males and 7 females was included in this study.

Spitalfields, United Kingdom

The skeletal remains from Spitalfields are housed at the Natural History Museum, London. The remains are from the parish of Christ Church, Spitalfields and date from 1729 (when the church was consecrated) to 1857, when the burials ceased. In total, 968 individuals were excavated from the crypt at Christ Church, and the remains have been studied extensively (Molleson and Cox 1993). The Spitalfields collection also consists of a smaller (n=368) "named" sample, where individuals had preserved coffin plates indicating their name, age, and date of death. The occupations and socio-economic status of the named sample are well-documented, with a majority of occupations listed as either artisans or master craftsmen. Knowledge of the occupations of the crypt sample as a whole is slightly more indirect (without exact names to research in baptism records, etc.), but trade directories indicate that until the early decades of the 19th century the silk industry dominated in Spitalfields, with food retail/manufacture taking over after that point as the largest industry (Molleson and Cox 1993).

There is no historical evidence directly related to the diet of the crypt sample. However, anecdotal records from the time indicate that among the most affluent members of society the diet was most likely characterized by an abundance of animal proteins and animal fats. The less affluent members of society had a diet that was more heavily supplemented by bread and root vegetables, as this was more affordable than animal proteins (Molleson and Cox 1993). In any case, it does not appear that the individuals of the crypt sample experienced severe nutritional deprivation, although the high incidence of cribra orbitalia appears to indicate a prevalence of childhood iron deficiency (Molleson and Cox 1993). A sample of 40 males and 65 females was included for this project, including 8 males and 14 females from the named sample.

Budec, Czech Republic

The skeletal remains from Budec are housed at the Peabody Museum of Archeology and Ethnology. They were excavated from the Budec cemetery from 1929-1931 by V.J. Fewkes. There are limited publications on this collection, but the field notes from the excavation were available for viewing at the Peabody. According to the field notes, most of the graves date to the early Slavic period (950-1050 A.D.). The subsistence base of central Europe in that time period was characterized by wheat, millet, and legume agriculture, supplemented by the use of domesticated animals and fishing (Gimbutas 1971; Gregg 1988). A sample of 6 males and 4 females was included for this study.

Mistihalj, Bosnia-Herzegovina

The skeletal remains from Mistihalj are also housed at the Peabody Museum of Archaeology and Ethnology. The skeletal remains were excavated by a joint U.S.-Yugoslav team in 1967. The Mistihalj cemetery is situated in Bosnia-Herzegovina, just west of Montenegro and northeast from the southern tip of the Dalmatian coast. The exact dates of the collection are not known, but the tombstones date to the late Medieval period, from 1300 to 1500 A.D. It should also be noted that the tombstones associated with the graves pre-date the Ottoman conquest of 1468, so the burials in all likelihood antedate this date (Redfield 1989, cited in Holliday, 1995). It was not possible to obtain information about the subsistence base pertaining to the Mistihalj site directly. However, it was most likely similar to the Budec sample (Gregg 1988). A sample of 19 males and 11 females was included for this analysis.

Dickson Mounds and Elizabeth Mounds, Illinois

The skeletal remains from Dickson Mounds, Illinois are housed at the Illinois State Museum Research and Collections Center in Springfield, Illinois. The Dickson Mounds site is located about three miles southeast of Lewistown, Illinois, and dates to the Mississippian Period, with peak usage between approximately 1100 and 1250 A.D. The subsistence base of this period was characterized by maize agriculture supplemented by some fishing and hunting activity (Milner 2004). In order to have a larger sample size from this region the Dickson Mounds sample was pooled with a sample from Elizabeth Mounds. The Elizabeth Mounds site is located in Pike County, Illinois on the western bluff overlooking the Illinois River. The skeletal remains from Elizabeth Mounds date to the early Late Woodland Period, approximately 500-1000 A.D. Although this site is earlier than Dickson Mounds, the subsistence economy was similar, with an emphasis on maize agriculture, along with some hunting and gathering (Charles et al. 1988). A total of 8 males and 10 females from both sites was included for this project.

Lower Nubia (El Shellal)

The skeletal remains from El Shellal are housed as part of The Duckworth Collection at Cambridge University. El Shellal is located immediately south of the Nile's First Cataract, and the skeletal remains under study are from the now-submerged island of Hesa, where a large collection of bodies (about 2,000) were buried. The skeletons were excavated prior to the construction of the Aswan dam, which flooded the island. The cemetery dates to the time of the adoption of Christianity in Nubia, approximately from the fourth to seventh centuries (Elliot Smith and Wood Jones 1910). The subsistence economy of Lower Nubia in that time period would be best characterized by small-scale farming, the use of some domesticated animals, and fishing (Adams 1977; Carlson and Van Gerven 1979). A sample of 12 males and 14 females was included from this collection.

Lower Nubia (Sayala)

The Egyptian Nubians from Sayala are housed at the Naturhistorisches Museum, Vienna. Sayala is located approximately 130 km south of Aswan, Egypt. The remains date to the Christian period, spanning the 6th to 11th centuries A.D. (Strouhal 1992). The subsistence base was very similar to that of El Shellal, with small-scale farming and some use of cattle and sheep (Adams 1977). A sample of 24 males and 26 females was included for this project.

Upper Nubia (Kulubnarti)

The skeletal collection of Nubians housed at the University of Colorado, Boulder is from the Medieval site of Kulubnarti in Sudanese Nubia. Kulubnarti is located approximately 80 miles south of Wadi Halfa in the Republic of Sudan. The subsistence economy of this part of Nubia (known as Batn el Hajr, or “belly of rock”) is characterized by small-scale farming, with sorghum, millet, barley, beans, lentils, peas, dates, and wheat as the staple crops. A few cattle, sheep, and pigs were also kept, but domesticated animals do not appear to have been a large part of the Nubian diet (Van Gerven et al. 1995). It should also be noted that as its name indicates, this particular region of Nubia was particularly barren and harsh. The steep banks of the Nile made it particularly difficult to irrigate, and subsistence was always marginal (Adams 1977). The human skeletal remains included for this study were excavated in 1976 by Dennis Van Gerven, and they consist of two cemeteries. The older cemetery, 21-S-46, dates to about 500 A.D., and was in use until the twelfth century. The second cemetery, 21-R-S, dates from 1100-1500 A.D. for the collection under study (Kilgore et al. 1997). Therefore, the two

Kulubnarti cemeteries represent an overlapping sequence that dates from approximately 500-1500 A.D. A sample of 64 males and 44 females was measured and studied for this project, with a slight bias towards the R cemetery due to the large number of juveniles in the S cemetery.

Ancon, Peru

The skeletal remains from the central coastal site of Ancon, Peru are housed at The Field Museum of Natural History, Chicago. Most of the collection dates from 1100 or 1200 A.D. to 1500 A.D., a time period spanning the Late Intermediate to Late Horizon cultural periods of Peru (P.R. Williams, personal communication). The subsistence base of the Ancon site has been reconstructed primarily from dried fragments found in vessels and placed in graves. This analysis indicates a maritime-based economy (based on the presence of fishing nets and numerous vessels containing dried fish), supplemented with some coastal agriculture, with maize as the predominant crop (Dorsey 1894). However, there is also evidence of several varieties of beans, peanuts, cassava, pacay, lucuma (a fruit), and guinea pig. These findings are also consistent with other excavations of contemporaneous sites in Ancon (Kaulicke 1997). A sample of 17 males and 11 females was included for this study.

Andaman Islands

The Andaman Islanders are housed at the Natural History Museum, London. The remains were collected in the late nineteenth and early twentieth centuries, and date from that time period based on documents at the museum. Most of the skeletons are labeled

"Port Blair," from the southern end of the Andaman Island chain. The subsistence base would best be described as hunting and gathering with an emphasis on maritime resources, in addition to some tropical forest plants and game animals (Radcliffe-Brown 1964). A sample of 6 males and 2 females was included for this project. Given the small size of this sample, there are limitations to the degree it can be considered representative of the climatic region from which it derives. However, as the only small stature population included for this project, it is worth analyzing to see if the patterns are the same as those for the other populations.

Measurements

Tables 2.3 and 2.4 list all measurements collected, along with a written description of each measurement. In the case of pelvic measurements (Table 2.3), there is also a notation of the figure number that illustrates that particular measurement with each description. Figures of all pelvic measurements are shown in Figures 2.1 through 2.12.

Measurements were chosen and carried out with four goals in mind. The first was to collect pelvic measurements that would accurately capture the overall dimensions of the birth canal. The pelvic measurements selected are based on those previously used by other researchers (Tague and Lovejoy 1986; Rak and Arensburg 1987; Sibley et al. 1992; Tague 2000), and the majority of these pelvic measurements have become standardized. The second goal was to collect measurements of body breadth to capture information related to climate. The two primary measurements that serve this purpose are biiliac breadth, to reflect maximum body breadth at the hips, and clavicular length, in order to reconstruct biacromial diameter following Tague (2000). The third goal was to collect measurements that could serve to adjust or account for the body size of an individual when conducting statistical analyses. The anteroposterior (AP) and superoinferior (SI) diameter of the femoral head was measured for this purpose, which is consistent with previous studies that have used femoral head diameter (or femoral head diameter squared) as a measure that is proportional to body weight (Lovejoy et al. 1973; Rosenberg 1986; Rosenberg 1988; Ruff et al. 1997; Ruff 2002). Finally, the fourth goal was to collect long bone measurements to be able to calculate brachial and crural indices, in order to have yet another index of climatic variation, and to make the results comparable to previous work on ecogeographic patterning in hominin limb proportions (Trinkaus 1981; Ruff 1994; Holliday 1997a, 1997b, 2002; Ruff 2002).

All measurements were collected by the author. The os coxae and sacrum were articulated using a non-toxic, non-damaging putty in order to reconstruct pelvic apertures. Measurements were collected with two kinds of sliding calipers. Metal Mitutoyo 200 mm calipers were used to collect the majority of the pelvic measurements. This set of calipers had one set of longer blades in order to measure distances such as the pelvic inlet without interference from other parts of the os coxae. Where internal pelvic measurements needed to be taken, a second smaller set of Mitutoyo 200 mm calipers were used. The larger set of calipers measured to a precision of 0.01mm, and the smaller set measured to the nearest 0.1 mm. Long bone measurements and biiliac breadth were measured on an osteometric board to the nearest 1.0 mm. For measurements of the unarticulated os coxa, only the right side was measured, unless it was damaged, in which case the left side was measured. For the long bones, both right and left sides were measured when they were available and complete. When two sides for an individual were present and measured, an average of both sides was used in statistical analyses. Intra-observer error was calculated following White and Folkens (2000). Intra-observer error varied depending on the measurement, from as low as 0.33% for the diagonal pelvic inlet, to 3.4% for the anteroposterior outlet. In general the anteroposterior pelvic measurements had a slightly higher error rate than mediolateral measurements, and this is attributed to the mobility of the sacrum when articulating the pelvis to collect measurements. However, all measurements collected are considered to have an acceptable degree of repeatability that is comparable to other studies, with most error rates under 2.0% (Rosenberg 1986; White and Folkens 2000). Inter-observer error was calculated by taking measurements collected independently by the author and K. Klingeman on the Spitalfields collection, and was calculated at 0.34% for biiliac breadth and 0.20% for the transverse pelvic inlet. It was only possible to calculate inter-observer error for those two measurements, but intra-observer error was calculated for all of the measurements collected.

Table 2.3: Description of pelvic measurements

Pelvic Measurements	Definition	Figure
Transverse Diameters:		
Biiliac breadth	maximum distance between tubercles of the iliac crest	2.1, Line A
Transverse inlet	the maximum transverse diameter of the pelvic inlet along the arcuate line	2.1, Line B
Transverse midplane	distance between ischial spines	2.1, Line C
Transverse outlet	distance between ischial tuberosities (from the inner margin of the transverse ridge)	2.1, Line D
Anteroposterior Diameters:		
Sagittal diameter of the pelvic inlet (obstetrical conjugate)	the anteroposterior distance from the midline of the sacral promontory to the dorsomedial aspect of the superior border of the pubis	2.2, Line A-B
AP midplane	distance from the point between the fourth and fifth sacral vertebra to the dorsomedial aspect of the inferior border of the pubis	2.2, Line C-D
AP outlet	distance from the apex of the fifth sacral vertebra to the dorsomedial aspect of the inferior border of the pubis	2.2, Line E-D
Diagonal inlet	distance from the apex of the auricular surface to where the iliopectineal eminence meets the iliopectineal line on the opposite side	2.3, Line A-B
Anterior Spaces:		
Linea terminalis	curved length along the arcuate line from the apex of auricular surface to the dorsomedial aspect of the superior border of the pubis	2.4, Line A-B
Anterior midplane	distance from the ischial spine to the dorsomedial aspect of the inferior border of the pubis	2.4, Line C-D
Posterior Spaces:		
Posterior midplane	distance from the point between the fourth and fifth sacral vertebra to the ischial spine	2.5, Line A-B
Posterior outlet	distance from the apex of the fifth sacral vertebra to the ischial tuberosity	2.5, Line C-D
Sacral Measurements:		
Sacral width	straight distance across the ventral surface of the sacrum where the sacrum meets the apex of the auricular surface when the pelvis is articulated	2.6, Line A-B
Angle Measurements:		
Subpubic angle	angle between a tangential line along the the inferior pubic ramus and a vertical line along the symphyseal face of the pubis; angle is 2X this measurement	2.7
Sacral angle	angulation of the sacrum, measured between sides 1 and 2 of the following triangle: side 1 (A-C), apex of the auricular surface to the ischial tuberosity; side 2 (A-B), apex of the auricular surface to the midpoint of the posterior inferior iliac spine	2.8, angle formed from A-B and A-C
Measurements of the Innominate:	**Definition**	**Figure**
Pubic length	the distance from the center of the acetabulum to the top of the pubic symphysis	2.9, Line E
Acetabulosymphyseal length	the distance from the most superior point on the pubic symphysis to the most medial point on the acetabular rim	2.10, Line B
Arcuate chord	the straight line distance from the most anterior (ventral) point on the auricular surface of the ilium to the most superior point on the pubic symphysis	2.3, Line A-C
Arcuate line depth	maximum chord from the arcuate chord	2.3, Line D-E

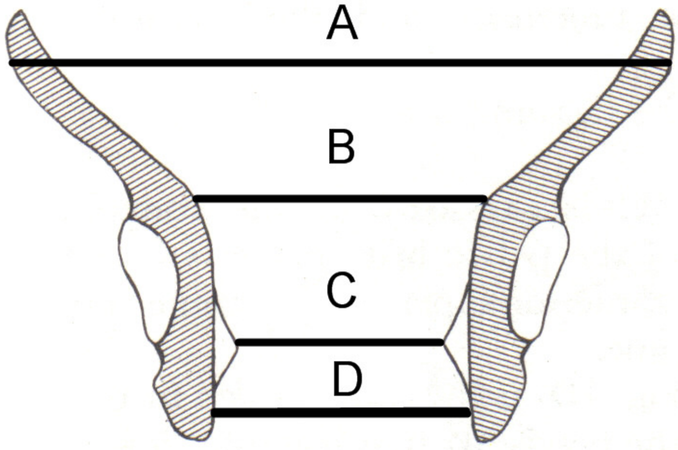
Table 2.3: Description of pelvic measurements (continued)

Measurements of the Innominate:	**Definition**	**Figure**
Transverse acetabular diameter	maximum acetabular diameter from the pubic eminence on the acetabular rim	2.10, Line A-B
Vertical acetabular diameter	maximum acetabular diameter from the point where the axis of the ischial body intersects the acetabular rim	2.10, Line C-D
Coxal height	maximum height of the os coxa	2.9, Line B
Maximum iliac breadth	maximum breadth between the anterior superior and posterior superior iliac spines	2.9, Line A
Iliac height	distance from the most superior point on the acetabular notch to the most distant point on the iliac crest	2.9, Line C
Ischial length	distance from the acetabular notch to the most distant point in the tuberosity of the ischium	2.9, Line D
Articular ischial length	distance from the ischium to the most distal point on the acetabular rim	2.10, Line A
True pelvis depth	the maximum distance from the iliopectineal line to the tuberosity of the ischium	2.11 Line A
Supra-acetabular auricular distance	the distance from the deepest point between the lower margin of the anterior inferior iliac spine and the acetabulum to the apex of the auricular surface	2.11 Line B-D
Anterior inferior iliac spine to auricular surface	the distance between the anterior inferior iliac spine (at its maximum) and the apex of the auricular surface	2.11, Line C-D
Anterior inferior iliac spine to greater sciatic notch	the distance from the anterior inferior iliac spine to the nearest point on the greater sciatic notch	2.12, Line B
Auricular length	the distance from the apex of the auricular surface to the most posterior point on the auricular surface	2.11, Line D-E
Sciatic notch breadth	the distance from the point where the superior margin of the sciatic notch meets the auricular surface to the greater sciatic notch	2.12, Line A
Sciatic notch height	the distance from the deepest point of the greater sciatic notch to the base of the ischial spine	2.11, Line F

Table 2.4: Description of long bone measurements

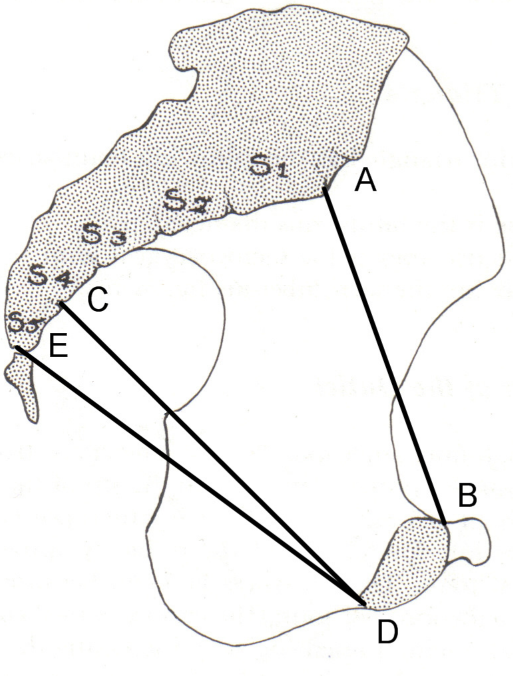
Long Bone Measurements:	**Definition**
Femoral length	bicondylar length of the femur taken using an osteometric board as the distance from a line passing across the distal points on the femoral condyles to the furthest point on the femoral head
AP femoral head diameter	maximum AP diameter of the head articular surface
SI head diameter	maximum vertical diameter of the head articular surface
Tibia maximum length	malleolus
Tibia articular length	distance from the medial condyle to the most proximal point on the medial talar trochlear articulation
Humerus maximum length	maximum length to the distal trochlear flange
Humeral head AP diameter	maximum diameter of the head in the AP direction of the head
Humeral head SI diameter	maximum diameter of the head in the SI direction of the head
Radius maximum length	maximum length to distal styloid process
Radius articular length	length from the middle of the head to the mid-lunate surface
Clavicular length	maximum length across normal proximal and distal end points

Figure 2.1: Transverse pelvic diameters



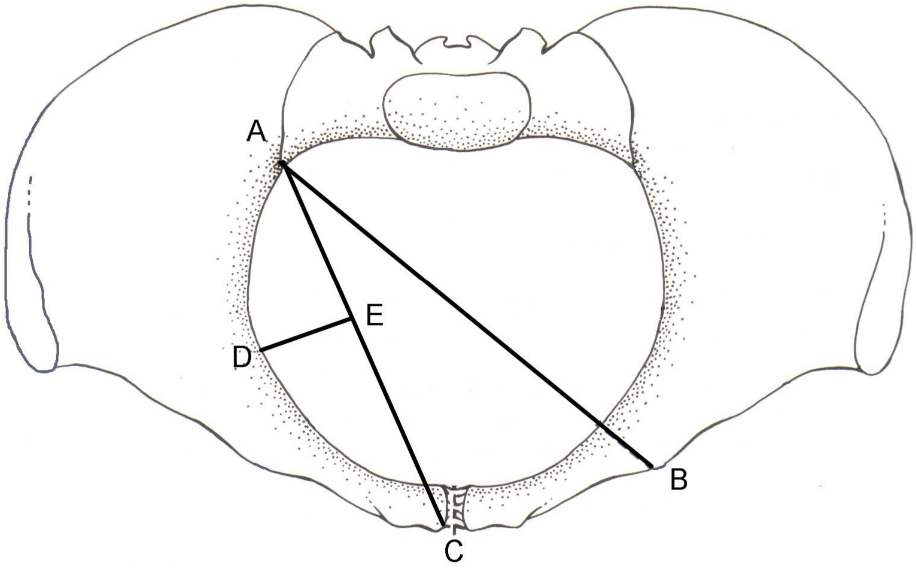
Transverse pelvic diameters: (A) biiliac breadth; (B) transverse pelvic inlet; (C) transverse pelvic midplane; (D) transverse pelvic outlet
Figure modified from Oxorn (1980)

Figure 2.2: Anteroposterior (AP) pelvic diameters



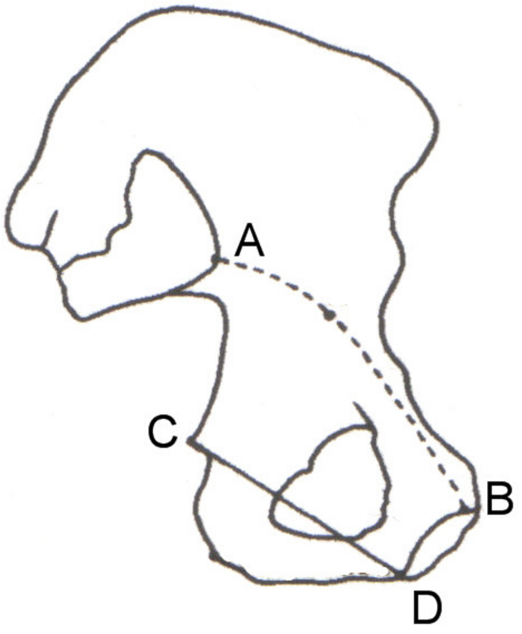
Anteroposterior pelvic diameters: Sagittal pelvic inlet (A-B); AP midplane (C-D); AP outlet (E-D)
Figure modified from Oxorn (1980)

Figure 2.3: Additional pelvic inlet diameters



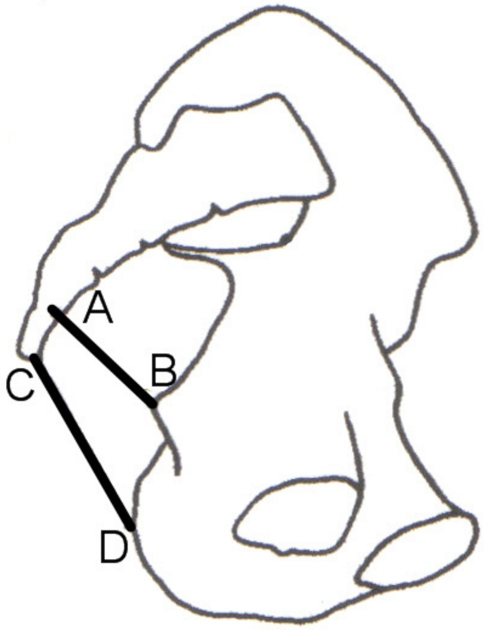
Additional inlet diameters: Diagonal pelvic inlet diameter (A-B); arcuate chord (A-C); arcuate line depth (D-E)
Figure modified from Oxorn (1980)

Figure 2.4: Anterior spaces



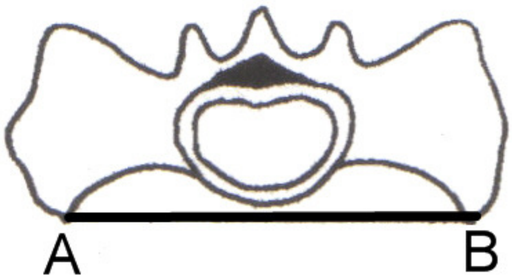
Anterior spaces: Linea terminalis (A-B); anterior midplane (C-D)
Figure modified from Tague (2000)

Figure 2.5: Posterior spaces



Posterior spaces: posterior midplane (A-B); posterior outlet (C-D)
Figure modified from Tague (2000)

Figure 2.6: Sacral width



Sacral width: A-B
Figure modified from Tague (2000)

Figure 2.7: Subpubic angle

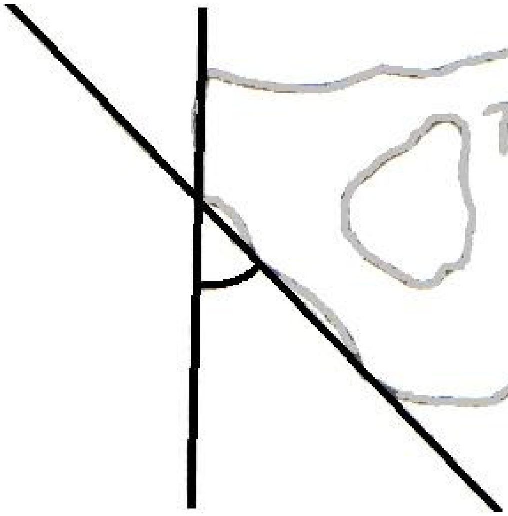
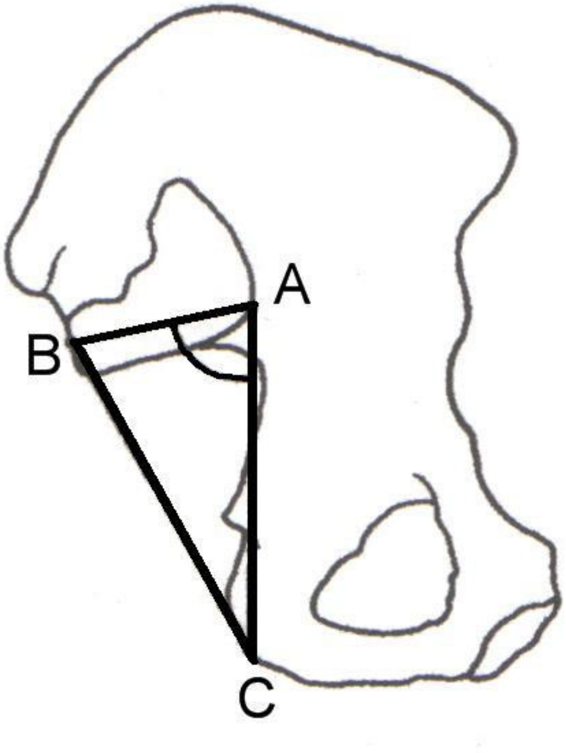


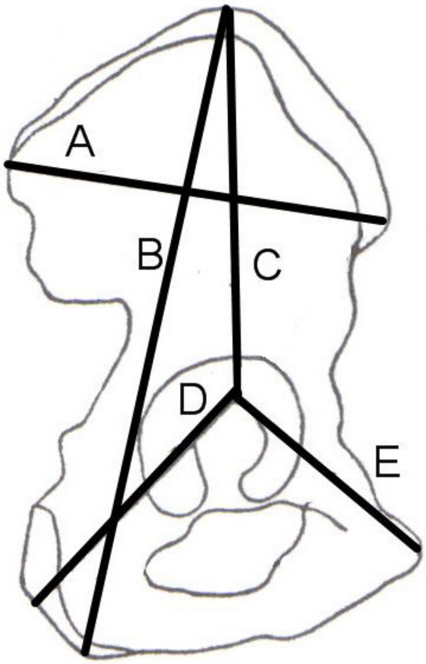
Figure modified from Tague (2000)

Figure 2.8: Sacral angle



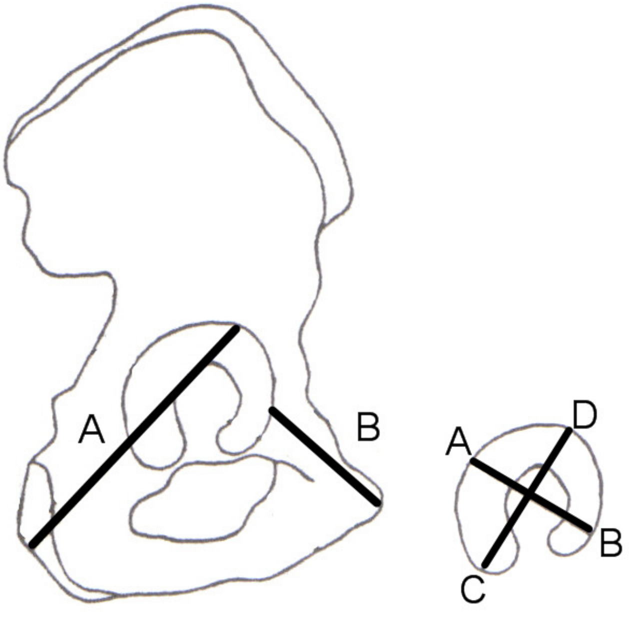
Sacral angle: Angle formed from A-B and A-C
Figure modified from Tague (2000)

Figure 2.9: Measurements of the os coxa, lateral (external) aspect



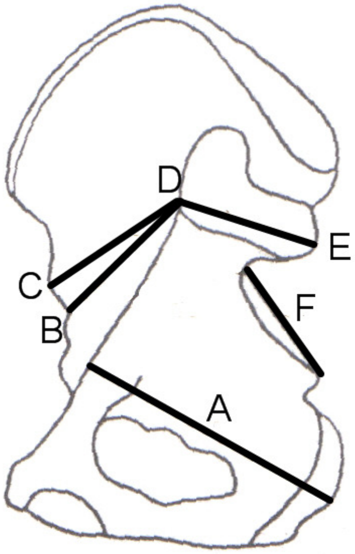
Measurements of the os coxa: Maximum iliac breadth (A); coxal height (B); iliac height (C); ischial length (D); pubic length (E)
Figure modified from Arsuaga and Carretero (1994)

Figure 2.10: Measurements of the os coxa and acetabulum



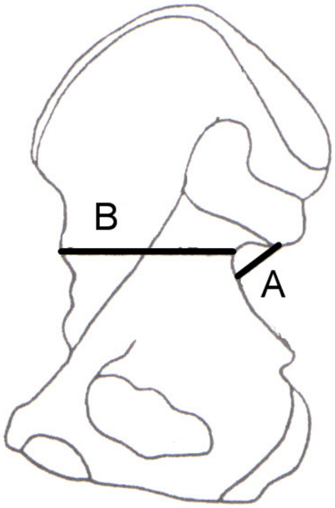
Measurements of the os coxa: Articular ischial length (A); acetabulosymphyseal length (B); transverse acetabular diameter (A-B); vertical acetabular diameter (C-D)
Figures modified from Arsuaga and Carretero (1994)

Figure 2.11: Measurements of the os coxa, medial (internal) aspect



Measurements of the os coxa: True pelvis depth (A); supra-acetabular auricular distance (B-D); anterior inferior iliac spine to auricular surface (C-D); auricular length (D-E); sciatic notch height (F)
Figure modified from Arsuaga and Carretero (1994)

Figure 2.12: Additional measurements of the os coxa, medial (internal) aspect



Measurements of the os coxa: Sciatic notch breadth (A); anterior inferior iliac spine to greater sciatic notch (B)
Figure modified from Arsuaga and Carretero (1994)

Analyses

Correlation methods

In order to examine the relationship between biiliac breadth and the other transverse diameters of the obstetrical pelvis, or between a pelvic measurement and a climatic variable, the Pearson product-moment correlation was utilized. There was no evidence that the variables under study were not normally distributed, so the assumptions of the Pearson *r* were not violated (Sokal and Rohlf 1995). After each test the Pearson r was examined to determine the strength of the linear relationship between biiliac breadth and the other pelvic variables under study. The r^2 value was also examined in order to determine the proportion of variance in biiliac breadth explained by the other pelvic variable.

In order to examine the relationship between climate and pelvic dimensions while accounting for body size, partial correlation analysis was used. Partial correlation is an appropriate test in this case, because it allows for examining the correlation between two variables (climate and obstetrical pelvic dimensions) after the influence of another variable (body size) has been controlled for or “partialed out” (Sokal and Rohlf 1995; George and Mallery 2006). Several osteological body size proxies (AP femoral head diameter, AP femoral head diameter squared, etc.) were used as a proxy for body size. These methods are comparable to previous work estimating body size from hominin osteological remains (McHenry 1992; Ruff et al. 1997; Lieberman et al. 2001; Ruff 2002). However, biiliac breadth was not used as a proxy to estimate body size because it is too closely related to the pelvic variables under study.

For the partial correlation analysis, several tests were conducted on the same variable, and it was therefore necessary to adjust the experimentwise error rate in order to reduce the likelihood of a type I error. In order to make this correction, the Bonferroni method was used, following Sokal and Rohlf (1995). As three independent significance tests were made for each variable (for correlations with latitude, MTCM, and MTWM), the experimentwise error rate of 0.05 was divided by 3. Therefore, correlations were considered statistically significant if they had a p-value ≤ 0.017 after a 2-tailed test of significance. As the Bonferroni correction is considered by some to be too harsh for most biological situations (Rice 1989), the less conservative sequential Bonferroni following Holm (1979) was also applied to see if this led to the inclusion of any tests initially rejected by the traditional Bonferroni method. However, the results did not differ at all for females when either correction was applied, and resulted in only minor differences for males. For the sake of simplicity, the traditional Bonferroni correction is applied here, and the tests exempted by the sequential Bonferroni will be noted when applicable.

Multivariate methods

Principal components analysis

Principal components analysis (PCA) was used to investigate population-level variation in pelvic morphology in multivariate space. PCA is a method that involves transforming a given set of variables into a new set of composite variables, or principal components. The first principal component is defined as the best linear combination of variables that accounts for more of the variance in the data as a whole than any other linear combination of variables (Nie et al. 1975). The second principal component is defined as the second best linear combination of variables that is orthogonal to the first principal component. Subsequent components are defined until all of the variance in the data has been explained. For this study the first five principal components were extracted. The number of components extracted was decided based on the Kaiser criterion (Kaiser 1960), which states that only factors with eigenvalues > 1.0 should be retained. This decision was reinforced by the use of the scree test (Cattell 1966), which plots the eigenvalues by component to determine the level at which the eigenvalues begin to level off.

PCA was initially used as a tool for data exploration and data reduction. For the initial PCA only raw variables on the pelvis were selected and a variance/covariance matrix (VCM) was used. This method reduced the large number of variables under study into a smaller number of interpretable components (Nie et al. 1975). An examination of PC score plots (in particular PC1 versus PC2) was used to aid in the determination of which morphological elements are responsible for differences between groups with regard to both sex and climate.

Once the pelvic variables for multivariate analysis were determined, the geometric mean was calculated for each individual, following Darroch and Mosimann (1985). The geometric mean is defined as the nth root of the product of n measurements, and is employed here because the geometric mean of an individual's measurements is considered the best measure of that individual's overall size (James and McCullough 1990; Holliday 1997a; Aiello et al. 1999**).** Therefore, it is useful for determining size components in PCA.

Finally, an effort was made to interpret the factor structure by examining the factor loadings associated with each principal component. The factor loadings are coefficients between each variable and the particular principal component in question. Therefore, a high correlation coefficient (in either the positive or negative direction), indicates a strong correlation between that variable and the relevant principal component. Significant variables were determined following Tague (1986), whereby the variables in a factor that have a coefficient at least one-half the value of the variable with the highest correlation coefficient are considered "significant." Upon determination of the variables with significant loadings, the principal component(s) with the highest loadings for obstetric variables were plotted against both latitude and temperature in order to determine the strength of the correlation between the two variables. This was done in order to examine the correlation between pelvic size/shape and climate in multivariate space.

CHAPTER 3

UNIVARIATE RESULTS AND ANALYSIS

Introduction

This chapter presents the findings of the univariate statistical analyses that were conducted on the data collected as described in the previous chapter. The first portion of this chapter presents and discusses the descriptive statistics for males and females for all of the measurements collected. The second section investigates the relationship between different measures of climate and the obstetric dimensions of the human pelvis. The third portion of the chapter analyzes the relationship between biiliac breadth and other transverse and anteroposterior (AP) pelvic dimensions, and investigates whether obstetrical and non-obstetrical pelvic dimensions are correlated with each other. The last portion of this chapter examines the long bone measurements that were collected. Brachial and crural indices were calculated in order to test Allen’s Rule and examine another source of climatic variation in the postcranial skeleton.

Descriptive statistics

Table 3.1.1 through Table 3.1.6 list the descriptive statistics for all of the measurements collected in this study by sex and locality. Due to space constraints, it is possible to show only two localities/samples per page. The localities are presented in order of decreasing latitude and increasing temperature (i.e., the coldest and highest latitude samples are shown in Table 3.1.1). As discussed in the previous chapter, the hypotheses presented predict that females from high latitude or cold climate localities will have larger pelvic obstetrical dimensions than those from low latitude or warm climate localities. The correlations of these variables with climate will be discussed later; however, it is worth noting the general trends of certain measurements of interest across localities. Boxplots are a useful illustrative tool for this particular examination of the data. For all of the boxplots shown, the box length equals the interquartile range of the sample and includes approximately 50% of the cases. The line across the boxplot demarcates the median value. The “outliers” (noted with an open circle) are cases with values between 1.5 and 3 interquartile ranges from the upper or lower edge of the box. The “extreme” cases (marked with an asterisk) represent cases with values more or less than three interquartile ranges from the upper or lower edge of the box. Finally, the box “whiskers” mark the smallest and largest values outside the interquartile range that are not outliers or extreme cases.

When one examines the values for female biiliac breadth by locality, the pattern that appears is suggestive of a trend in increasing biiliac breadth with samples from higher latitude/colder climate localities. Point Hope is the highest latitude/coldest climate sample and the Andaman Islanders are the lowest latitude/warmest climate sample. This can be seen in the boxplot in Figure 3.1. This trend is also suggested for male biiliac breadth, although it is not as readily apparent as it is for females because of the higher values for the Ancon and Mistihalj samples. The transverse pelvic inlet diameter also shows a trend of increasing with the colder climate/higher latitude populations (Figure 3.2). The same pattern holds for the transverse pelvic midplane diameter (Figure 3.3). With the transverse pelvic midplane diameter there is more of a marked difference between the male and female range of values. The degree of sexual dimorphism in this measurement is consistent with the findings of previous studies of pelvic morphology (Hoyme 1957; Rosenberg 1986; Sibley et al. 1992; Tague 1992; Stone 2000).

One transverse measurement that does not meet the expectation in terms of the relationship with climate is sacral width (Figure 3.4), which is largest for the Point Hope and Kulubnarti samples for both males and females. This pattern obviously does not follow expectations, as these two populations are one of the highest latitude and one of the lowest latitude samples. It is not known exactly why this is the case, and this pattern will be discussed further in the multivariate chapter. Sacral width is also sexually dimorphic in most of the samples, which differs from the findings of previous studies of sacral morphology (Flander 1978; Tague 1992; 2007). Table 3.2 indicates the degree of sexual dimorphism in sacral width for each sample, as calculated by the following equation: percentage dimorphism = $\left|[(\text{male mean}/\text{female mean}) \times 100] - 100\right|$. The two samples that are the least sexually dimorphic for sacral width are the Kulubnarti Nubians (0.65%) and Point Hope (2.30%). Furthermore, if one considers 5% the threshold value for whether a sample is sexually dimorphic or not following Tague (1986), then only the Point Hope, Kulubnarti, and Andaman Islanders sample (2.73%) are *not* sexually dimorphic, while all of the remaining samples are.

These results contradict the findings of Tague (2007), who does not find sacral width to be sexually dimorphic, and finds that it is actually the costal process of the first sacral vertebra (S1) that is the ultimate cause of sexual dimorphism in the pelvic inlet (Figure 3.5**,** shaded region), as this measurement is statistically significantly larger in females than in males. This is opposed to the straight distance across the ventral breadth of the sacrum (Figure 3.6), which has traditionally not differed between the sexes, although in this particular study it does in most samples (Table 3.2). However, the data for this study were collected prior to Tague's publication and subsequently the measurements taken follow the measurement protocols in Tague (2000), meaning that sacral width (Figure 3.6) was collected but the costal process of S1 (Figure 3.5) was not. It is possible that the costal process of S1 is responsible for increasing the obstetric capacity of the pelvic inlet. However, the data collected in this study suggest, given the sexual dimorphism in sacral width, that the ventral distance across the sacrum is also contributing to the increased pelvic inlet size in females to some extent.

When the AP pelvic measurements are examined, a different pattern emerges compared to the transverse pelvic measurements. As shown in the boxplot in Figure 3.7 for the sagittal pelvic inlet, there is not a trend of a decreasing pelvic inlet with the lower latitude/warmer climate samples. A similar pattern is found with most of the other AP pelvic measurements, which will be discussed further in the next section.

It should also be noted that the Andaman Islanders sample is notably smaller than all of the other samples in many measurements. However, both sacral width and the sagittal pelvic inlet are within the range of the other samples for both males and females. The differences will be returned to in the next section.

Table 3.1.1: Descriptive statistics

Locality:	Point Hope						SkælskØr					
	Females			Males			Females			Males		
	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.
<u>Pelvic Measurements:</u>												
Transverse Diameters:												
Biiliac breadth	269.56	52	15.18	280.14	55	13.93	271.00	14	18.14	278.91	23	16.16
Transverse inlet	127.69	52	8.91	121.17	55	6.61	133.95	14	6.66	127.62	23	9.67
Transverse midplane	111.16	52	8.59	91.47	55	9.82	113.51	14	6.55	94.02	23	6.42
Transverse outlet	111.49	52	9.50	90.10	55	11.43	109.52	14	12.48	91.42	23	8.18
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	105.33	52	8.95	102.97	55	8.06	102.11	14	7.75	97.81	22	6.95
AP midplane	124.15	42	8.93	121.58	48	10.28	130.42	11	6.70	120.95	23	9.41
AP outlet	117.89	38	9.12	114.09	44	9.58	119.63	7	8.66	114.55	23	8.46
Diagonal inlet	127.08	52	7.80	120.93	55	6.89	135.45	14	4.61	129.55	23	8.10
Anterior Spaces:												
Linea terminalis	143.45	49	7.52	138.11	55	8.10	147.86	14	5.62	140.30	23	8.39
Anterior midplane	94.43	51	5.87	91.56	55	5.12	95.34	14	5.11	95.18	23	3.59
Posterior Spaces:												
Posterior midplane	74.33	42	5.35	64.65	48	5.94	76.56	12	9.10	64.68	23	11.61
Posterior outlet	89.67	38	7.15	81.23	44	8.99	91.70	8	18.98	79.14	23	7.52
Sacral Measurements:												
Sacral width (M-5)	106.69	51	10.12	104.24	55	8.48	74.50	14	8.94	66.48	23	4.83
Angle Measurements:												
Subpubic angle	101.87	52	11.05	74.40	55	6.93	114.25	13	3.95	109.20	23	8.32
Sacral angle	69.48	52	5.52	58.96	55	5.05	109.14	14	11.71	79.96	23	8.41
<u>Measurements of the Innominate:</u>												
Pubic length (M-17)	88.83	51	6.62	87.46	55	6.75	95.24	14	7.49	93.87	23	4.75
Acetabulosymphyseal length	68.45	51	4.35	65.33	55	4.50	74.59	14	6.16	71.58	23	4.56
Arcuate chord	122.49	52	7.56	121.47	55	8.28	125.99	14	5.44	122.45	23	6.48
Arcuate line depth	24.27	52	2.90	20.20	55	2.53	25.14	14	3.23	21.74	23	3.22
Transverse acetabular diameter	49.02	52	3.39	53.71	55	3.56	50.42	14	3.30	57.39	23	2.54
Vertical acetabular diameter	50.19	52	2.92	54.98	55	2.88	49.47	14	3.90	56.51	23	2.60
Coxal height	194.79	52	11.68	210.69	55	14.31	203.21	14	12.57	220.87	23	8.86
Maximum iliac breadth	149.24	50	7.49	158.78	51	7.37	157.73	13	9.82	166.45	21	7.44
Iliac height	112.28	52	5.92	122.06	55	6.84	115.19	14	8.75	122.86	23	6.38
Ischial length	82.39	52	4.24	90.07	55	5.87	82.93	14	4.18	92.34	23	5.33
Articular ischial length	96.85	52	5.14	106.37	55	5.71	93.22	14	4.81	104.90	23	4.96
True pelvis depth	91.83	52	4.97	101.83	55	6.19	93.67	14	4.14	106.19	23	5.35
Supra-acetabular auricular distance	69.53	52	5.57	71.00	55	5.08	70.88	14	4.62	71.71	23	5.56
Anterior inferior iliac spine to auricular surface	74.63	52	5.56	76.90	55	5.47	74.66	14	4.93	77.73	23	6.01
Anterior inferior iliac spine to greater	69.39	52	3.88	75.34	55	4.89	67.61	14	4.00	75.20	23	4.96
Auricular length	49.72	52	4.74	55.65	54	4.87	53.69	14	4.79	60.28	23	5.35
Sciatic notch breadth	39.50	52	4.69	36.54	55	5.46	45.54	14	4.54	41.05	23	7.47
Sciatic notch height	50.77	52	3.47	53.44	55	4.42	56.15	14	4.33	58.00	23	5.17
<u>Long Bone Measurements:</u>												
Femoral length (M-2)	394.32	49	17.97	433.47	53	27.55	425.25	14	24.72	464.68	22	17.78
AP femoral head diameter (M-19)	42.49	51	1.98	47.11	54	2.31	42.43	14	3.37	48.98	23	2.09
SI head diameter (M-18)	42.33	51	2.12	46.90	54	2.48	42.87	14	3.41	49.49	23	2.43
Tibia maximum length (M-1A)	324.76	50	19.12	357.86	53	23.59	345.41	11	13.79	379.47	17	19.56
Tibia articular length (M-2)	310.14	50	18.54	341.31	54	22.84	324.55	11	13.86	358.00	17	19.78
Humerus maximum length (M1)	278.03	50	11.18	304.99	55	19.59	309.40	10	17.63	341.86	21	11.95
Humeral head AP diameter (M-10)	42.49	51	1.98	47.11	54	2.31	42.43	14	3.37	48.98	23	2.09
Humeral head SI diameter	42.33	51	2.12	46.90	54	2.48	42.87	14	3.41	49.49	23	2.43
Radius maximum length (M-1)	205.44	51	12.69	229.54	52	12.94	228.82	11	12.67	251.25	22	11.57
Radius articular length (M-2)	201.30	51	12.83	225.29	53	12.24	223.59	11	12.65	244.09	22	11.47
Clavicular length (M-1)	129.31	50	7.17	146.41	52	10.48	135.32	11	8.29	150.26	21	7.32

Table 3.1.2: Descriptive statistics (continued)

Locality:	**Tierra del Fuego**						**Spitalfields**					
	Females			**Males**			**Females**			**Males**		
	$\bar{X}$	**N**	**S.D.**	$\bar{X}$	**N**	**S.D.**	$\bar{X}$	**N**	**S.D.**	$\bar{X}$	**N**	**S.D.**
<u>Pelvic Measurements:</u>												
Transverse Diameters:												
Biiliac breadth	264.14	7	13.91	263.67	9	15.96	265.63	64	16.50	268.40	40	18.46
Transverse inlet	130.01	7	5.92	118.76	9	7.51	131.19	65	8.37	121.60	40	8.87
Transverse midplane	110.34	7	8.41	90.59	9	7.55	111.44	65	9.06	90.35	40	8.22
Transverse outlet	105.06	7	6.59	85.74	9	4.64	111.36	65	8.46	86.70	40	7.66
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	104.47	7	8.03	102.94	9	10.46	104.19	65	9.87	96.89	40	8.87
AP midplane	139.04	7	14.41	122.01	7	3.83	121.49	62	10.84	115.66	39	10.84
AP outlet	134.01	7	14.01	118.76	8	3.00	115.41	59	10.82	107.39	37	10.10
Diagonal inlet	129.94	7	4.08	120.42	9	5.04	131.28	65	7.66	123.70	40	7.08
Anterior Spaces:												
Linea terminalis	146.57	7	8.37	132.17	9	7.35	145.98	65	9.34	136.24	40	8.71
Anterior midplane	98.81	7	6.83	92.14	9	3.90	94.62	65	5.48	92.79	40	5.08
Posterior Spaces:												
Posterior midplane	78.91	7	9.38	64.20	8	5.43	73.90	62	8.39	59.87	40	6.92
Posterior outlet	99.17	7	11.50	83.08	8	8.64	91.69	58	9.25	76.29	37	8.84
Sacral Measurements:												
Sacral width (M-5)	67.14	7	7.86	58.29	7	5.74	74.18	65	6.48	65.88	40	5.40
Angle Measurements:												
Subpubic angle	105.31	7	5.41	104.51	9	4.74	108.44	65	6.77	103.33	40	7.86
Sacral angle	98.57	7	6.19	73.78	9	4.41	107.15	65	11.06	74.58	40	9.34
<u>Measurements of the Innominate:</u>												
Pubic length (M-17)	89.66	7	6.27	85.58	9	4.21	92.88	65	5.58	91.48	40	5.73
Acetabulosymphyseal length	68.66	7	5.62	66.17	9	4.45	71.38	65	4.77	68.32	40	4.86
Arcuate chord	123.27	7	9.59	114.90	9	5.32	121.76	65	8.03	119.27	40	7.99
Arcuate line depth	26.00	7	2.71	21.22	9	2.86	25.32	65	3.66	20.68	40	2.98
Transverse acetabular diameter	46.57	7	3.22	51.84	9	3.50	48.31	65	2.64	55.09	40	3.15
Vertical acetabular diameter	45.50	7	2.73	51.96	9	3.94	48.41	65	2.62	54.25	40	3.18
Coxal height	191.29	7	6.90	201.89	9	10.99	194.52	65	10.25	214.98	40	12.36
Maximum iliac breadth	146.54	7	7.40	151.12	9	6.55	152.15	62	9.06	157.91	39	9.85
Iliac height	109.34	7	5.43	113.77	9	6.54	109.03	65	7.15	118.39	40	7.17
Ischial length	79.09	7	3.83	84.46	9	3.20	79.85	65	4.59	90.41	40	5.95
Articular ischial length	89.57	7	4.76	98.43	9	4.98	90.15	65	5.17	102.34	40	6.27
True pelvis depth	89.69	7	4.43	97.32	9	3.79	88.50	65	5.33	100.62	40	6.76
Supra-acetabular auricular distance	70.57	7	6.71	67.39	9	5.75	71.35	65	5.58	71.94	40	6.46
Anterior inferior iliac spine to auricular surface	73.49	7	6.26	71.37	9	6.03	75.09	65	6.26	76.28	40	7.24
Anterior inferior iliac spine to greater	65.15	7	5.81	69.48	7	5.08	66.91	65	4.38	73.48	40	5.61
Auricular length	49.08	7	5.61	53.25	7	4.10	49.57	64	5.98	54.86	40	4.94
Sciatic notch breadth	48.30	7	5.17	33.27	9	7.82	47.07	65	5.15	41.31	39	6.32
Sciatic notch height	51.19	7	2.51	54.88	9	7.67	50.68	65	4.29	55.77	40	4.17
<u>Long Bone Measurements:</u>												
Femoral length (M-2)	390.42	6	13.57	405.00	1	N/A	410.12	64	24.69	449.24	40	28.52
AP femoral head diameter (M-19)	40.11	6	2.56	43.98	1	N/A	41.30	64	2.25	47.17	40	2.44
SI head diameter (M-18)	40.34	6	2.66	44.20	1	N/A	41.64	65	2.41	47.48	40	2.62
Tibia maximum length (M-1A)	300.00	1	N/A	342.50	1	N/A	338.37	59	19.08	370.72	37	24.24
Tibia articular length (M-2)	280.00	1	N/A	316.00	1	N/A	318.74	59	18.98	349.19	37	24.60
Humerus maximum length (M1)	290.21	7	12.31	300.25	2	16.62	291.25	57	16.13	322.58	37	19.16
Humeral head AP diameter (M-10)	40.11	6	2.56	43.98	1	N/A	41.30	64	2.25	47.17	40	2.44
Humeral head SI diameter	40.34	6	2.66	44.20	1	N/A	41.64	65	2.41	47.48	40	2.62
Radius maximum length (M-1)	216.42	6	6.98	246.25	2	13.79	209.15	60	11.55	235.43	36	12.61
Radius articular length (M-2)	212.17	6	6.36	242.75	2	12.37	202.92	60	11.54	228.22	36	12.18
Clavicular length (M-1)	138.25	6	6.46	146.25	4	10.44	134.96	55	7.47	150.72	30	11.41

Table 3.1.3: Descriptive statistics (continued)

Locality:	Budec						Mistihalj					
	Females			Males			Females			Males		
	$\overline{X}$	N	S.D.	$\overline{X}$	N	S.D.	$\overline{X}$	N	S.D.	$\overline{X}$	N	S.D.
Pelvic Measurements:												
Transverse Diameters:												
Biiliac breadth	267.00	4	23.20	278.50	6	7.56	268.09	11	17.97	286.11	19	13.40
Transverse inlet	133.12	4	8.01	126.83	6	3.93	129.80	11	8.33	124.69	19	8.46
Transverse midplane	111.58	4	5.65	94.82	6	10.29	114.40	11	10.91	93.70	17	9.25
Transverse outlet	113.60	4	6.39	92.63	6	9.98	110.85	11	12.18	83.11	19	11.55
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	96.30	4	6.06	103.08	6	5.17	105.30	11	7.61	105.34	19	8.61
AP midplane	116.53	4	9.08	116.17	6	13.01	129.26	8	7.43	128.69	17	8.60
AP outlet	105.68	4	7.33	98.48	5	8.04	120.59	7	8.44	118.27	15	9.81
Diagonal inlet	130.18	4	9.17	128.27	6	3.53	132.51	11	7.01	129.65	19	5.25
Anterior Spaces:												
Linea terminalis	140.00	4	7.01	144.50	6	5.40	146.23	11	8.20	142.24	19	6.30
Anterior midplane	93.15	4	6.84	97.88	6	3.56	95.77	11	5.45	96.17	18	5.19
Posterior Spaces:												
Posterior midplane	72.60	4	7.10	58.58	6	6.78	79.89	7	8.20	67.61	15	6.45
Posterior outlet	89.43	4	3.67	74.14	5	8.41	96.83	7	7.08	82.08	15	7.23
Sacral Measurements:												
Sacral width (M-5)	74.50	4	2.08	62.00	6	7.85	71.45	11	7.23	61.68	19	5.29
Angle Measurements:												
Subpubic angle	115.30	4	10.44	108.65	6	4.61	110.04	11	7.94	108.50	19	7.91
Sacral angle	111.50	4	8.23	74.67	6	12.32	100.55	11	19.72	70.89	19	8.01
Measurements of the Innominate:												
Pubic length (M-17)	90.39	4	7.55	93.28	6	3.08	89.99	11	6.73	92.00	19	5.87
Acetabulosymphyseal length	69.79	4	9.29	71.74	6	3.74	68.89	11	4.85	70.56	19	4.68
Arcuate chord	118.25	4	8.05	125.05	6	1.90	124.28	11	7.89	125.90	19	5.84
Arcuate line depth	24.75	4	3.78	24.00	6	1.41	25.82	11	3.03	21.89	19	2.77
Transverse acetabular diameter	47.36	4	4.31	54.78	6	1.17	48.46	11	2.75	56.64	19	2.57
Vertical acetabular diameter	47.23	4	2.77	55.51	6	2.06	49.56	11	1.97	57.05	19	3.38
Coxal height	193.00	4	10.92	221.33	6	5.96	200.45	11	9.61	222.68	19	8.71
Maximum iliac breadth	146.88	4	8.19	163.79	6	8.12	156.39	10	9.37	165.41	19	6.66
Iliac height	108.63	4	6.27	124.39	6	4.59	114.59	11	6.91	126.24	19	6.91
Ischial length	78.28	4	4.45	92.61	6	3.47	81.13	11	5.23	92.11	19	4.18
Articular ischial length	86.71	4	3.68	103.25	6	2.81	91.12	11	4.74	102.93	19	6.25
True pelvis depth	86.65	4	2.16	102.14	6	3.27	91.40	11	4.36	103.10	19	5.03
Supra-acetabular auricular distance	64.27	4	3.86	71.42	6	5.50	72.31	11	5.23	73.56	19	3.75
Anterior inferior iliac spine to auricular surface	66.87	4	3.92	75.39	6	5.17	75.95	11	5.56	77.88	19	3.65
Anterior inferior iliac spine to greater	62.94	4	3.97	72.16	6	3.83	67.78	11	4.22	76.41	19	5.08
Auricular length	49.54	4	6.31	52.68	6	6.25	52.80	11	4.90	57.99	19	2.89
Sciatic notch breadth	40.58	4	0.97	38.43	6	5.96	45.82	11	5.54	38.03	19	4.91
Sciatic notch height	53.38	4	3.37	55.53	6	2.26	54.15	11	4.64	56.96	17	3.89
Long Bone Measurements:												
Femoral length (M-2)	390.50	4	21.08	453.58	6	11.74	416.59	11	22.02	461.21	19	25.07
AP femoral head diameter (M-19)	39.89	4	2.56	48.35	6	1.27	42.06	11	1.70	49.33	19	2.72
SI head diameter (M-18)	40.60	4	3.05	48.41	6	1.33	42.17	11	1.87	49.60	19	2.69
Tibia maximum length (M-1A)	320.50	4	24.54	370.25	6	10.47	352.60	10	22.02	384.76	19	21.33
Tibia articular length (M-2)	300.00	4	24.53	348.08	6	11.81	332.10	10	23.53	361.24	19	21.75
Humerus maximum length (M1)	288.50	4	22.13	329.25	6	8.62	301.18	11	16.22	330.63	19	15.19
Humeral head AP diameter (M-10)	39.89	4	2.56	48.35	6	1.27	42.06	11	1.70	49.33	19	2.72
Humeral head SI diameter	40.60	4	3.05	48.41	6	1.33	42.17	11	1.87	49.60	19	2.69
Radius maximum length (M-1)	206.17	3	18.66	247.00	5	9.38	221.55	10	12.78	249.29	19	9.67
Radius articular length (M-2)	197.50	3	16.58	238.30	5	9.19	214.35	10	12.98	240.11	19	9.32
Clavicular length (M-1)	132.63	4	5.54	148.88	4	8.96	136.83	9	9.12	151.92	18	10.35

Table 3.1.4: Descriptive statistics (continued)

Locality:	**Dickson Mounds**						**El Shellal**					
	Females			**Males**			**Females**			**Males**		
	$\bar{X}$	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**
Pelvic Measurements:												
Transverse Diameters:												
Biiliac breadth	255.90	10	8.14	274.63	8	16.20	241.86	14	18.65	264.08	12	14.56
Transverse inlet	125.22	10	7.11	127.06	8	7.40	121.53	14	6.74	116.54	12	6.07
Transverse midplane	105.56	10	10.91	91.11	8	5.23	101.76	14	8.57	81.99	12	7.39
Transverse outlet	100.68	10	11.27	83.68	8	4.73	104.96	14	7.70	82.55	12	7.61
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	101.36	10	7.57	100.96	7	7.54	104.84	14	7.85	96.83	12	9.45
AP midplane	117.91	9	8.80	112.10	6	7.51	115.29	14	11.85	109.21	12	9.14
AP outlet	111.50	8	8.93	107.98	5	5.17	106.68	11	10.73	102.21	11	10.74
Diagonal inlet	126.43	10	6.53	123.20	8	7.15	123.76	14	5.54	119.64	12	5.99
Anterior Spaces:												
Linea terminalis	141.70	10	6.04	136.81	8	6.68	143.38	13	7.09	135.33	12	7.57
Anterior midplane	93.16	10	6.24	88.73	8	4.13	88.86	14	8.69	87.18	12	4.73
Posterior Spaces:												
Posterior midplane	67.22	10	7.71	60.27	6	4.37	71.06	14	7.87	56.04	12	5.84
Posterior outlet	80.23	9	7.73	74.38	6	6.39	85.25	10	10.57	68.21	11	9.39
Sacral Measurements:												
Sacral width (M-5)	69.10	10	7.48	59.63	8	7.73	72.86	14	7.12	60.67	12	5.10
Angle Measurements:												
Subpubic angle	109.06	10	6.89	107.40	8	10.15	99.84	14	5.68	98.53	12	5.81
Sacral angle	102.40	10	8.98	75.00	8	7.71	102.71	14	10.37	79.17	12	6.85
Measurements of the Innominate:												
Pubic length (M-17)	88.61	10	3.70	86.61	8	5.13	84.25	13	5.92	85.08	12	4.63
Acetabulosymphyseal length	69.42	10	3.85	68.63	8	4.70	66.34	13	4.47	66.74	12	5.11
Arcuate chord	119.14	10	6.95	118.16	8	8.26	118.05	14	6.34	113.94	12	6.71
Arcuate line depth	22.40	10	2.07	23.13	8	3.09	25.00	14	2.54	22.25	12	2.80
Transverse acetabular diameter	46.41	10	2.29	50.02	8	2.31	44.06	14	2.25	51.13	12	3.24
Vertical acetabular diameter	47.25	10	2.27	51.53	8	2.65	45.03	14	2.22	51.33	12	3.05
Coxal height	192.60	10	7.50	209.88	8	7.24	182.43	14	7.70	204.83	12	8.90
Maximum iliac breadth	145.18	9	5.47	153.22	8	7.16	140.30	13	7.44	149.97	12	7.14
Iliac height	110.69	9	5.96	121.38	8	4.38	101.72	14	4.80	113.24	12	6.09
Ischial length	79.69	10	2.83	86.02	8	3.46	74.74	14	4.48	84.89	12	5.22
Articular ischial length	91.37	10	3.44	99.11	8	6.80	84.84	14	4.08	96.94	12	5.46
True pelvis depth	90.47	10	4.21	100.28	8	3.46	81.84	14	3.84	93.35	12	5.31
Supra-acetabular auricular distance	67.44	10	3.22	69.31	8	3.57	71.94	14	4.29	71.43	12	6.55
Anterior inferior iliac spine to auricular surface	70.88	10	2.81	71.80	8	3.90	74.68	14	4.42	75.90	12	5.70
Anterior inferior iliac spine to greater	65.39	10	2.98	69.90	8	5.32	62.21	14	3.75	69.89	12	4.90
Auricular length	49.72	10	5.98	51.64	6	3.09	44.85	14	6.66	50.29	12	3.23
Sciatic notch breadth	43.70	10	5.10	36.23	7	4.77	48.55	14	4.50	40.32	12	5.67
Sciatic notch height	51.44	10	2.92	54.26	8	5.67	45.58	14	2.35	52.40	12	6.88
Long Bone Measurements:												
Femoral length (M-2)	418.29	7	23.16	441.50	6	19.31	396.89	14	18.50	441.42	12	28.00
AP femoral head diameter (M-19)	40.72	10	1.67	44.93	8	1.49	37.93	14	1.74	44.82	12	2.60
SI head diameter (M-18)	40.74	10	1.52	44.88	8	1.47	38.14	14	2.00	44.86	12	2.60
Tibia maximum length (M-1A)	349.71	7	16.99	373.58	6	14.50	333.89	14	18.75	372.63	12	29.32
Tibia articular length (M-2)	328.29	7	15.64	348.90	5	11.57	312.86	14	17.78	347.96	12	28.77
Humerus maximum length (M1)	299.83	6	9.33	315.17	6	13.35	281.11	14	12.15	312.91	11	16.06
Humeral head AP diameter (M-10)	40.72	10	1.67	44.93	8	1.49	37.93	14	1.74	44.82	12	2.60
Humeral head SI diameter	40.74	10	1.52	44.88	8	1.47	38.14	14	2.00	44.86	12	2.60
Radius maximum length (M-1)	231.25	6	8.32	252.13	4	9.39	212.08	13	10.90	241.86	11	11.64
Radius articular length (M-2)	225.75	6	9.41	246.00	4	10.38	206.50	13	10.43	235.27	11	11.75
Clavicular length (M-1)	134.17	6	5.42	155.25	4	8.88	127.85	13	6.30	144.23	11	7.91

Table 3.1.5: Descriptive statistics (continued)

Locality:	**Sayala**						**Kulubnarti**					
	Females			**Males**			**Females**			**Males**		
	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.	$\bar{X}$	N	S.D.
Pelvic Measurements:												
Transverse Diameters:												
Biiliac breadth	259.08	24	12.28	269.38	26	13.38	242.88	64	15.02	255.84	44	13.65
Transverse inlet	123.71	24	7.91	121.03	26	6.79	118.29	64	8.16	114.48	44	6.57
Transverse midplane	106.23	24	9.14	87.01	26	8.09	100.04	64	8.60	81.16	44	6.38
Transverse outlet	104.41	24	8.63	81.45	25	6.27	90.37	64	8.48	72.73	44	7.95
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	106.55	24	6.78	97.62	26	8.18	101.33	63	7.38	96.39	44	8.75
AP midplane	120.94	22	8.16	114.17	26	6.79	114.30	64	8.99	106.72	44	9.68
AP outlet	115.48	19	8.05	107.02	23	8.07	108.00	64	8.99	100.46	44	10.48
Diagonal inlet	131.19	24	6.53	124.41	26	6.86	123.18	64	5.94	115.68	44	6.34
Anterior Spaces:												
Linea terminalis	146.08	24	7.53	136.71	26	7.07	139.95	64	7.17	130.84	44	8.12
Anterior midplane	92.50	24	4.15	90.47	26	3.91	87.89	64	5.42	85.42	44	3.97
Posterior Spaces:												
Posterior midplane	72.08	21	5.64	59.10	26	5.25	65.77	64	7.44	53.24	43	5.99
Posterior outlet	88.73	19	6.93	71.76	23	7.66	76.44	64	10.11	64.17	44	7.59
Sacral Measurements:												
Sacral width (M-5)	69.00	24	7.34	58.08	26	5.48	97.51	64	6.45	96.88	44	5.38
Angle Measurements:												
Subpubic angle	103.52	23	4.47	103.62	25	5.63	95.70	64	7.82	75.00	44	6.70
Sacral angle	106.17	24	10.38	77.81	26	8.04	68.88	64	5.82	57.34	44	5.93
Measurements of the Innominate:												
Pubic length (M-17)	89.10	24	4.27	87.15	26	5.34	82.77	64	5.11	83.11	44	5.01
Acetabulosymphyseal length	68.63	24	3.11	67.16	26	6.32	66.59	64	5.15	65.99	44	4.82
Arcuate chord	124.58	24	6.16	119.14	26	7.02	119.33	64	6.68	113.70	44	6.60
Arcuate line depth	26.08	24	3.74	22.77	26	2.63	24.19	64	3.61	21.70	44	2.94
Transverse acetabular diameter	46.35	24	1.85	52.64	26	2.39	43.75	64	2.62	49.26	43	2.48
Vertical acetabular diameter	45.84	24	2.16	51.87	26	2.62	44.60	64	2.40	49.56	44	2.42
Coxal height	187.17	24	15.91	205.96	26	9.04	186.98	64	7.98	199.86	44	9.41
Maximum iliac breadth	151.46	22	6.38	156.93	26	9.44	142.51	64	7.53	149.64	44	7.04
Iliac height	108.64	24	5.98	118.22	26	11.08	105.65	64	5.78	112.50	44	6.43
Ischial length	77.72	24	3.31	85.88	26	7.06	75.98	64	4.93	82.29	44	4.89
Articular ischial length	88.17	24	3.91	96.09	26	7.37	86.66	64	4.69	94.32	44	4.21
True pelvis depth	86.46	24	3.89	96.52	26	5.11	82.53	64	4.59	90.50	44	7.65
Supra-acetabular auricular distance	73.96	24	4.72	71.99	26	5.02	69.53	64	4.62	67.39	44	5.96
Anterior inferior iliac spine to auricular surface	77.01	24	5.26	76.84	26	5.36	73.02	64	5.12	72.00	44	5.84
Anterior inferior iliac spine to greater	65.71	24	3.64	72.67	26	4.33	63.75	64	4.69	68.89	44	4.10
Auricular length	46.44	24	3.34	51.65	26	4.48	46.44	64	4.60	49.52	44	3.89
Sciatic notch breadth	44.21	24	6.35	36.64	26	4.47	44.07	64	4.49	33.83	44	5.35
Sciatic notch height	51.93	24	3.31	54.58	26	3.29	49.25	64	3.67	52.02	44	4.10
Long Bone Measurements:												
Femoral length (M-2)	414.52	24	19.35	447.40	24	22.89	411.34	64	19.91	440.47	43	18.96
AP femoral head diameter (M-19)	39.64	24	1.88	45.58	26	2.25	38.79	64	2.09	43.60	44	2.03
SI head diameter (M-18)	39.82	24	1.85	45.70	26	2.19	38.89	64	2.08	43.67	44	1.84
Tibia maximum length (M-1A)	358.17	23	20.05	387.04	23	16.18	356.02	64	17.20	383.73	43	17.45
Tibia articular length (M-2)	336.07	23	20.46	363.00	23	15.47	335.04	64	16.67	360.65	43	16.84
Humerus maximum length (M1)	298.64	21	16.19	325.70	22	13.45	294.25	64	15.68	318.98	43	12.79
Humeral head AP diameter (M-10)	39.64	24	1.88	45.58	26	2.25	38.79	64	2.09	43.60	44	2.03
Humeral head SI diameter	39.82	24	1.85	45.70	26	2.19	38.89	64	2.08	43.67	44	1.84
Radius maximum length (M-1)	226.17	23	12.78	256.23	22	9.36	228.10	63	11.53	249.93	44	9.83
Radius articular length (M-2)	219.23	24	12.76	248.23	22	9.79	221.17	63	11.24	240.47	43	9.73
Clavicular length (M-1)	134.73	22	7.96	150.85	20	8.08	131.92	61	7.70	145.75	44	7.81

Table 3.1.6: Descriptive statistics (continued)

Locality:	**Andaman Islands**						**Ancon**					
	Females			**Males**			**Females**			**Males**		
	$\bar{X}$	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**	**$\bar{X}$**	**N**	**S.D.**
Pelvic Measurements:												
Transverse Diameters:												
Biiliac breadth	201.50	2	13.44	202.33	6	6.89	258.91	11	11.86	271.71	17	16.31
Transverse inlet	101.53	2	7.55	89.00	6	7.51	122.81	11	6.63	120.69	17	7.06
Transverse midplane	87.65	2	12.23	65.87	6	6.78	103.05	11	9.92	87.76	17	6.91
Transverse outlet	92.30	2	6.08	71.32	6	8.57	104.79	11	10.59	88.35	17	7.60
Anteroposterior Diameters:												
Sagittal diameter of the pelvic inlet	92.85	2	5.16	90.27	6	6.09	98.18	10	7.24	98.48	17	9.77
AP midplane	106.55	2	0.71	101.83	6	8.92	124.73	11	9.44	118.84	17	10.79
AP outlet	104.80	2	2.26	98.18	6	9.90	114.31	9	5.43	112.63	16	11.21
Diagonal inlet	106.60	2	9.05	97.32	6	6.69	123.90	11	6.88	120.22	17	5.58
Anterior Spaces:												
Linea terminalis	122.50	2	7.78	113.75	6	7.69	138.64	11	7.27	134.53	17	5.45
Anterior midplane	74.75	2	1.91	71.15	6	5.46	89.97	11	5.40	86.99	17	3.29
Posterior Spaces:												
Posterior midplane	66.25	2	4.88	53.40	6	6.48	74.49	11	4.33	64.06	17	8.73
Posterior outlet	85.90	2	3.54	68.13	6	6.46	89.03	10	6.26	78.07	16	11.14
Sacral Measurements:												
Sacral width (M-5)	67.00	2	4.24	65.17	6	6.08	73.36	11	5.12	61.82	17	4.82
Angle Measurements:												
Subpubic angle	89.20	2	7.50	80.12	6	5.26	104.01	11	5.91	102.26	17	3.77
Sacral angle	101.00	2	1.41	69.97	6	10.07	110.27	11	11.17	78.65	17	8.81
Measurements of the Innominate:												
Pubic length (M-17)	69.99	2	0.82	68.46	6	4.79	87.36	11	4.65	84.79	17	5.05
Acetabulosymphyseal length	51.35	2	1.90	48.95	6	4.49	70.11	11	4.14	65.80	17	3.85
Arcuate chord	103.70	2	6.79	100.33	6	5.93	116.05	11	6.16	114.55	17	4.95
Arcuate line depth	20.50	2	2.12	15.50	6	2.26	25.36	11	3.44	21.94	17	2.44
Transverse acetabular diameter	39.56	2	1.88	43.13	6	2.75	47.27	11	1.25	52.43	17	4.34
Vertical acetabular diameter	40.42	2	1.01	43.52	6	2.89	46.81	11	1.73	51.45	17	3.74
Coxal height	159.00	2	8.49	164.83	6	6.94	181.36	11	9.01	197.41	17	10.28
Maximum iliac breadth	117.96	2	5.10	119.04	6	5.74	144.26	11	7.69	154.06	17	6.67
Iliac height	90.24	2	8.04	93.26	6	4.75	103.24	11	5.03	111.46	17	7.28
Ischial length	63.79	2	1.62	67.10	6	4.22	76.56	11	2.34	83.38	17	4.70
Articular ischial length	71.59	2	0.69	76.39	6	5.22	88.09	11	1.84	95.71	17	5.71
True pelvis depth	72.27	2	1.04	75.71	6	3.90	86.59	11	2.93	95.50	17	4.46
Supra-acetabular auricular distance	62.08	2	4.48	57.25	6	2.67	66.90	11	4.04	70.33	17	4.50
Anterior inferior iliac spine to auricular surface	63.82	2	1.35	58.17	6	2.76	70.63	11	4.99	73.97	17	3.73
Anterior inferior iliac spine to greater	53.84	2	1.52	53.29	6	2.77	63.50	11	3.93	66.99	17	5.15
Auricular length	41.22	2	1.59	40.58	6	2.85	50.14	11	5.45	50.38	17	4.62
Sciatic notch breadth	41.30	2	1.41	34.55	6	2.60	43.09	11	4.85	36.61	17	4.79
Sciatic notch height	41.30	2	0.85	46.08	6	2.07	50.13	11	2.00	54.01	17	4.47
Long Bone Measurements:												
Femoral length (M-2)	374.75	2	3.18	379.25	6	22.04	376.90	10	19.52	409.18	17	19.15
AP femoral head diameter (M-19)	34.04	2	0.09	36.96	6	2.01	40.74	11	1.33	46.09	17	3.26
SI head diameter (M-18)	34.01	2	0.05	36.67	6	1.99	40.69	11	1.38	46.03	17	3.26
Tibia maximum length (M-1A)	314.00	2	2.82	318.40	5	16.18	323.72	9	16.57	349.78	16	18.17
Tibia articular length (M-2)	298.00	2	5.66	298.20	5	16.74	305.83	9	17.07	329.50	16	16.80
Humerus maximum length (M1)	253.50	2	1.41	268.83	6	15.78	268.00	9	10.08	297.68	17	12.78
Humeral head AP diameter (M-10)	34.04	2	0.09	36.96	6	2.01	40.74	11	1.33	46.09	17	3.26
Humeral head SI diameter	34.01	2	0.05	36.67	6	1.99	40.69	11	1.38	46.03	17	3.26
Radius maximum length (M-1)	202.50	2	4.95	216.17	6	13.40	206.69	8	10.99	228.56	17	11.28
Radius articular length (M-2)	197.75	2	4.60	211.17	6	13.26	203.44	8	11.67	224.00	17	11.60
Clavicular length (M-1)	103.25	2	1.77	110.75	6	10.11	125.56	8	10.21	145.71	17	5.09

Figure 3.1: Boxplot of biiliac breadth by locality

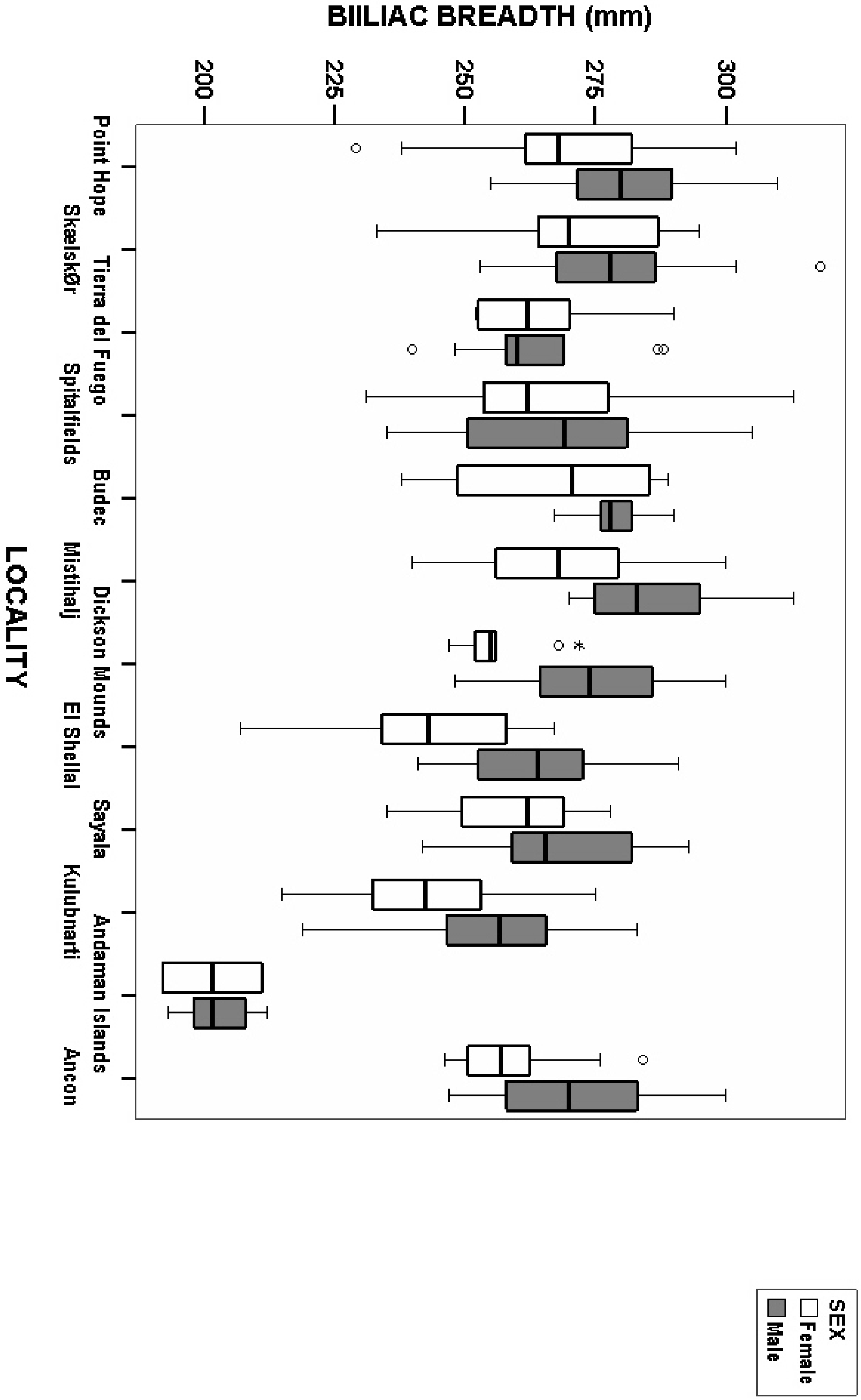


Figure 3.2: Boxplot of transverse pelvic inlet by locality

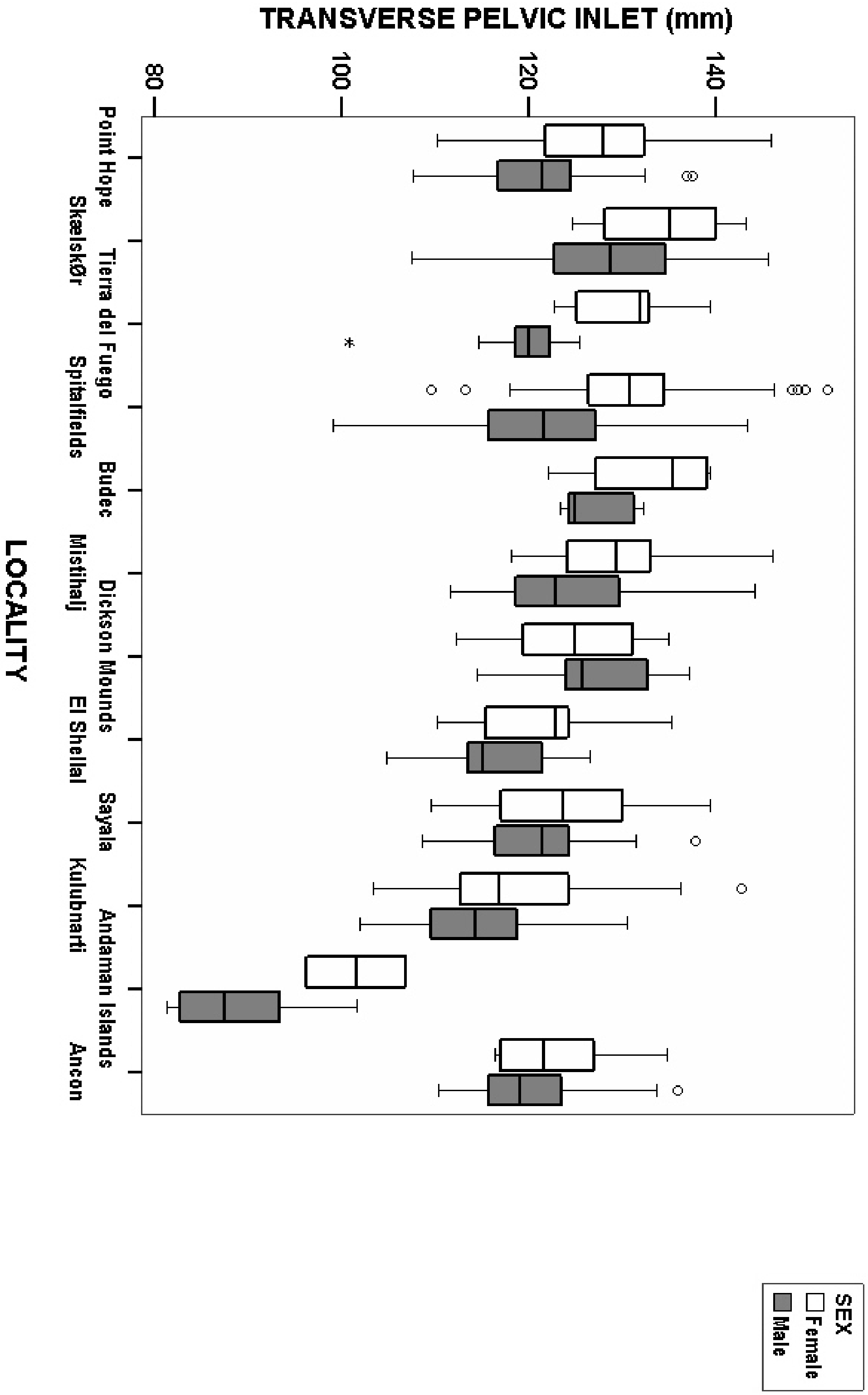


Figure 3.3: Boxplot of transverse pelvic midplane by locality

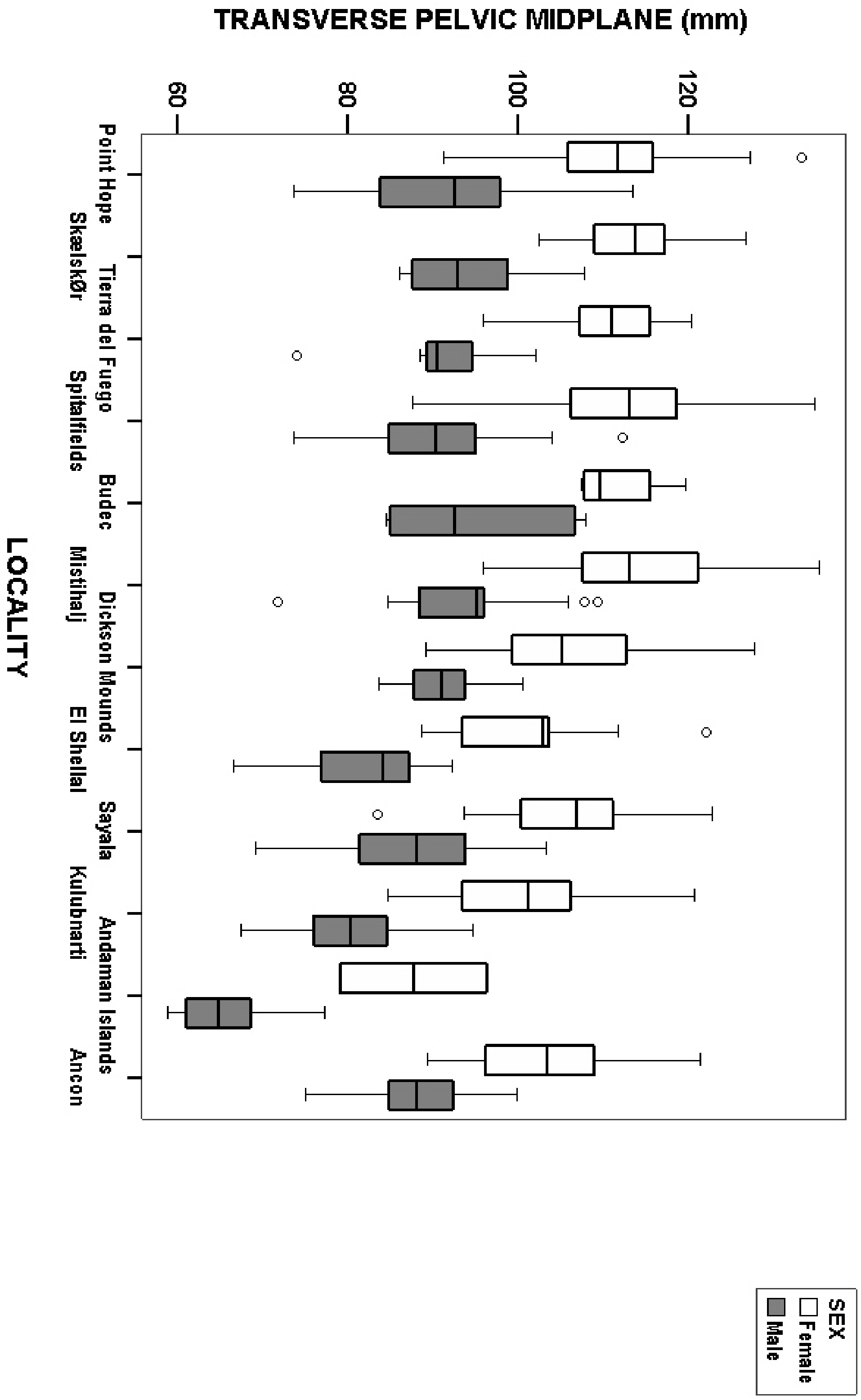


Figure 3.4: Boxplot of sacral width by locality

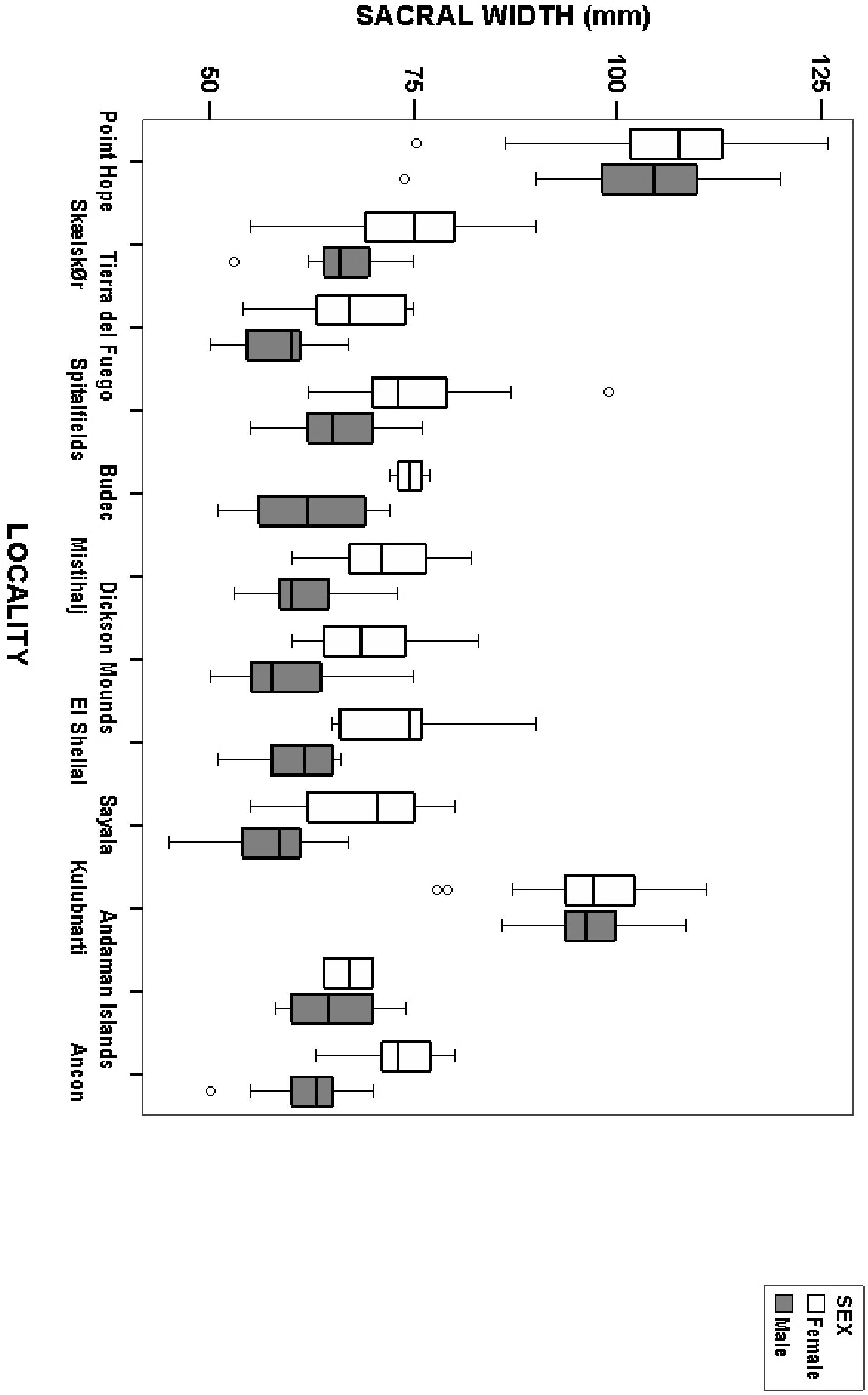
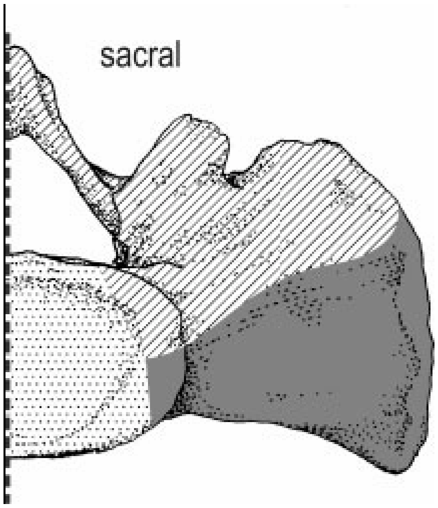


Figure 3.5: Costal process of the sacrum (dark gray)



Modified from Tague (2007)

Figure 3.6: Ventral sacral width

Modified from Tague (2000)

Figure 3.7: Sagittal inlet by locality

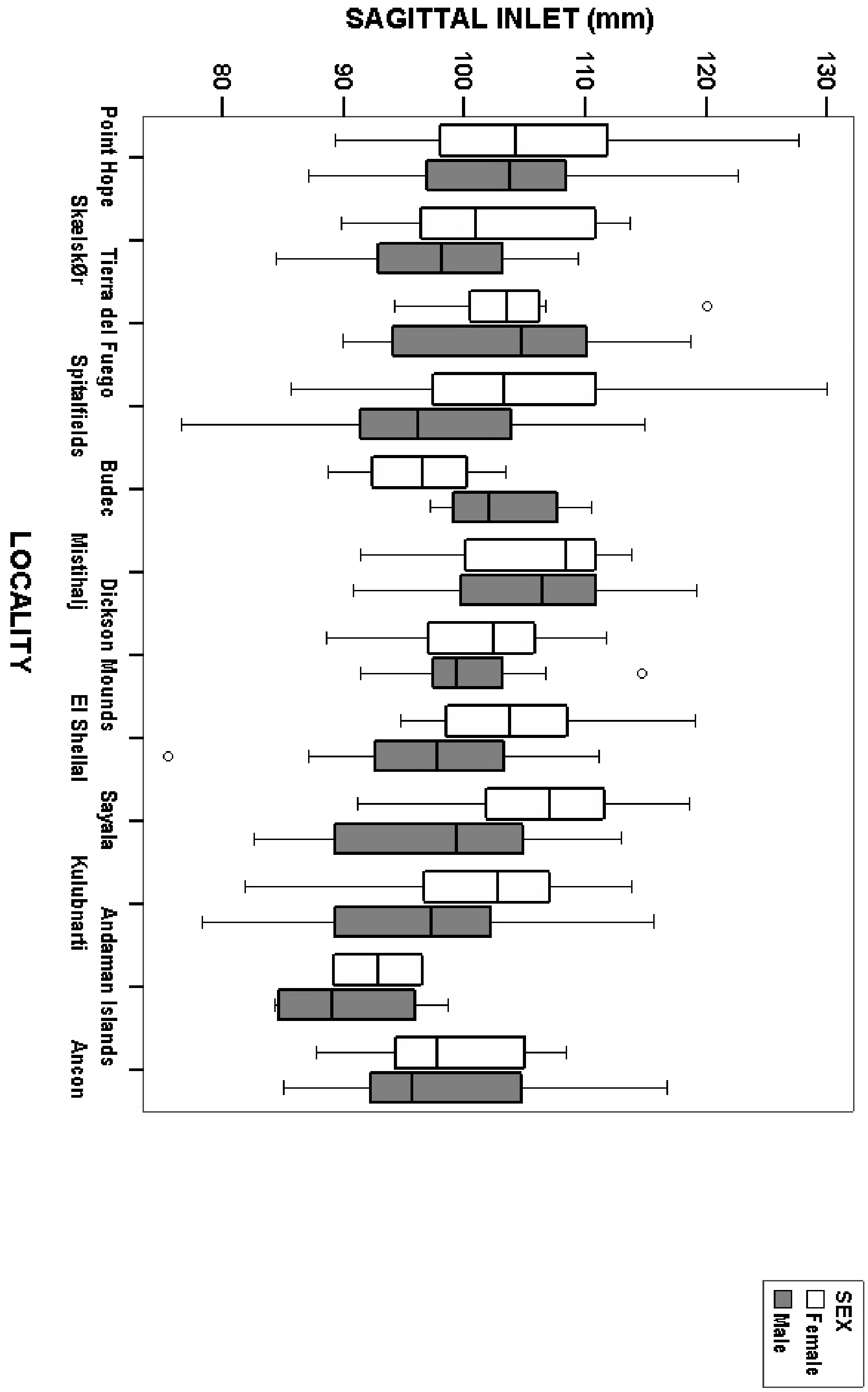


Table 3.2: Sexual dimorphism in sacral width

Locality	Females			Males			Percentage Dimorphism
	$\overline{X}$	N	S.D.	$\overline{X}$	N	S.D.	
Point Hope	106.69	51	10.12	104.24	55	8.48	2.30%
SkælskØr	74.50	14	8.94	66.48	23	4.83	10.77%
Tierra del Fuego	67.14	7	7.86	58.29	7	5.74	13.18%
Spitalfields	74.18	65	6.48	65.88	40	5.40	11.20%
Budec	74.50	4	2.08	62.00	6	7.85	16.78%
Mistihalj	71.45	11	7.23	61.68	19	5.29	13.67%
Dickson Mounds	69.10	10	7.48	59.63	8	7.73	13.70%
El Shellal	72.86	14	7.12	60.67	12	5.10	16.73%
Sayala	69.00	24	7.34	58.08	26	5.48	15.83%
Kulubnarti	97.51	64	6.45	96.88	44	5.38	0.65%
Andaman Islands	67.00	2	4.24	65.17	6	6.08	2.73%
Ancon	73.36	11	5.12	61.82	17	4.82	15.73%
Total	84.51	277	16.56	77.07	263	19.87	8.80%

Partial correlation analysis

Although a preliminary investigation illustrates some of the expected trends between the transverse pelvic measurements and climate, it is important to examine this relationship in quantitative terms. As discussed earlier, the hypotheses presented predict that females from high latitude or cold climate localities will have larger pelvic obstetrical dimensions than those from low latitude or warm climate localities. Therefore, it is expected that pelvic variables will be positively correlated with latitude, and negatively correlated with mean temperature of the coldest month and mean temperature of the warmest month. Partial correlation analysis was utilized in order to investigate this relationship. Partial correlation analysis allows one to study the association between two variables while adjusting for the effects of one or more additional variables (Sokal and Rohlf 1995). In this particular case, I wished to study the relationship between climate and the obstetrical measurements of the pelvis, while adjusting for the effects of body size. Table 3.3.1 through Table 3.3.3 (females) and

Table 3.4.1 through Table 3.4.3 (males) show the results of partial correlation analysis. In the table, each pelvic measurement is correlated with climate as quantified by latitude, mean temperature of the coldest month (MTCM), and mean temperature of the warmest month (MTWM). Under the control variables column, where it states "none," the correlation value listed is the zero-order partial, or Pearson correlation. The Pearson correlation is included because it allows one to see the amount of variance that body size absorbs. AP femoral head diameter is used as the control variable for body size. As AP femoral head diameter quantifies the surface area of a weight-bearing joint, it is considered a suitable body size proxy (McHenry 1992; Ruff et al. 1997; Lieberman et al. 2001; Ruff 2002). Other body size proxies (AP femoral head diameter squared, etc.) were also used, but the results did not differ greatly from those presented here. P-values are in bold only if they are ≤ 0.017 (the adjusted significance level after a Bonferroni correction) *and* after using the body size control variable.

Partial correlation analysis—females

As can be seen in Table 3.3.1, the major transverse obstetrical measurements are positively correlated with latitude and negatively correlated with temperature. In almost all of the cases, these correlations are statistically significant ($p \leq 0.017$) even after accounting for body size using AP femoral head diameter. The only exception with a non-significant p-value is the correlation between the pelvic inlet and MTCM after body size correction.

Biiliac breadth is statistically significantly correlated with latitude, mean temperature of the coldest month, and mean temperature of the warmest month. These results corroborate the work of Ruff (1991, 1994). It should be noted that the correlation coefficient of 0.509 for biiliac breadth with latitude is lower than that of 0.866 for biiliac with latitude reported by Ruff (1994). However, this difference is most likely related to plotting all of the data points versus plotting the sample mean, as is the case with Ruff (1994). Figure 3.8 is a scatter plot of biiliac breadth versus latitude, where all of the data points are plotted. In the scatter plots shown in Figure 3.8 through Figure 3.23, the plot at the top of the page is the pelvic variable versus latitude where all of the data points have been plotted. The plot at the bottom of the page is the same pelvic variable versus latitude where the sample means have been plotted. The sample mean plots are shown because it is easier to see the trend the latitude than when all of the data points are plotted. However, the correlation coefficients in Tables 3.3.1-3.3.3 and Tables 3.4.1-3.4.3 are based on the Pearson r from all of the data points, not the sample mean.

When the sample means for biiliac breadth for females are plotted (Figure 3.9), the correlation coefficient is much higher ($r = 0.702$, $p < 0.02$, compared to $r = 0.509$, $p < 0.01$ for all data points). The same case can be made for the transverse pelvic inlet (Figure 3.11) and transverse pelvic midplane (Figure 3.13), when the sample means have been plotted. When the sample means for the transverse pelvic inlet are correlated with latitude the correlation coefficient is also higher ($r = 0.752$, $p < 0.01$, compared to $r = 0.452$, $p < 0.01$ for all data points), and the results are similar when the transverse pelvic midplane is plotted against latitude ($r = 0.797$, $p < 0.01$, compared to $r = 0.447$, $p < 0.01$ for all data points). A commonality on all of the female plots is that the Andaman Islanders sample is a significant outlier compared to the rest of the samples. It should also be noted that sacral width, another transverse measure, was statistically significantly correlated with latitude and MTCM (refer to Table 3.3.2), even after body size correction (despite the larger values for the Point Hope and Kulubnarti samples noted earlier).

The partial correlation results for AP measurements are quite different from those for the transverse measurements. Unlike the transverse measurements, very few of the AP measurements are statistically significantly correlated with climate *after* accounting for body size. The sample means for the sagittal inlet versus latitude are plotted in Figure 3.15 ($r = 0.412$, $p > 0.05$). The AP measurement with the strongest correlation with climate in females is the AP outlet, which after controlling for body size has a p-value ≤ 0.017 when correlated with latitude and MTCM. For measurements in the "Posterior Spaces" category (Figure 2.5 in Chapter 2), the posterior midplane is statistically significantly correlated with latitude and MTCM, and the posterior outlet is significantly correlated with all three measures of climate (after controlling for body size for both measurements), but these were the only other pelvic measurements to do so. The partial correlation coefficients for AP diameters, anterior spaces, and posterior spaces are lower than those for transverse diameters, and are for the most part not statistically significantly correlated with measures of climate after correcting for body size. There are no measurements of the innominate that are statistically significantly correlated with climate in females after correcting for body size.

Partial correlation analysis—males

The results for partial correlation analysis in males are similar to the female results, but there are some differences (Table 3.4.1 through Table 3.4.3). First, some of the transverse diameters are not statistically significantly correlated with climatic measures. Biiliac breadth is not statistically significantly correlated with MTWM after body size correction the way it is in females. Biiliac breadth is not statistically significantly correlated with latitude after body size correction and the standard Bonferroni correction ($p = 0.018$); however, this test retains significance after a sequential Bonferroni correction (Holm 1979). The pelvic inlet is not statistically significantly correlated with any measure of climate in males after body size correction. However, in females the transverse pelvic inlet is strongly correlated with latitude and MTWM after body size correction. The correlation of the pelvic midplane with latitude, MTCM, and MTWM after body size correction is statistically significant as it is in females, and the same relationship holds for the pelvic outlet. Sacral width was also statistically significantly correlated with all three measures of climate.

Figure 3.16 is a scatter plot of male biiliac breadth versus latitude, where all of the data points are plotted. With the male results, the difference between the correlation coefficients when the sample means are plotted versus when all of the data points are plotted is not as great as it is for females. Figure 3.17 plots the sample means for biiliac breadth versus latitude ($r = 0.574$, $p = 0.051$), for all data points ($r = 0.428$, $p <0.01$). Figure 3.19 plots the sample means for transverse pelvic inlet versus latitude ($r = 0.566$, $p = 0.055$), for all data points ($r = 0.326$, $p <0.01$). Figure 3.21 plots the sample means for transverse pelvic midplane versus latitude ($r = 0.715$, $p < 0.01$), for all data points $r = 0.419$, $p <0.01$). The results for the transverse pelvic midplane are comparable to the female results, but for biiliac breadth and the transverse pelvic inlet the correlation coefficients are lower for males than females.

The results for AP measurements for males are slightly different from the results for females. Figure 3.22 plots the sagittal pelvic inlet against latitude with all of the data points, and Figure 3.23 shows the same variables when the sample means are plotted. As with the females, the sagittal pelvic inlet is not statistically significantly correlated with any measure of climate after size correction (when all of the data points are plotted).

The AP midplane and AP outlet are statistically significantly correlated with all three measures of climate after body size correction, whereas only the AP outlet is in females. The anterior midplane, posterior midplane, and posterior outlet (also after size correction) are statistically significantly correlated with all three climatic measures, a result that is similar to the findings in females. For measurements of the innominate, acetabulosymphyseal length, arcuate chord length, and arcuate line depth are all statistically significantly correlated with climate after body size correction. In contrast, measurements of the innominate are not statistically significant in females across all three measures of climate after body size adjustment and statistical corrections. In males, acetabulosymphyseal length is not statistically significantly correlated with latitude after the traditional Bonferroni correction, but retains significance after the sequential Bonferroni correction. This is the only other measurement where the adjusted significance level differs based on the type of Bonferroni correction. Given that acetabulosymphyseal length is statistically significantly correlated with both MTCM and MTWM after the more conservative correction, this pelvic measurement overall can be considered as having a climatic signal in males.

The overall male pattern indicates that transverse pelvic diameters are statistically significantly correlated with climate as they are in females, with the notable exceptions of biiliac breadth when correlated with the mean temperature of the warmest month, and the transverse pelvic inlet diameter when correlated with latitude, mean temperature of the coldest month, and mean temperature of the warmest month.

Additionally, some AP pelvic measurements are statistically significantly correlated with climate in males where they are not in females, in particular the AP pelvic midplane diameter. As with the female plots, the Andaman Islanders are a notable outlier from the other samples.

Table 3.3.1: Partial correlation analysis (females)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
	Transverse Diameters				
None	Biiliac	correlation	0.509	-0.468	-0.507
	N=274	significance (2-tailed)	0.000	0.000	0.000
		df	272	272	272
AP Femoral Head Diameter	Biiliac	correlation	0.228	-0.188	-0.228
	N=274	significance (2-tailed)	**0.000**	**0.002**	**0.000**
		df	271	271	271
None	Pelvic Inlet	correlation	0.452	-0.358	-0.449
	N=275	significance (2-tailed)	0.000	0.000	0.000
		df	273	273	273
AP Femoral Head Diameter	Pelvic Inlet	correlation	0.217	-0.101	-0.216
	N=275	significance (2-tailed)	**0.000**	0.095	**0.000**
		df	272	272	272
None	Pelvic Midplane	correlation	0.447	-0.379	-0.433
	N=275	significance (2-tailed)	0.000	0.000	0.000
		df	273	273	273
AP Femoral Head Diameter	Pelvic Midplane	correlation	0.275	-0.196	-0.259
	N=275	significance (2-tailed)	**0.000**	**0.001**	**0.000**
		df	272	272	272
None	Pelvic Outlet	correlation	0.547	-0.500	-0.555
	N=275	significance (2-tailed)	0.000	0.000	0.000
		df	273	273	273
AP Femoral Head Diameter	Pelvic Outlet	correlation	0.434	-0.380	-0.445
	N=275	significance (2-tailed)	**0.000**	**0.000**	**0.000**
		df	272	272	272
	Anteroposterior Diameters				
None	Sagittal Inlet	correlation	0.142	-0.137	-0.107
	N=273	significance (2-tailed)	0.019	0.024	0.078
		df	271	271	271
AP Femoral Head Diameter	Sagittal Inlet	correlation	-0.013	0.010	0.053
	N=273	significance (2-tailed)	0.835	0.871	0.385
		df	270	270	270
None	AP Midplane	correlation	0.316	-0.285	-0.345
	N=253	significance (2-tailed)	0.000	0.000	0.000
		df	251	251	251
AP Femoral Head Diameter	AP Midplane	correlation	0.110	-0.083	-0.147
	N=253	significance (2-tailed)	0.081	0.189	0.020
		df	250	250	250
None	AP Outlet	correlation	0.338	-0.304	-0.362
	N=232	significance (2-tailed)	0.000	0.000	0.000
		df	230	230	230
AP Femoral Head Diameter	AP Outlet	correlation	0.164	-0.133	-0.199
	N=232	significance (2-tailed)	**0.013**	0.043	**0.002**
		df	229	229	229

Table 3.3.2: Partial correlation analysis continued (females)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
	Anteroposterior Diameters				
None	Diagonal Inlet	correlation	0.275	-0.180	-0.247
	N=275	significance (2-tailed)	0.000	0.001	0.000
		df	273	273	273
AP Femoral Head Diameter	Diagonal Inlet	correlation	0.009	0.103	0.026
	N=275	significance (2-tailed)	0.878	0.089	0.670
		df	272	272	272
	Anterior Spaces				
None	Linea Terminalis	correlation	0.217	-0.153	-0.183
	N=271	significance (2-tailed)	0.000	0.012	0.003
		df	269	269	269
AP Femoral Head Diameter	Linea Terminalis	correlation	-0.040	0.107	0.083
	N=271	significance (2-tailed)	0.512	0.079	0.176
		df	268	268	268
None	Anterior Midplane	correlation	0.414	-0.357	-0.403
	N=274	significance (2-tailed)	0.000	0.000	0.000
		df	272	272	272
AP Femoral Head Diameter	Anterior Midplane	correlation	0.163	-0.097	-0.151
	N=274	significance (2-tailed)	**0.007**	0.108	**0.013**
		df	271	271	271
	Posterior Spaces				
None	Posterior Midplane	correlation	0.345	-0.301	-0.372
	N=253	significance (2-tailed)	0.000	0.000	0.000
		df	251	251	251
AP Femoral Head Diameter	Posterior Midplane	correlation	0.174	-0.129	-0.208
	N=253	significance (2-tailed)	**0.006**	0.040	**0.001**
		df	250	250	250
None	Posterior Outlet	correlation	0.412	-0.349	-0.451
	N=233	significance (2-tailed)	0.000	0.000	0.000
		df	231	231	231
AP Femoral Head Diameter	Posterior Outlet	correlation	0.272	-0.201	-0.323
	N=233	significance (2-tailed)	**0.000**	**0.002**	**0.000**
		df	230	230	230
	Sacral Measurements				
None	Sacral Width	correlation	0.194	-0.316	-0.143
	N=274	significance (2-tailed)	0.001	0.000	0.018
		df	272	272	272
AP Femoral Head Diameter	Sacral Width	correlation	0.164	-0.306	-0.105
	N=274	significance (2-tailed)	**0.007**	**0.000**	0.084
		df	271	271	271
	Measurements of the Innominate				
None	Pubic Length	correlation	0.408	-0.310	-0.410
	N=273	significance (2-tailed)	0.000	0.000	0.000
		df	271	271	271
AP Femoral Head Diameter	Pubic Length	correlation	0.120	0.006	-0.127
	N=273	significance (2-tailed)	0.048	0.922	0.036
		df	270	270	270

Table 3.3.3: Partial correlation analysis continued (females)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
	Measurements of the Innominate				
None	Acetabulosymphyseal	correlation	0.245	-0.165	-0.251
	Length	significance (2-tailed)	0.000	0.006	0.000
	N=273	df	271	271	271
AP Femoral Head Diameter	Acetabulosymphyseal	correlation	-0.050	0.142	0.037
	Length	significance (2-tailed)	0.410	0.019	0.539
	N=273	df	270	270	270
None	Arcuate Chord	correlation	0.200	-0.166	-0.153
	N=275	significance (2-tailed)	0.001	0.006	0.011
		df	273	273	273
AP Femoral Head Diameter	Arcuate Chord	correlation	-0.063	0.094	0.123
	N=275	significance (2-tailed)	0.296	0.122	0.041
		df	272	272	272
None	Arcuate Line Depth	correlation	0.001	0.037	-0.006
	N=275	significance (2-tailed)	0.986	0.536	0.917
		df	273	273	273
AP Femoral Head Diameter	Arcuate Line Depth	correlation	-0.101	0.140	0.094
	N=275	significance (2-tailed)	0.095	0.020	0.122
		df	272	272	272

Table 3.4.1: Partial correlation analysis (males)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
	Transverse Diameters				
None	Biiliac	correlation	0.428	-0.420	-0.364
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Biiliac	correlation	0.147	-0.230	-0.098
	N=256	significance (2-tailed)	0.018	**0.000**	0.118
		df	253	253	253
None	Pelvic Inlet	correlation	0.326	-0.279	-0.264
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Pelvic Inlet	correlation	0.053	-0.059	-0.007
	N=256	significance (2-tailed)	0.400	0.347	0.909
		df	253	253	253
None	Pelvic Midplane	correlation	0.419	-0.376	-0.390
	N=254	significance (2-tailed)	0.000	0.000	0.000
		df	252	252	252
AP Femoral Head Diameter	Pelvic Midplane	correlation	0.238	-0.225	-0.224
	N=254	significance (2-tailed)	**0.000**	**0.000**	**0.000**
		df	251	251	251
None	Pelvic Outlet	correlation	0.448	-0.446	-0.486
	N=255	significance (2-tailed)	0.000	0.000	0.000
		df	253	253	253
AP Femoral Head Diameter	Pelvic Outlet	correlation	0.338	-0.357	-0.395
	N=255	significance (2-tailed)	**0.000**	**0.000**	**0.000**
		df	252	252	252
	Anteroposterior Diameters				
None	Sagittal Inlet	correlation	0.228	-0.257	-0.195
	N=254	significance (2-tailed)	0.000	0.000	0.002
		df	252	252	252
AP Femoral Head Diameter	Sagittal Inlet	correlation	0.048	-0.120	-0.032
	N=254	significance (2-tailed)	0.446	0.057	0.616
		df	251	251	251
None	AP Midplane	correlation	0.375	-0.366	-0.372
	N=244	significance (2-tailed)	0.000	0.000	0.000
		df	242	242	242
AP Femoral Head Diameter	AP Midplane	correlation	0.185	-0.214	-0.209
	N=244	significance (2-tailed)	**0.004**	**0.001**	**0.001**
		df	241	241	241
None	AP Outlet	correlation	0.335	-0.342	-0.343
	N=229	significance (2-tailed)	0.000	0.000	0.000
		df	227	227	227
AP Femoral Head Diameter	AP Outlet	correlation	0.159	-0.201	-0.194
	N=229	significance (2-tailed)	**0.008**	**0.002**	**0.003**
		df	226	226	226

Table 3.4.2: Partial correlation analysis continued (males)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
None	Diagonal Inlet	correlation	0.292	-0.204	-0.211
	N=256	significance (2-tailed)	0.000	0.001	0.001
		df	254	254	254
AP Femoral Head Diameter	Diagonal Inlet	correlation	-0.039	0.082	0.108
	N=256	significance (2-tailed)	0.269	0.194	0.085
		df	253	253	253
	Anterior Spaces				
None	Linea Terminalis	correlation	0.315	-0.282	-0.246
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Linea Terminalis	correlation	0.047	-0.070	0.007
	N=256	significance (2-tailed)	0.454	0.265	0.907
		df	253	253	253
None	Anterior Midplane	correlation	0.469	-0.367	-0.386
	N=255	significance (2-tailed)	0.000	0.000	0.000
		df	253	253	253
AP Femoral Head Diameter	Anterior Midplane	correlation	0.234	-0.157	-0.152
	N=255	significance (2-tailed)	**0.000**	**0.012**	**0.015**
		df	252	252	252
	Posterior Spaces				
None	Posterior Midplane	correlation	0.358	-0.369	-0.380
	N=242	significance (2-tailed)	0.000	0.000	0.000
		df	240	240	240
AP Femoral Head Diameter	Posterior Midplane	correlation	0.192	-0.239	-0.241
	N=242	significance (2-tailed)	**0.003**	**0.000**	**0.000**
		df	239	239	239
None	Posterior Outlet	correlation	0.461	-0.463	-0.500
	N=230	significance (2-tailed)	0.000	0.000	0.000
		df	228	228	228
AP Femoral Head Diameter	Posterior Outlet	correlation	0.335	-0.360	-0.398
	N=230	significance (2-tailed)	**0.000**	**0.000**	**0.000**
		df	227	227	227
	Sacral Measurements				
None	Sacral Width	correlation	0.334	-0.433	-0.304
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Sacral Width	correlation	0.424	-0.505	-0.375
	N=256	significance (2-tailed)	**0.000**	**0.000**	**0.000**
		df	253	253	253
	Measurements of the Innominate				
None	Pubic Length	correlation	0.391	-0.273	-0.328
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Pubic Length	correlation	0.100	-0.005	-0.053
	N=256	significance (2-tailed)	0.112	0.930	0.398
		df	253	253	253

Table 3.4.3: Partial correlation analysis continued (males)

Control Variables	Pelvic Measurement		Latitude	MTCM	MTWM
None	Acetabulosymphyseal	correlation	0.158	-0.059	-0.075
	Length	significance (2-tailed)	0.011	0.348	0.234
	N=256	df	254	254	254
AP Femoral Head Diameter	Acetabulosymphyseal	correlation	-0.130	0.193	0.200
	Length	significance (2-tailed)	0.038	**0.002**	**0.001**
	N=256	df	253	253	253
None	Arcuate Chord	correlation	0.394	-0.346	-0.317
	N=256	significance (2-tailed)	0.000	0.000	0.000
		df	254	254	254
AP Femoral Head Diameter	Arcuate Chord	correlation	0.150	-0.152	-0.082
	N=256	significance (2-tailed)	**0.016**	**0.015**	0.190
		df	253	253	253
None	Arcuate Line Depth	correlation	-0.135	0.138	0.194
	N=256	significance (2-tailed)	0.031	0.028	0.002
		df	254	254	254
AP Femoral Head Diameter	Arcuate Line Depth	correlation	-0.238	0.216	0.288
	N=256	significance (2-tailed)	**0.000**	**0.001**	**0.000**
		df	253	253	253

Figure 3.8: Biiliac breadth vs. latitude, all data points plotted (females)

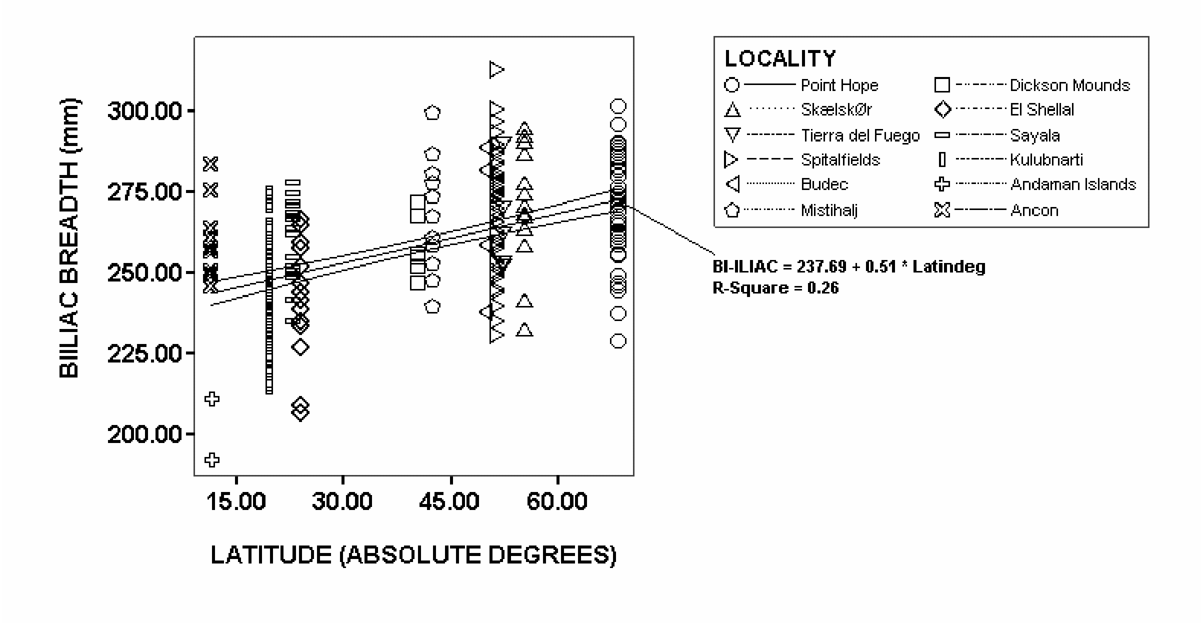


Figure 3.9: Biiliac breadth vs. latitude, sample means plotted (females)

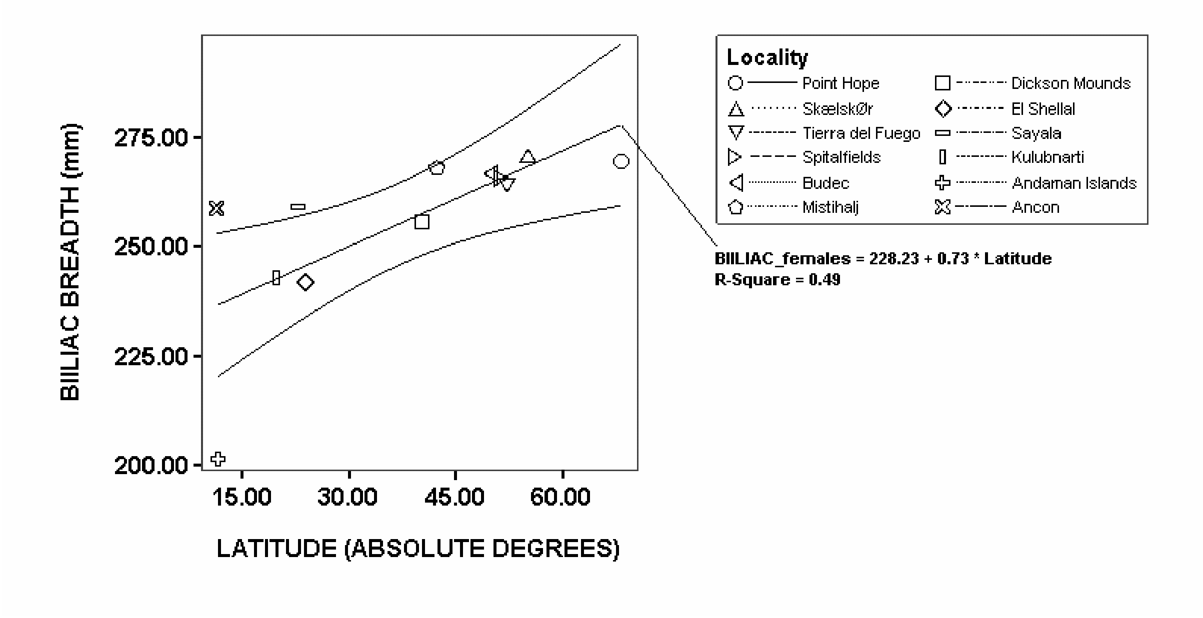


Figure 3.10: Transverse pelvic inlet vs. latitude, all data points plotted (females)

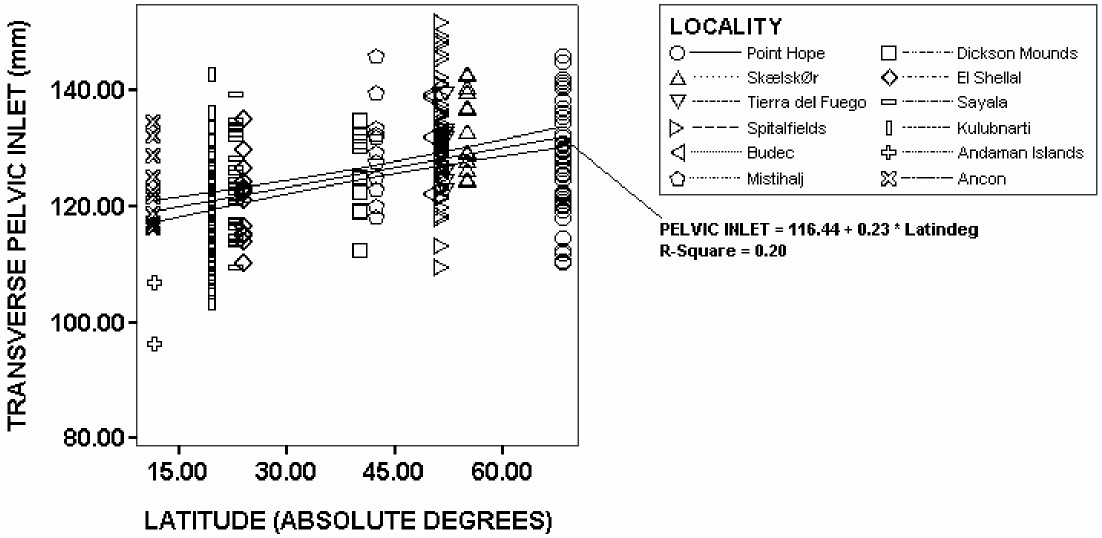


Figure 3.11: Transverse pelvic inlet vs. latitude, sample means plotted (females)

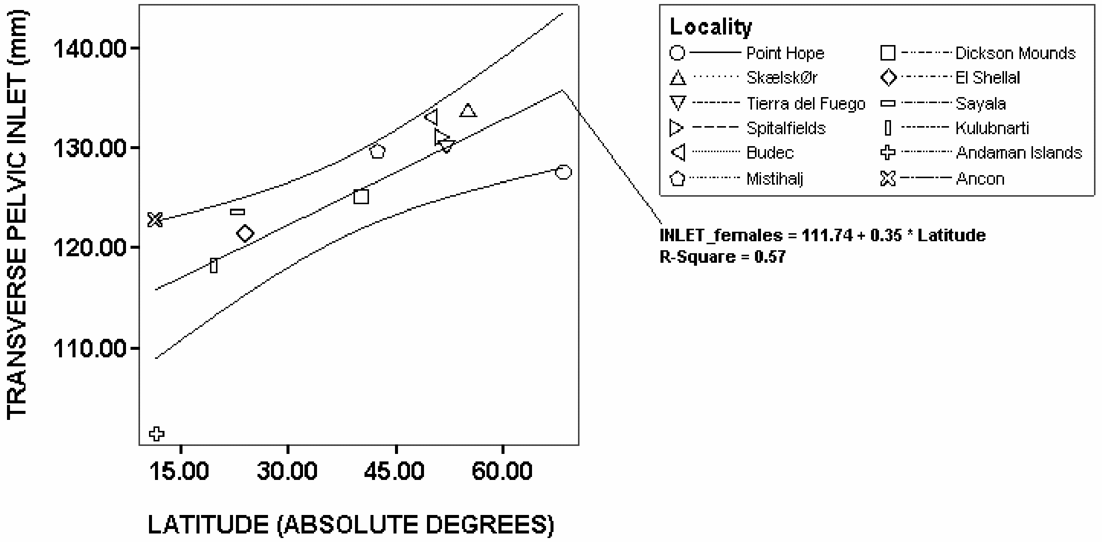


Figure 3.12: Transverse pelvic midplane vs. latitude, all data points plotted (females)

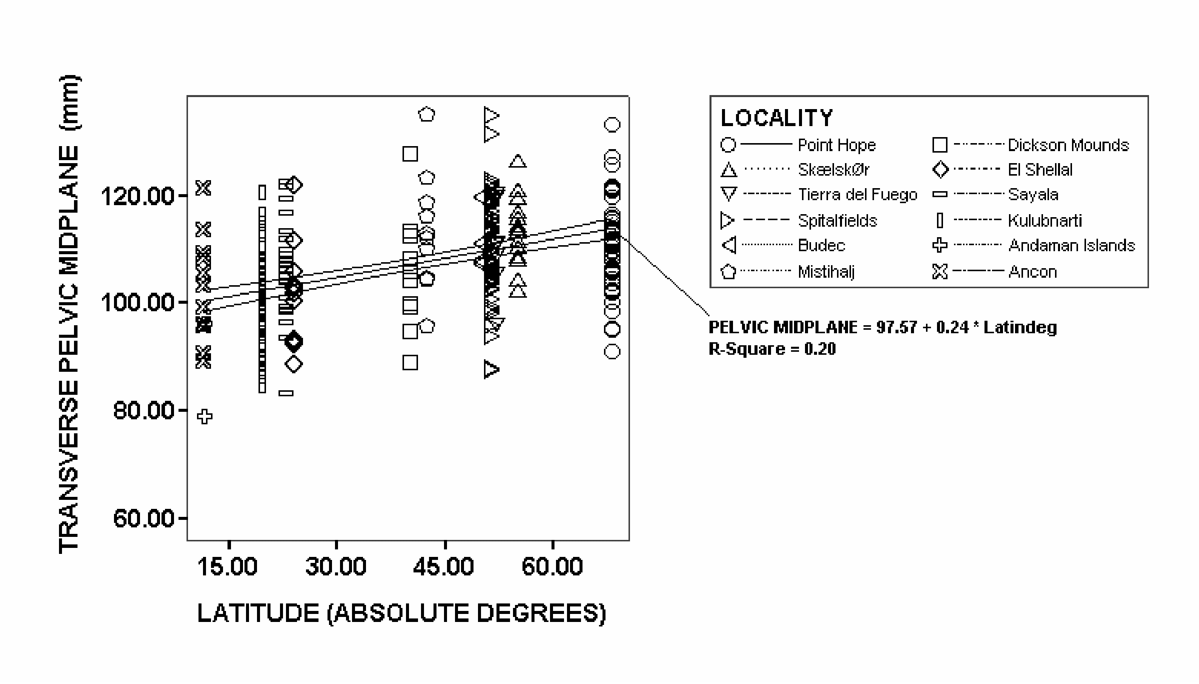


Figure 3.13: Transverse pelvic midplane vs. latitude, sample means plotted (females)

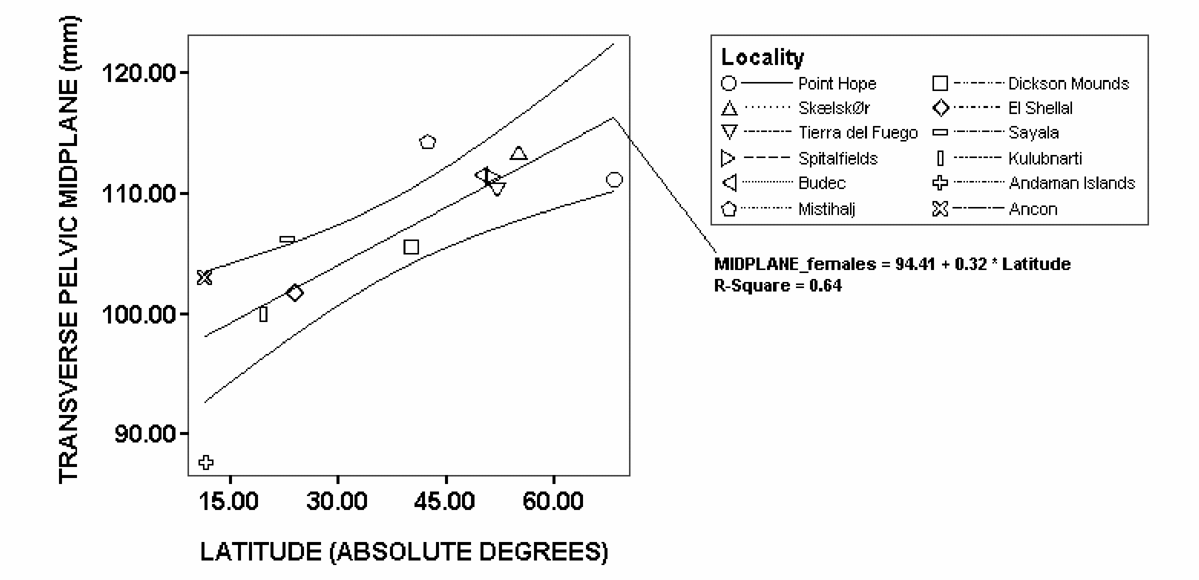


Figure 3.14: Sagittal pelvic inlet vs. latitude, all data points plotted (females)

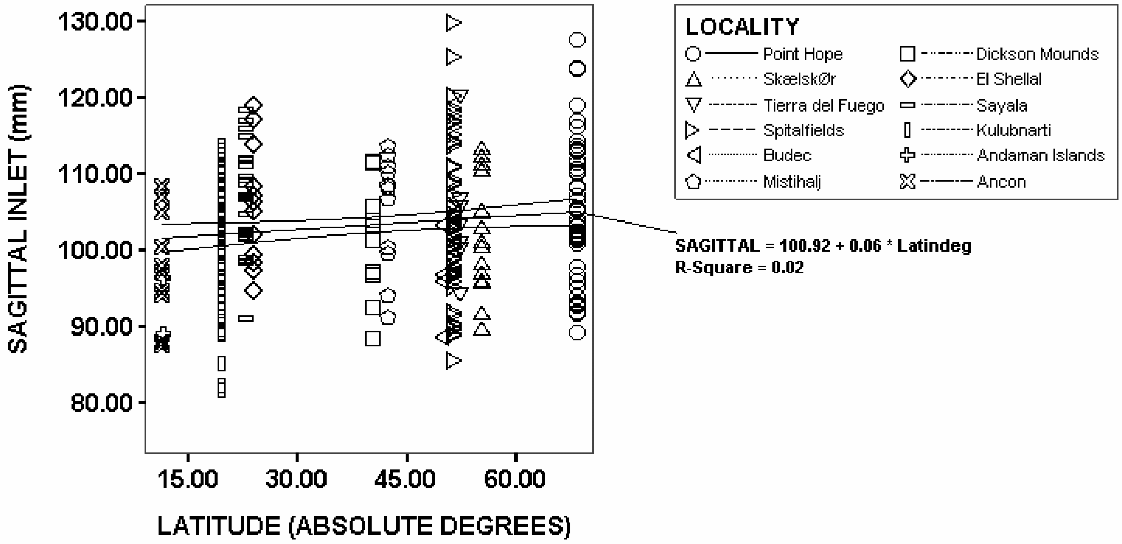


Figure 3.15: Sagittal pelvic inlet vs. latitude, sample means plotted (females)

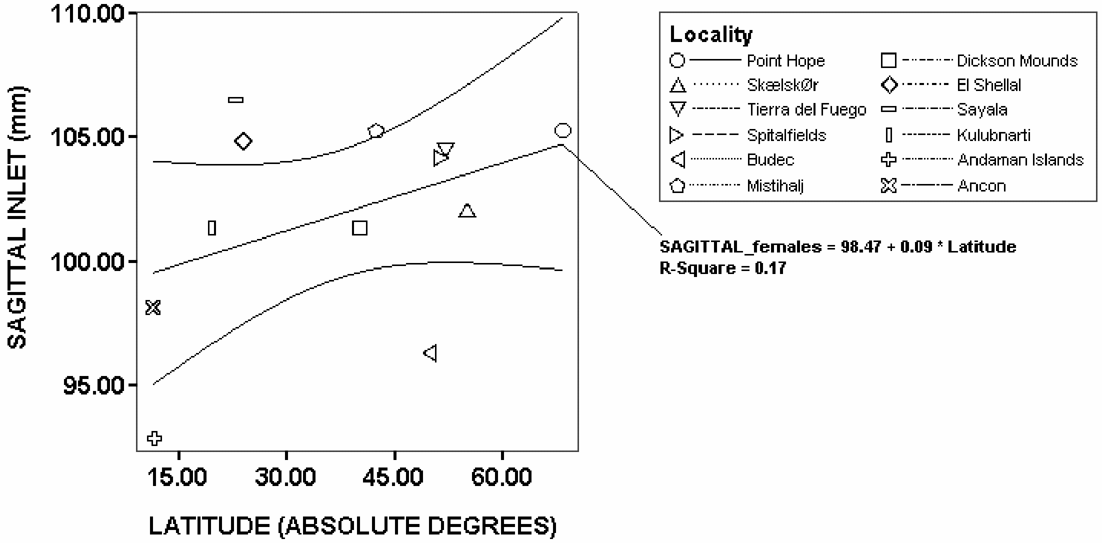


Figure 3.16: Biiliac breadth vs. latitude, all data points plotted (males)

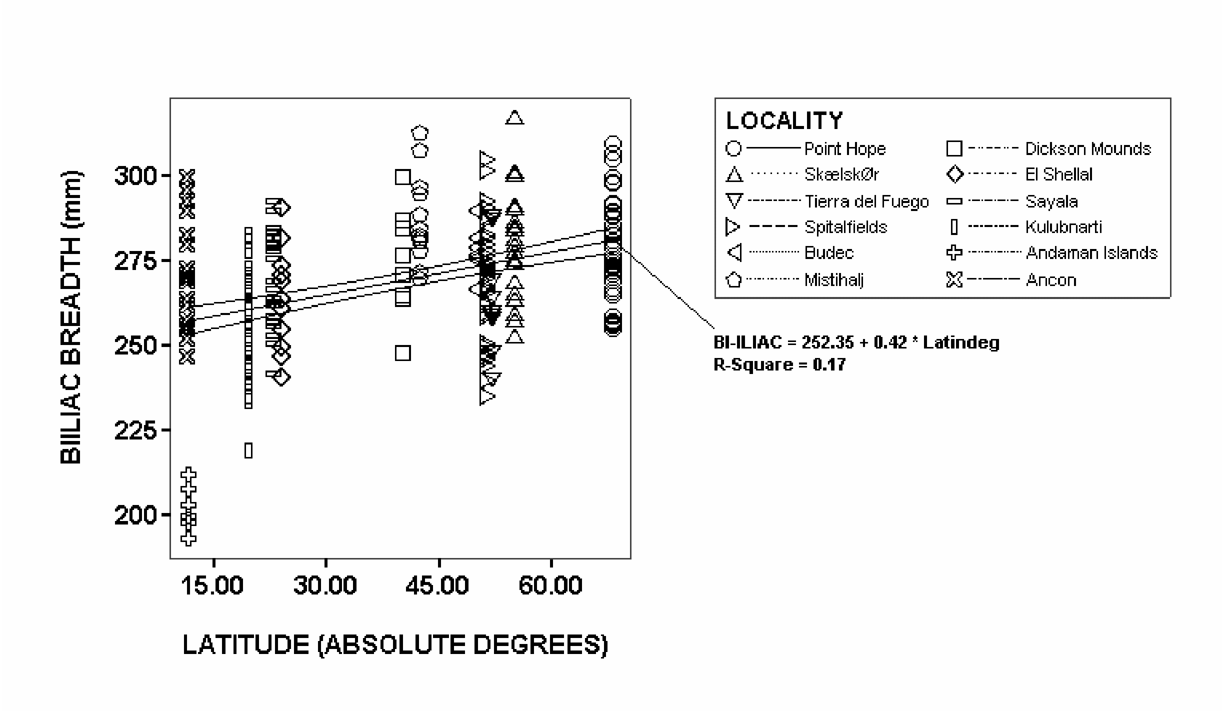


Figure 3.17: Biiliac breadth vs. latitude, sample means plotted (males)

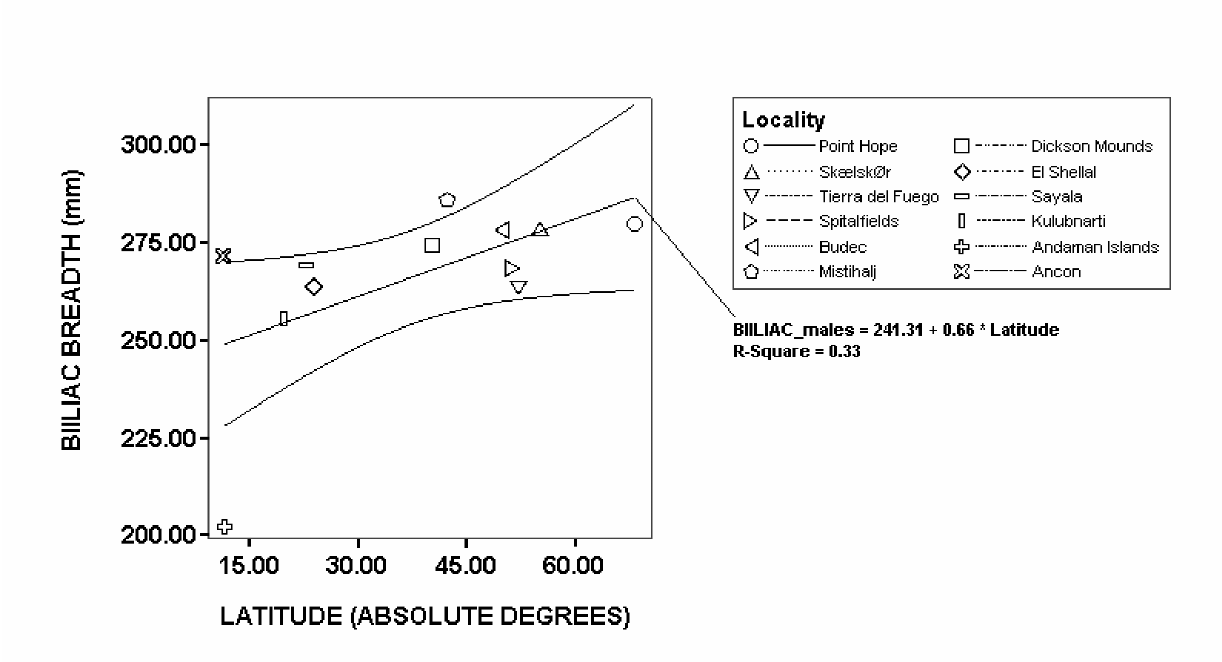


Figure 3.18: Transverse pelvic inlet vs. latitude, all data points plotted (males)

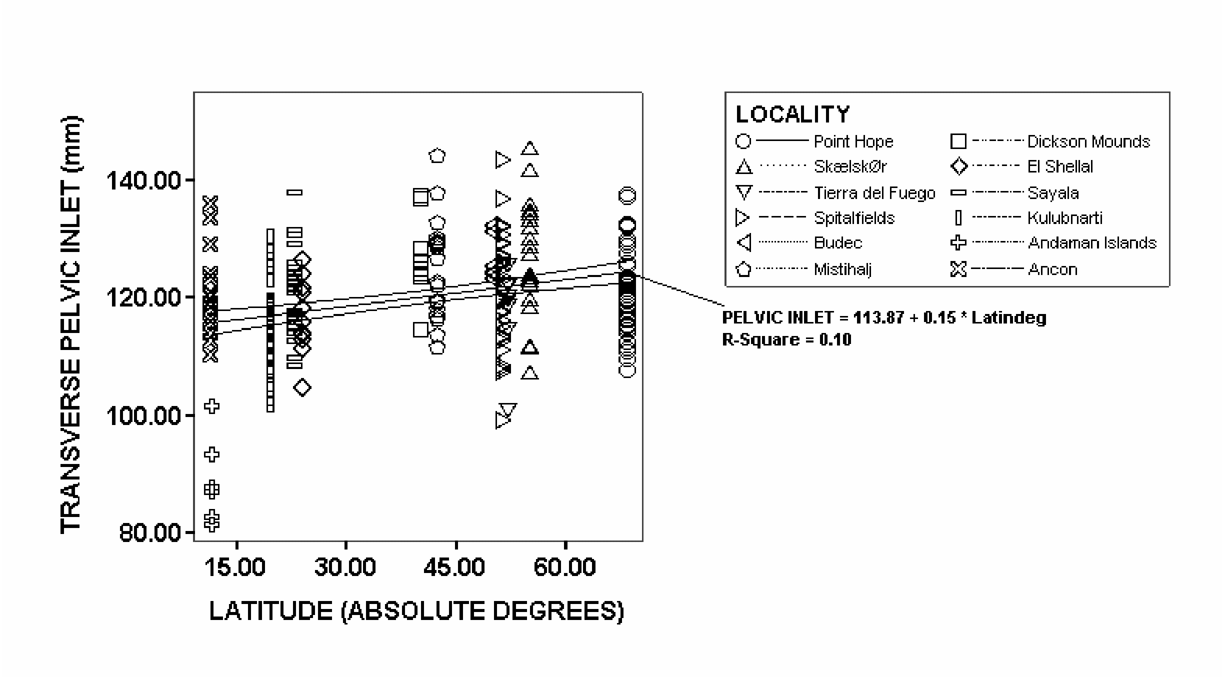


Figure 3.19: Transverse pelvic inlet vs. latitude, sample means plotted (males)

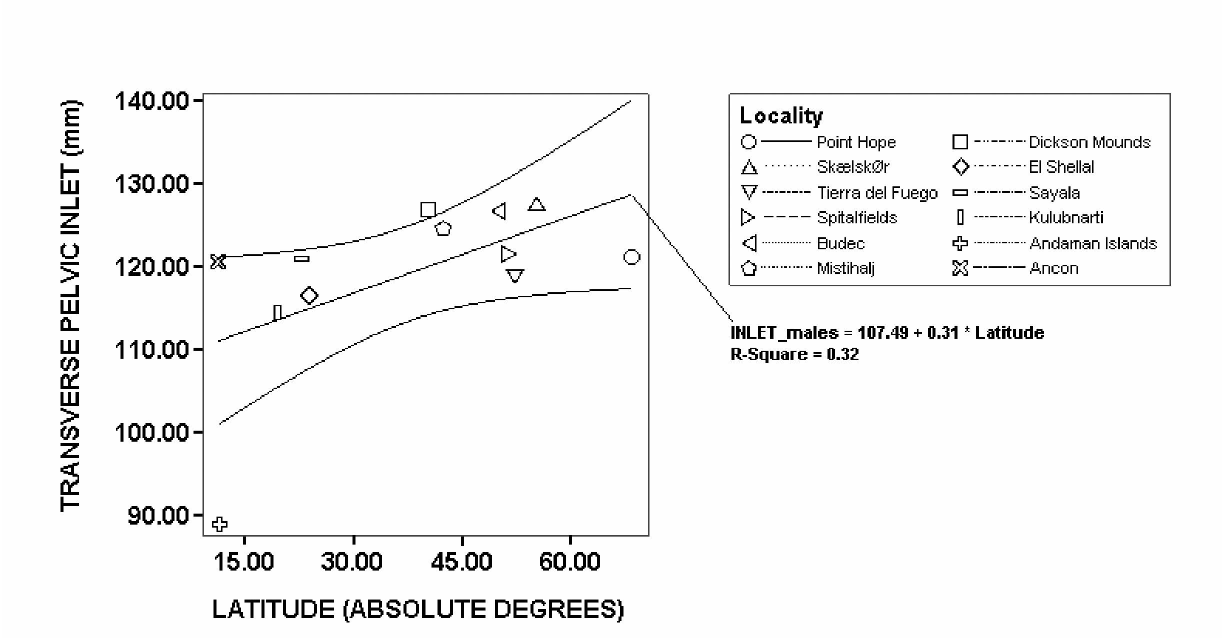


Figure 3.20: Transverse pelvic midplane vs. latitude, all data points plotted (males)

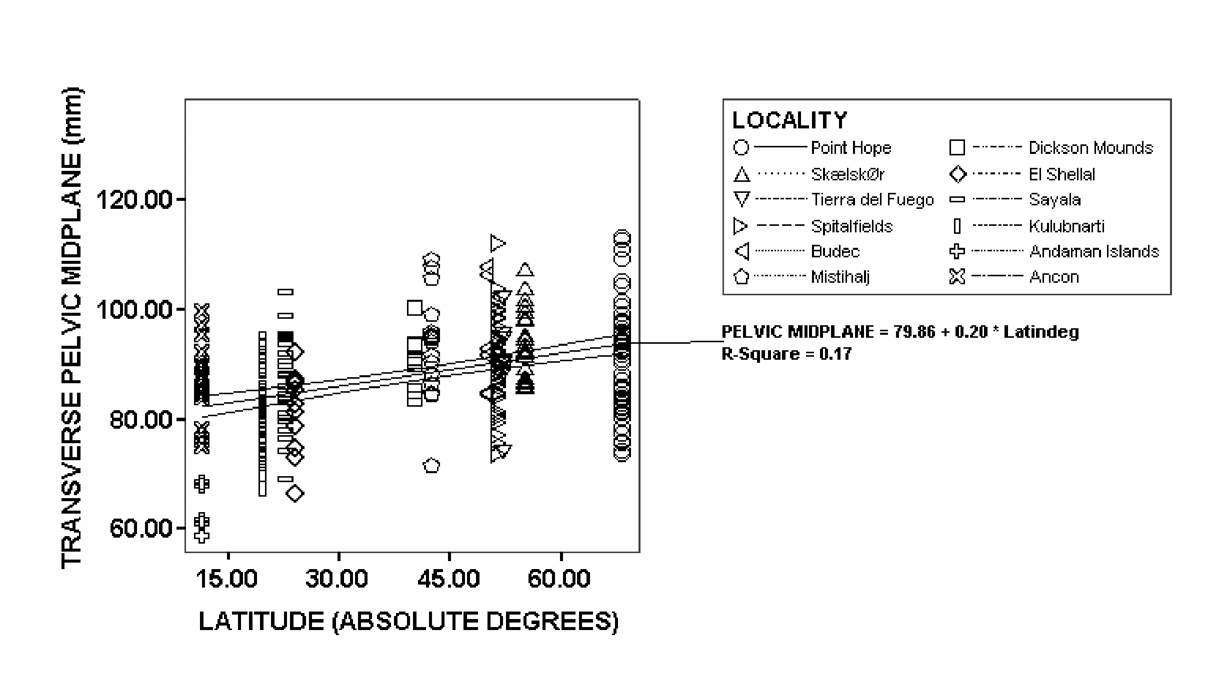


Figure 3.21: Transverse pelvic midplane vs. latitude, sample means plotted (males)

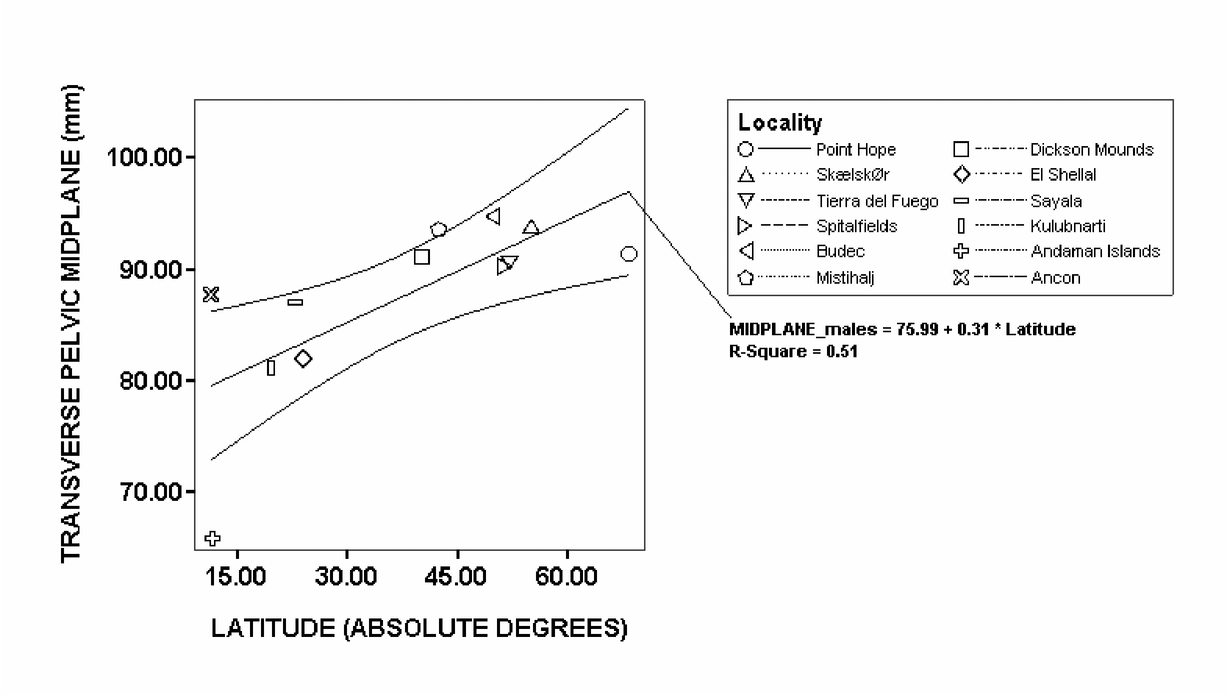


Figure 3.22: Sagittal pelvic inlet vs. latitude, all data points plotted (males)

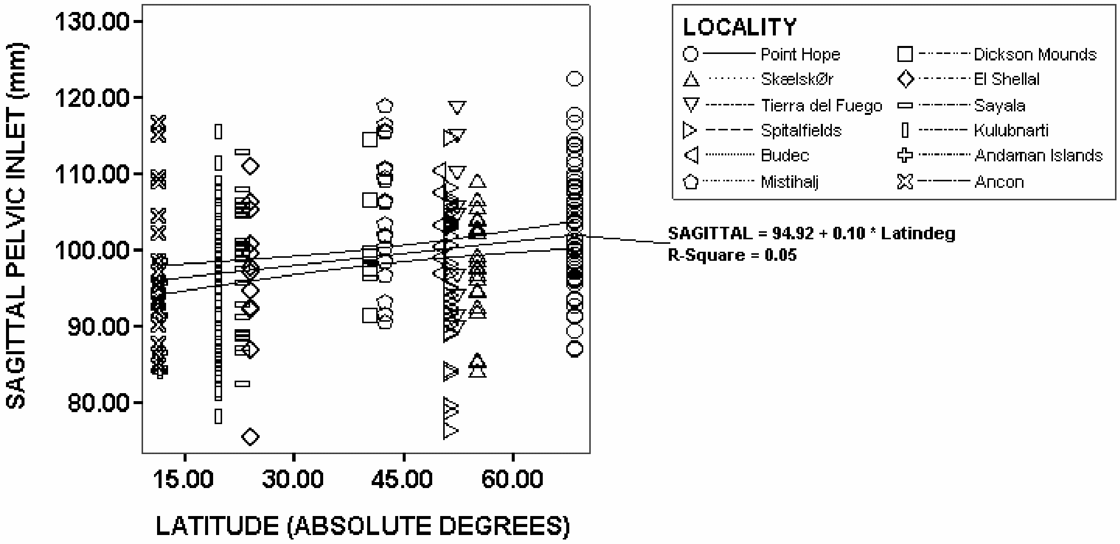
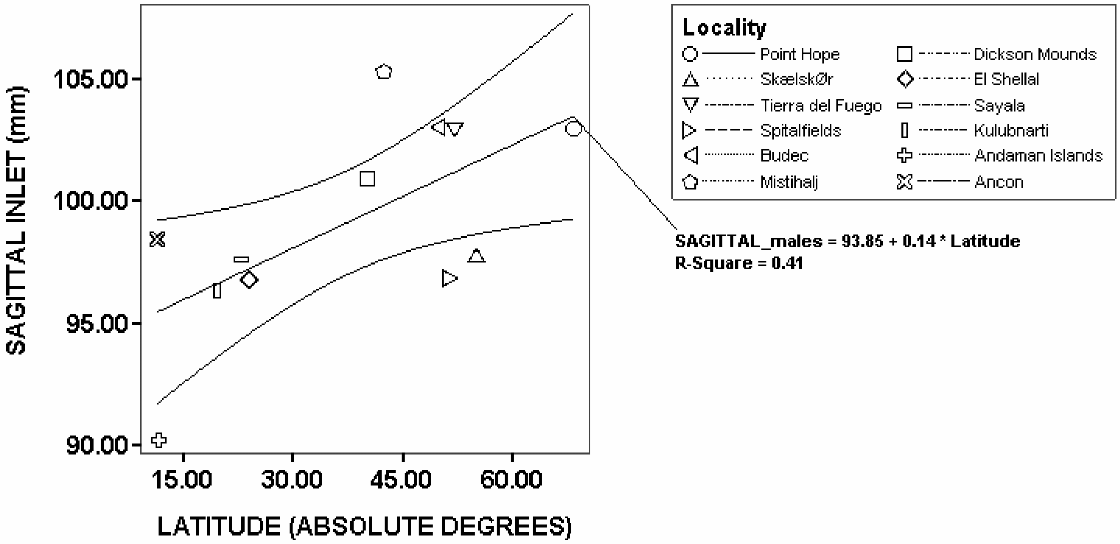


Figure 3.23: Sagittal pelvic inlet vs. latitude, sample means plotted (males)



Correlations with biiliac breadth

A second question investigated in this chapter is whether biiliac breadth is strongly correlated with the other transverse measures of the pelvis, in particular the measurements that are most significant for obstetrics. In order to answer this question, biiliac breadth was plotted against the transverse diameters of the pelvic inlet, pelvic midplane, and pelvic outlet. Table 3.5 summarizes the correlations of biiliac breadth with other pelvic variables. It was not necessary to apply a Bonferroni correction due to the high statistical significance ($p < 0.001$) associated with the correlation coefficients. Figures 3.24, 3.25, and 3.26 show the results for females. As can be seen in Table 3.5 and Figure 3.24, the correlation of biiliac breadth with the pelvic inlet diameter is high ($r = 0.802$, $p<0.000$). In Figure 3.25, the strength of the correlation drops off for the pelvic midplane diameter ($r = 0.518$, $p<0.000$), and drops off even more for the pelvic outlet diameter ($r = 0.414$, $p<0.000$) (Figure 3.26).

There are most likely several reasons why the correlation between biiliac breadth and the transverse pelvic inlet diameter in females is so strong. First, there is a biomechanical relationship between the two measurements related to the attachment of the hip flexors (Ruff 1995). Second, from an obstetrical perspective, there is greater flexibility with the midplane and outlet dimensions, as these two measurements can change shape during labor due to the relaxation of pelvic ligaments (Tague 1986; Trevathan 1987; Abitbol 1996; Rosenberg and Trevathan 1996). In contrast, the pelvic inlet is a bony measurement that does not change shape during labor. Perhaps, it is this increased obstetric capacity that is hidden until the onset of labor that leads to a weaker correlation between biiliac breadth and the pelvic midplane and pelvic outlet.

When one examines the correlation between biiliac breadth and the AP diameters of the pelvis, there is also a statistically significant relationship between the measures. Figure 3.27 shows a plot of the biiliac breadth versus the sagittal pelvic inlet diameter. The correlation coefficient is lower than the transverse diameters ($r = 0.319$, $p < 0.000$), but the sagittal pelvic inlet is still statistically significantly correlated with biiliac breadth. The correlation coefficient is slightly higher for the AP midplane ($r = 0.456$, $p < 0.000$), see Figure 3.28**,** and AP outlet ($r = 0.400$, $p < 0.000$), plotted in Figure 3.29.

The results for males are similar to the results for females when biiliac breadth is correlated with the other transverse measurements of the pelvis. As can be seen in Figure 3.30, the correlation of biiliac breadth with the pelvic inlet diameter is also strong ($r = 0.769$, $p<0.000$). The results for the correlation of biiliac with the pelvic midplane diameter ($r = 0.499$, $p<0.000$) and pelvic outlet diameter ($r = 0.306$, $p<0.000$) are similar to the values for females (Figures 3.31 and 3.32). It appears that the relationship between biiliac breadth and the other transverse diameters of the pelvis does not differ greatly between the sexes. Biiliac breadth is correlated very strongly with the pelvic inlet diameter, biiliac breadth is correlated less strongly with the pelvic midplane diameter, and the weakest correlation is between biiliac breadth and the transverse diameter of the pelvic outlet. However, it should be noted that in both males and females when biiliac breadth is correlated with all three measures, the correlation is statistically significant ($p < 0.000$).

When biiliac breadth is plotted against the AP pelvic measurements in males, it is statistically significantly correlated with the sagittal inlet diameter ($r = 0.424$, $p < 0.000$), as plotted in Figure 3.33. Biiliac breadth is also statistically significantly correlated with the AP midplane diameter (r = 0.445, p < 0.000) and AP outlet diameter (r = 0.375, p < 0.000), as seen in Figures 3.34 and 3.35, respectively.

Table 3.5: Correlations with biiliac breadth

Pelvic Measurement		Females	Males
	Transverse Diameters		
Pelvic Inlet	correlation	0.802	0.769
	significance (2-tailed)	**0.000**	**0.000**
	N	277	265
Pelvic Midplane	correlation	0.518	0.499
	significance (2-tailed)	**0.000**	**0.000**
	N	277	263
Pelvic Outlet	correlation	0.414	0.306
	significance (2-tailed)	**0.000**	**0.000**
	N	277	264
	Anteroposterior Diameters		
Sagittal Inlet	correlation	0.319	0.424
	significance (2-tailed)	**0.000**	**0.000**
	N	275	263
AP Midplane	correlation	0.456	0.445
	significance (2-tailed)	**0.000**	**0.000**
	N	255	251
AP Outlet	correlation	0.400	0.375
	significance (2-tailed)	**0.000**	**0.000**
	N	234	237

Figure 3.24: Transverse pelvic inlet vs. biiliac breadth (females)

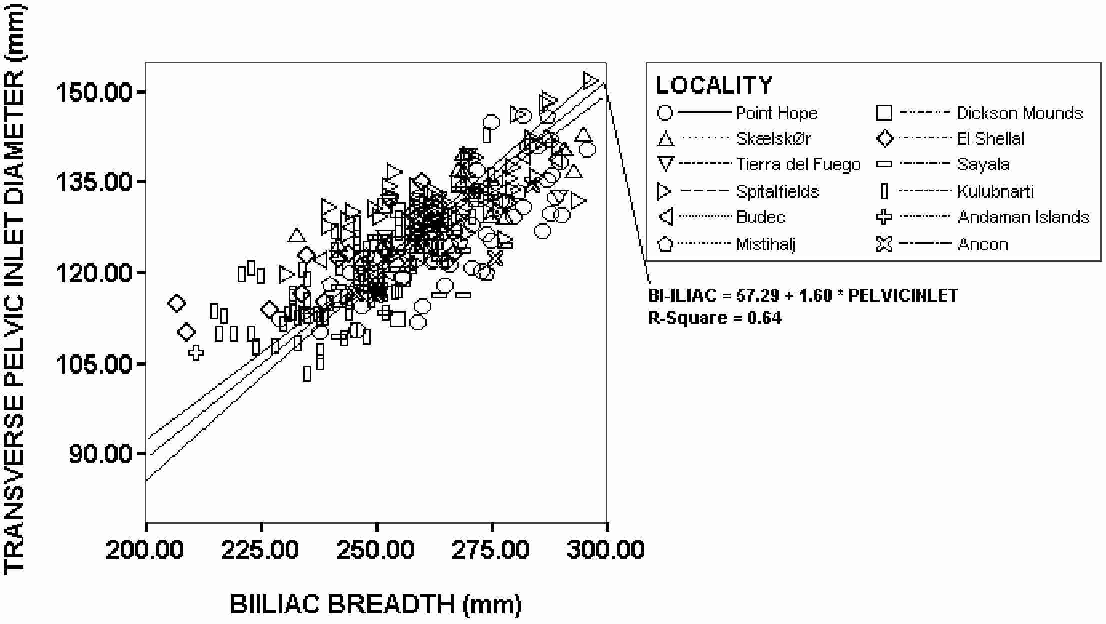


Figure 3.25: Transverse pelvic midplane vs. biiliac breadth (females)

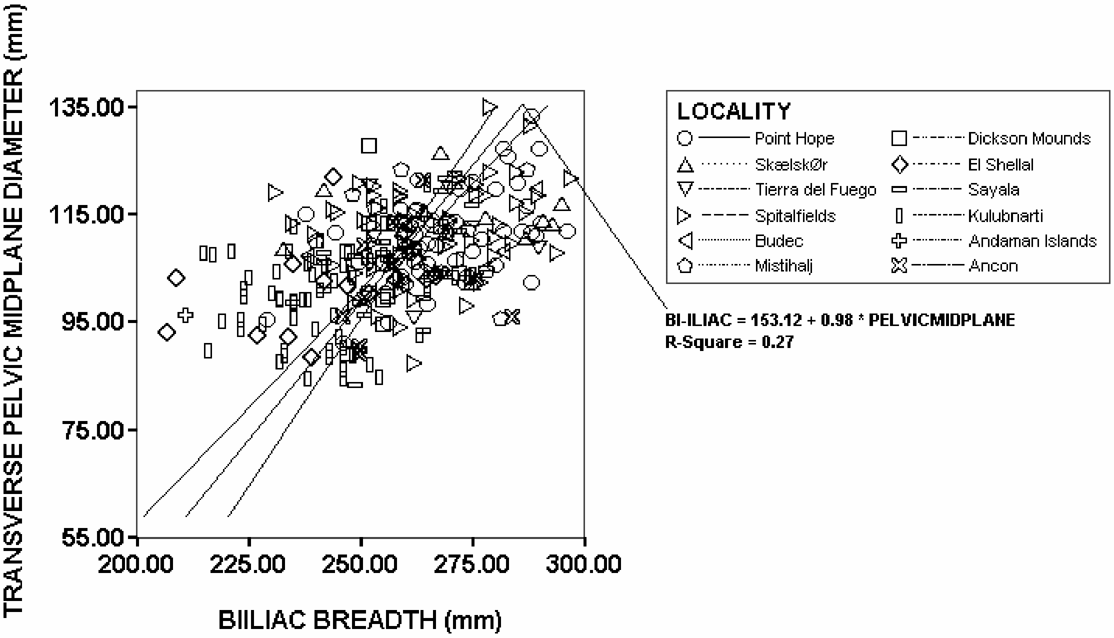


Figure 3.26: Transverse pelvic outlet vs. biiliac breadth (females)

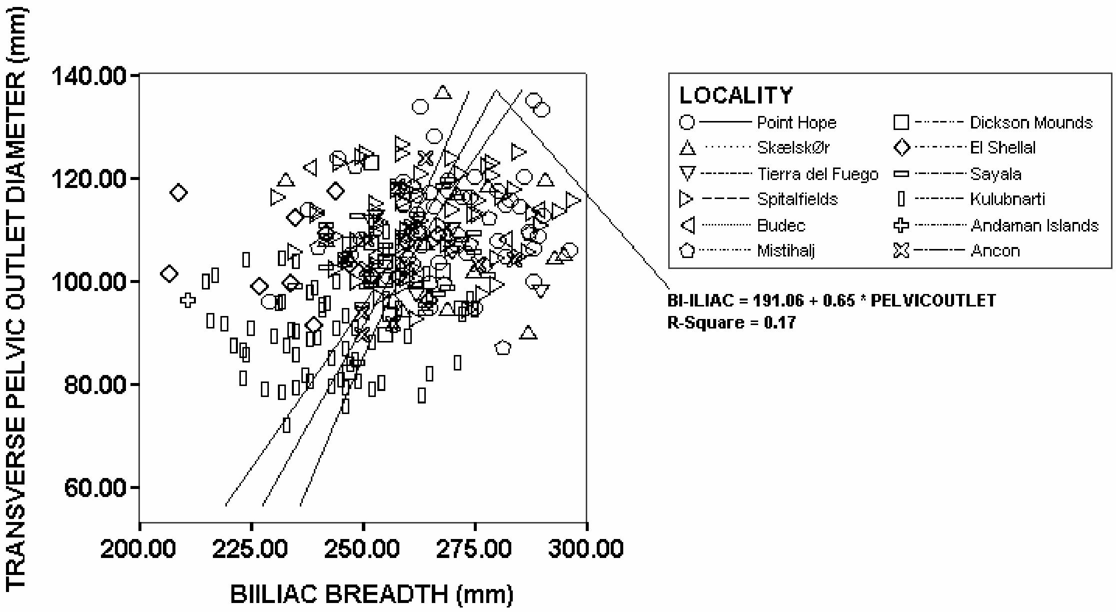


Figure 3.27: Sagittal pelvic inlet diameter vs. biiliac breadth (females)

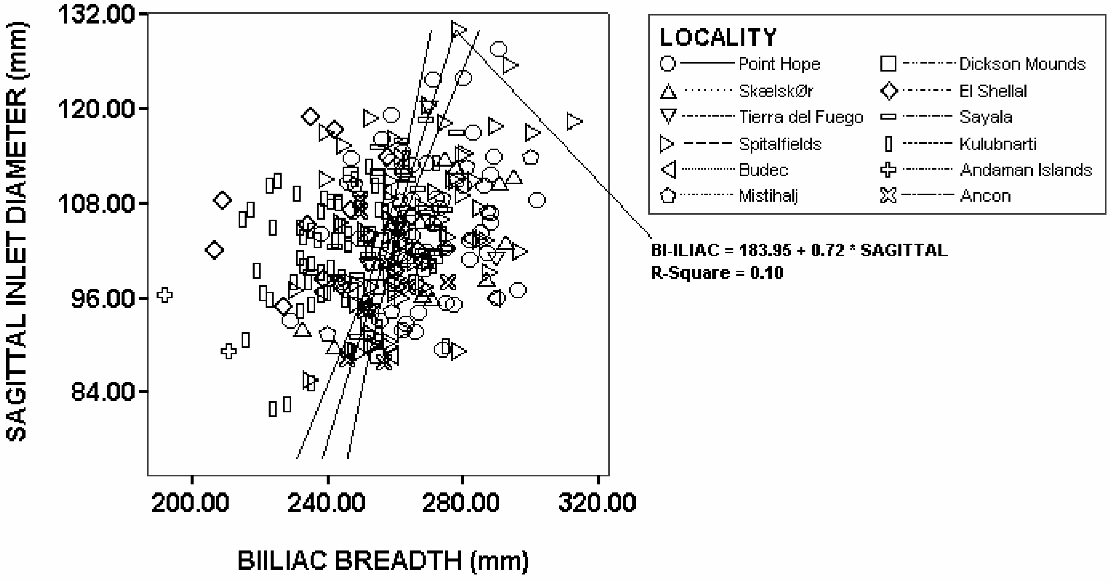


Figure 3.28: AP midplane diameter vs. biiliac breadth (females)

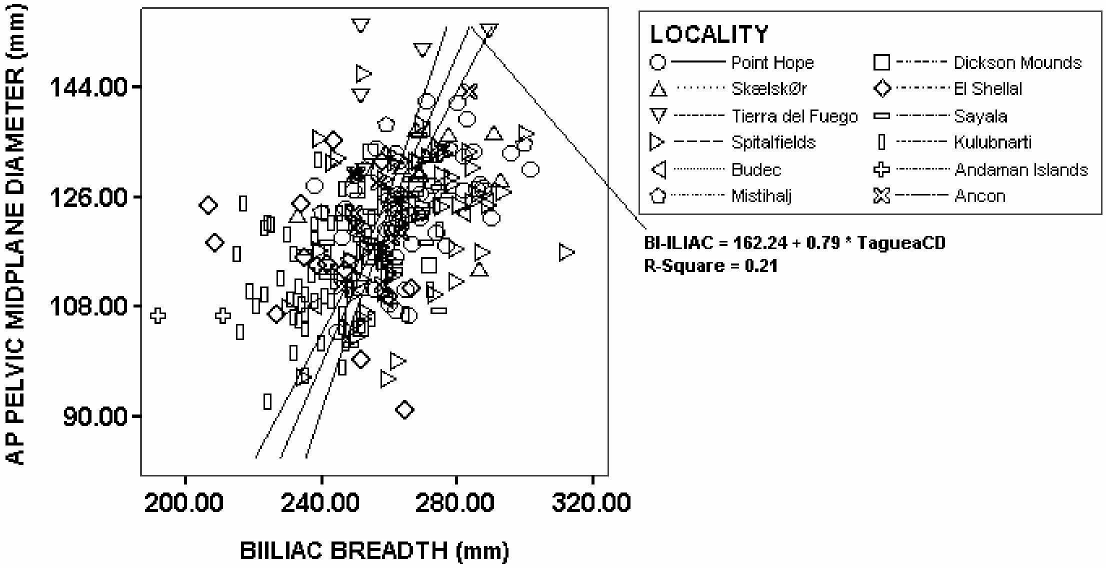


Figure 3.29: AP outlet diameter vs. biiliac breadth (females)

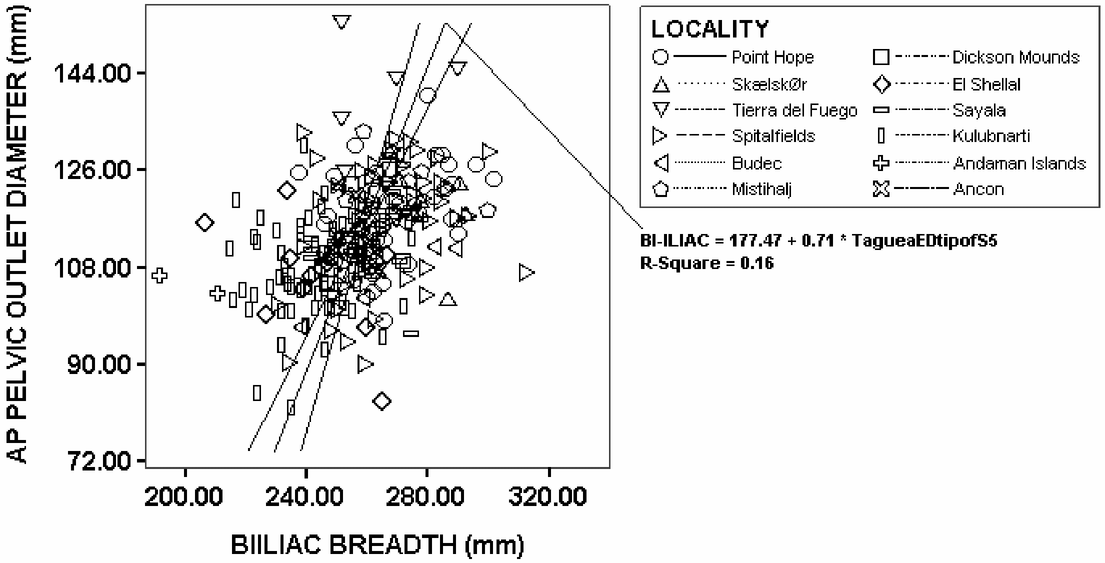


Figure 3.30: Transverse pelvic inlet vs. biiliac breadth (males)

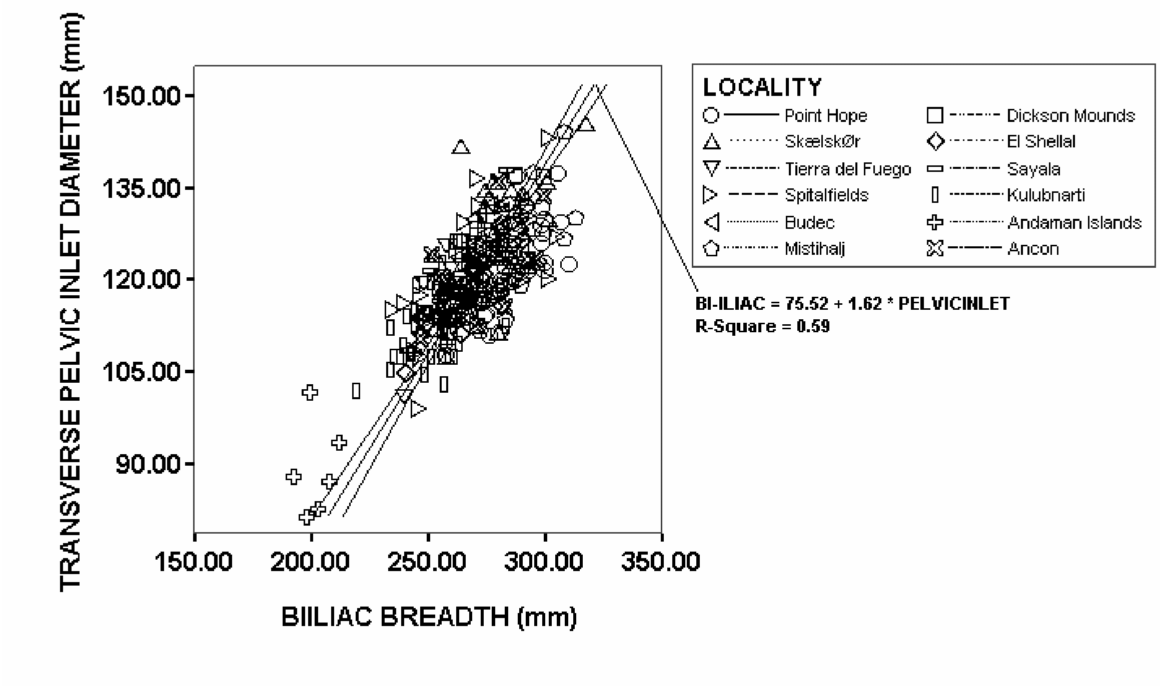


Figure 3.31: Transverse pelvic midplane vs. biiliac breadth (males)

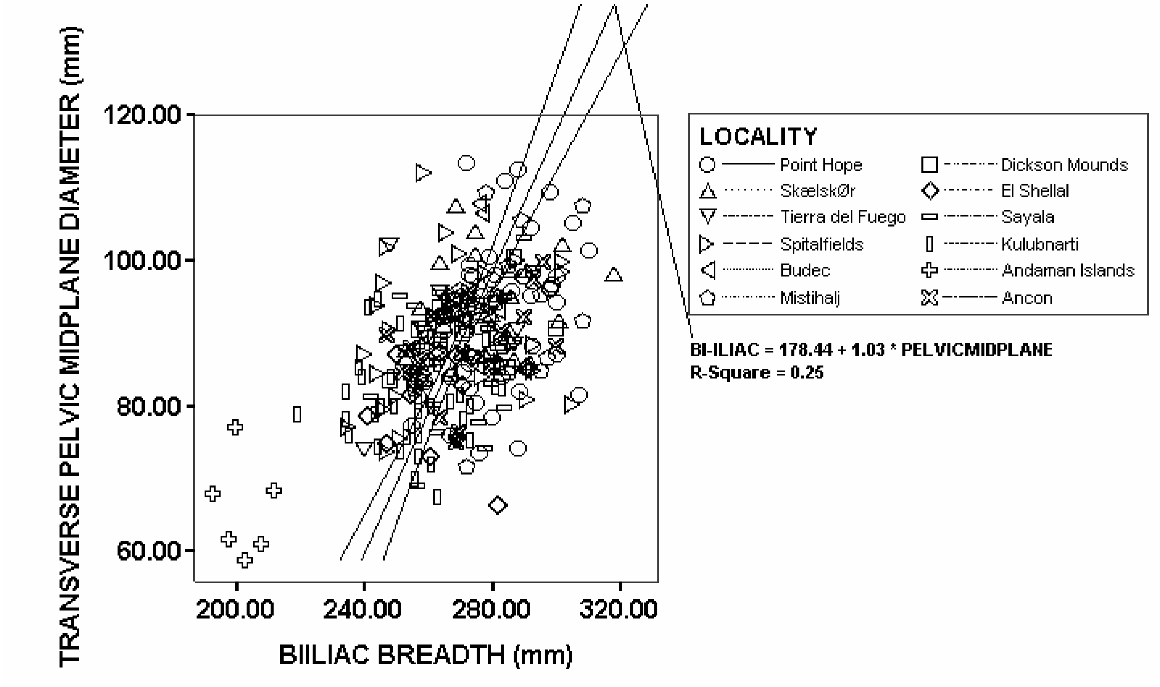


Figure 3.32: Transverse pelvic outlet vs. biiliac breadth (males)

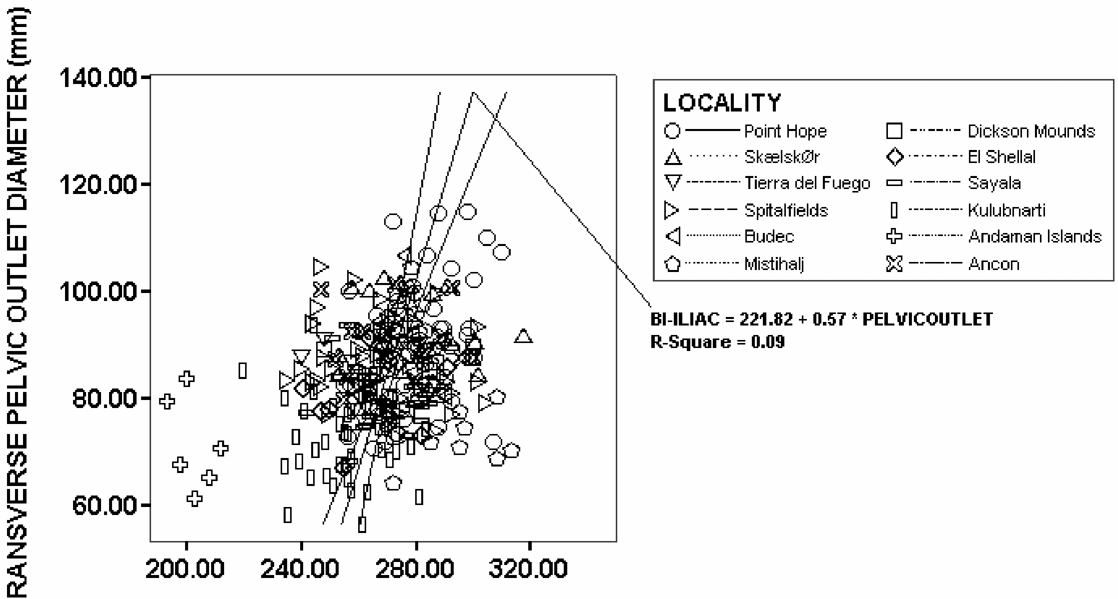


Figure 3.33: Sagittal pelvic inlet vs. biiliac breadth (males)

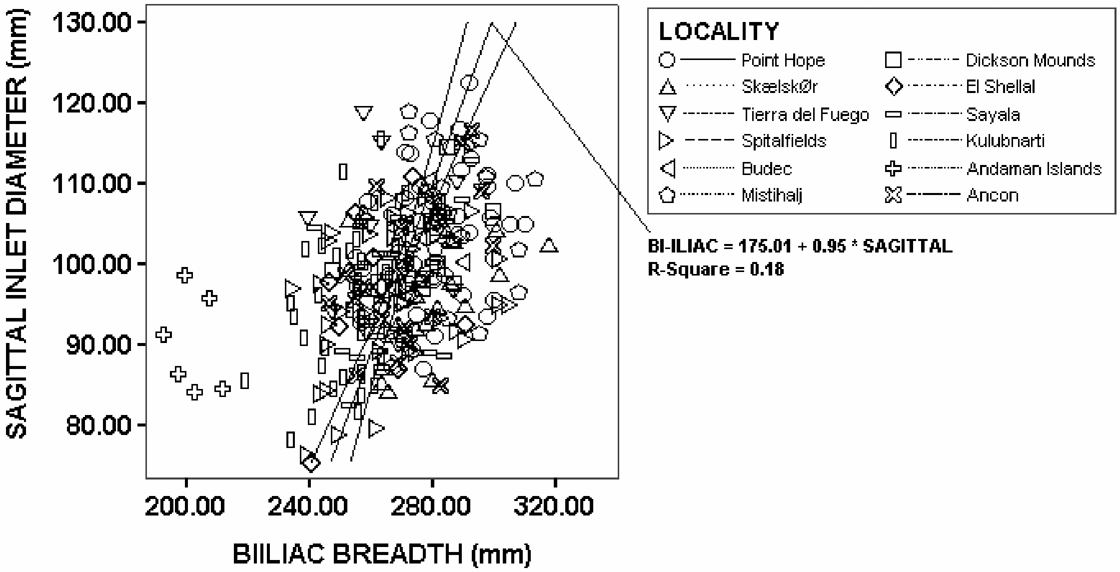


Figure 3.34: AP midplane diameter vs. biiliac breadth (males)

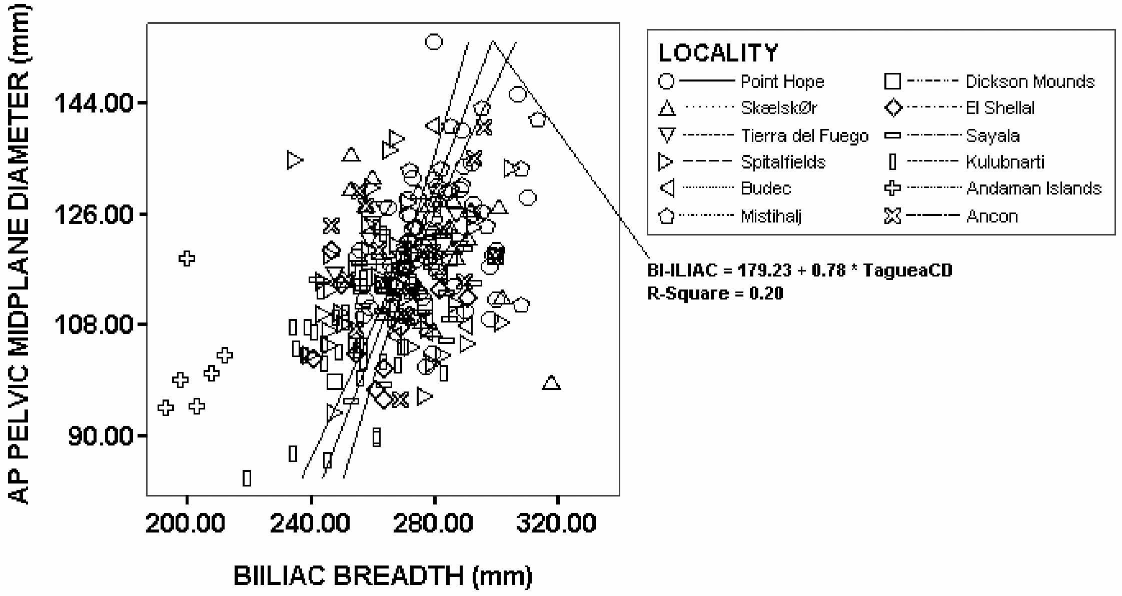
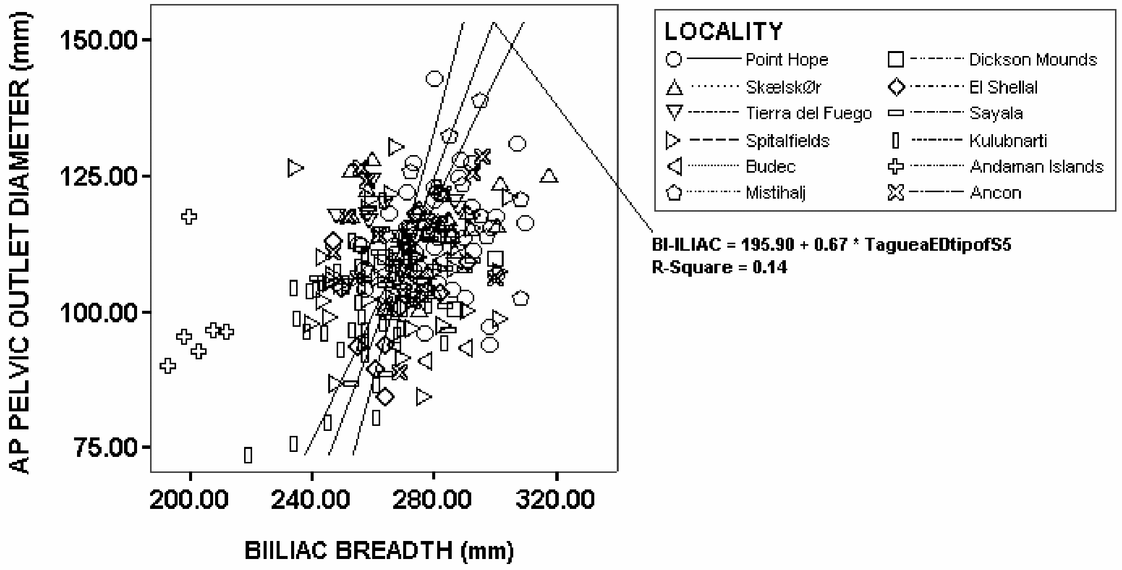


Figure 3.35: AP outlet diameter vs. biiliac breadth (males)



Brachial and crural indices

Although the focus of this study has been testing Bergmann's Rule as it applies to the pelvis, it is also worth noting limb proportions and investigating Allen's Rule on the same dataset. Allen's Rule (1877) states that animals tend to have smaller peripheral body parts in colder climates than animals in warmer climates. As Allen was speaking more generally about all animal species, "peripheral body parts" refers to bill or wing size in birds, tail length, or limb size/length in a variety of animals. In the context of humans, biological anthropologists have interpreted Allen's Rule in terms of limb proportions, whereby cold climate populations tend to have shorter extremities relative to their height than warm climate populations (Trinkaus 1981; Holliday 1995; 1997a). As with Bergmann's Rule, this is thought to be related to the body's ability to retain or dissipate heat. In a cold climate it is more advantageous to have shortened distal limb segments, and in a hot climate it is more advantageous to have elongated distal limb segments. Therefore, one would expect a lower brachial index (radius length divided by humeral length) and crural index (tibial length divided by femoral length) in a cold climate and a higher brachial and crural index in a hot climate.

Table 3.6 lists the correlation between brachial and crural indices and measures of climate in both males and females. Both brachial and crural indices for both males and females are statistically significantly correlated with latitude, MTCM, and MTWM. All p-values are < 0.01. In all cases the correlation coefficients are higher for crural indices than for brachial indices, and in all cases females have higher correlation coefficients than males. These results indicate that for the samples included in this study, the lower limb adheres more closely to the predictions of Allen's Rule than the upper limb, and females follow the predictions of Allen's Rule more closely than males.

Figure 3.36 is a boxplot indicating the brachial indices for males and females by locality, and Figure 3.37 is a boxplot of crural indices for males and females by locality. Both males and females have higher brachial and crural indices as the samples increase in temperature, which is to be expected. A notable exception to this pattern are the males from the Tierra del Fuego sample, which have a higher index than would be expected for the cold climate (at least relative to the Point Hope and SkælskØr sample). Unfortunately, the Tierra del Fuego male sample is an extremely small sample size (N = 2 for the brachial index and N = 1 for the crural index), and therefore more data would be necessary to determine how representative these values are.

Table 3.6: Brachial and crural indices for males and females, correlated with climate

		Females	**Males**
	Brachial Indices		
Latitude	correlation	-0.500	-0.445
	significance (2-tailed)	**0.000**	**0.000**
	N	246	233
MTCM	correlation	0.389	0.336
	significance (2-tailed)	**0.000**	**0.000**
	N	246	233
MTWM	correlation	0.505	0.453
	significance (2-tailed)	**0.000**	**0.000**
	N	246	233
	Crural Indices		
Latitude	correlation	-0.624	-0.568
	significance (2-tailed)	**0.000**	**0.000**
	N	251	235
MTCM	correlation	0.571	0.508
	significance (2-tailed)	**0.000**	**0.000**
	N	251	235
MTWM	correlation	0.617	0.589
	significance (2-tailed)	**0.000**	**0.000**
	N	251	235

Figure 3.36: Brachial indices

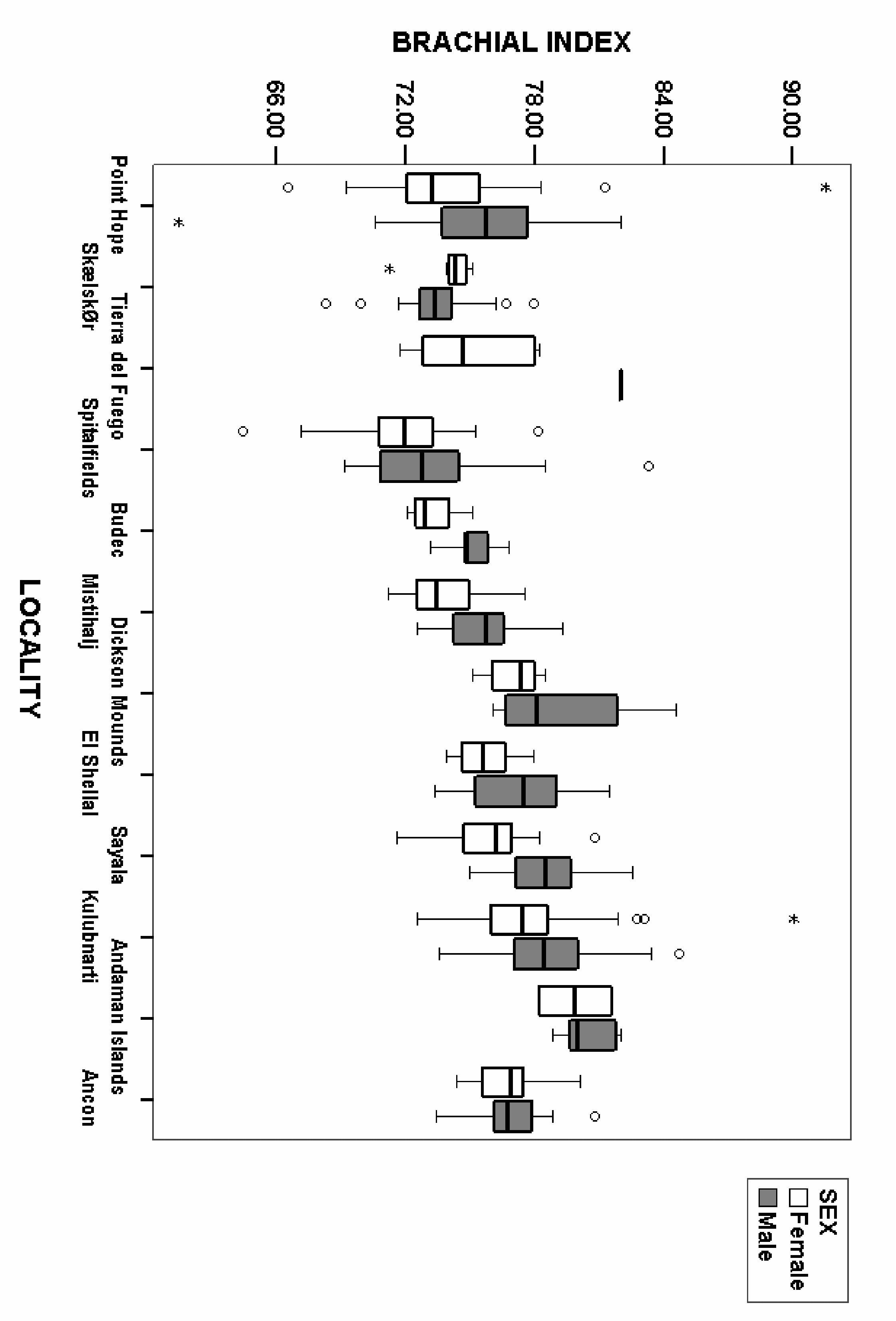
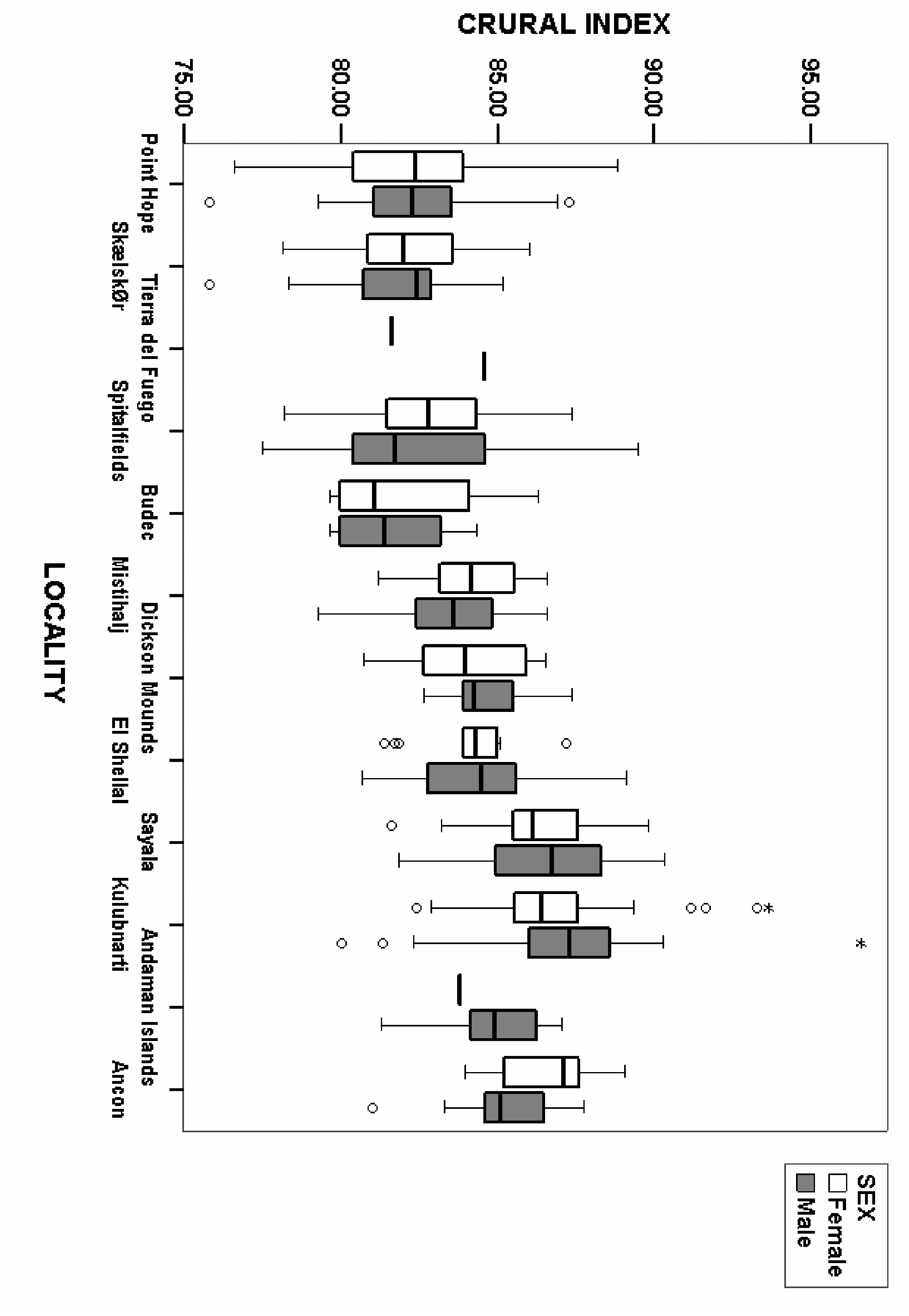


Figure 3.37: Crural indices



Conclusions

This chapter examined the relationship between climate and the dimensions of the obstetrical pelvis. The results of partial correlation analysis correcting for body size indicate that this relationship is stronger, and more consistent, for transverse measurements of the pelvis than for AP measurements, especially for females. These findings support the work of Weaver (2002), who also found that transverse pelvic measurements show more geographic patterning than AP pelvic measurements. It is unclear why the AP pelvic dimensions are not as variable with climate as transverse pelvic dimensions. Weaver (2002) suggests that sagittal variation is biomechanically constrained, because sagittally "deep" hips would be difficult to balance during bipedal locomotion. It should also be noted that when the pelvis is in anatomical position, the "AP" diameters are not truly AP, but rather on an oblique (Figure 2.2 in Chapter 2). If sagittal pelvic measurements are on an oblique, then they are not going to have the same impact as a parameter of body depth that transverse measurements would have as a parameter of body breadth, with regard to the cylindrical model (Ruff 1994).

The most striking difference in the results between males and females is that the transverse pelvic inlet is statistically significantly correlated with latitude and MTWM after body size correction in females. However, in males the pelvic inlet, corrected for body size, is not statistically significantly correlated with any of the same three measures of climate. These results are potentially indicative of a relationship between obstetrics and climate for the pelvic inlet, in particular because these correlations are not present in males at a statistically significant level the way they are in females.

It should also be noted, with regard to the partial correlation analysis results, that in most cases the correlation coefficient is not very high. The highest correlation coefficient prior to size correction is -0.555, and the highest correlation coefficient after size correction is -0.445, in both cases for the transverse pelvic outlet and latitude in females. However, there are several points to keep in mind despite the low correlation coefficients. First, as the purpose of a partial correlation analysis is to "partial out" the variance related to another intervening variable, it is expected that the correlation coefficients will be lower after adjusting for body size in this type of analysis. As a result of the lower correlation coefficients, the results here have been interpreted with a greater reliance on the statistical significance of various correlations rather than the magnitude of the Pearson r itself. Second, as a statistically significant p-value is driven in part by the large sample size utilized in this study, this lends greater support to the idea that there is a high probability of association between particular pelvic variables and climate, and it is unlikely that the association between these pelvic variables and climate is random. However, given the reliance of this study on the interpretation of statistically significant p-values, it was important to make an adjustment for the several simultaneous tests of significance conducted in this study. In response to this problem, the author has applied what is considered to be the most conservative multiple comparisons correction procedure, the standard Bonferroni, for adjusting the group-wide Type I error rate (Rice 1989; Sokal and Rohlf 1995). Therefore, in light of the lower correlation coefficients and multiple tests, the appropriate steps have been taken to reduce the probability of rejecting a true false null, and statistically significant tests can be interpreted to be robust.

The second portion of this chapter investigated the relationship between biiliac breadth and the other transverse pelvic measurements, in particular the pelvic inlet, pelvic midplane, and pelvic outlet diameters. The results indicate a very strong correlation of biiliac breadth with the pelvic inlet, a less strong relationship with the pelvic midplane, and a weaker (but nonetheless still statistically significant) correlation of biiliac breadth with the pelvic outlet. The results were similar for both males and females. These results are significant because if selection is acting on biiliac breadth, this could in turn affect the other transverse diameters of the pelvis.

When the relationship between biiliac breadth and the AP measurements of the pelvis were examined, they were also found to be statistically significantly correlated with biiliac breadth, albeit with a lower correlation coefficient compared to the transverse measurements.

In the last section of this chapter brachial and crural indices were calculated for all of the samples. Both brachial and crural indices were statistically significantly correlated with latitude, MTCM, and MTWM. However, the lower limb adhered more closely to the predictions of Allen's Rule than the upper limb, as it was more strongly correlated with climatic variables. Also, brachial and crural indices in females had a higher correlation coefficient when correlated with climatic variables than the comparable values in males.

A consistent pattern in all of the interpretations of the data (descriptive statistics, partial correlation analysis, and correlations with biiliac breadth) is the uniqueness of the Andaman Islanders sample. With the descriptive statistics the Andaman Islanders are smaller in almost every measurement compared to the other samples (even the Ancon sample which is from the same latitude). When pelvic measurements are plotted against temperature variables, and biiliac breadth is plotted against other pelvic measurements, the Andaman Islands sample is far removed from the regression line for both males and females. The uniqueness of the Andaman Islanders sample will be explored further in the next chapter.

In conclusion, the results here indicate that there is a statistically significant relationship between the obstetrical diameters of the human bony pelvis and climate. This relationship is consistent when different quantifications of climate are utilized (latitude, mean temperature of the coldest month, and mean temperature of the warmest month). Furthermore, the relationship between climatic measures and the obstetrical pelvis remains statistically significant even after accounting for body size. As it appears that certain variables have a stronger climatic signal than others, the multivariate analysis that follows in the next chapter will further explore the relationship between climate and the obstetrical pelvis.

CHAPTER 4

MULTIVARIATE RESULTS AND ANALYSIS

Introduction

This chapter presents the findings of multivariate statistical analysis for a pooled sample of all of the male and female pelves in the study. Multivariate statistical techniques were utilized in order to extract information that results from analyzing a large number of variables simultaneously. The first portion of this chapter presents the results of principal components analysis (PCA) on the raw variables created from the pelvic measurements collected in this study. The second portion of this chapter examines the relationship between the principal components extracted and the same measures of climate utilized in the previous chapter (latitude, mean temperature of the coldest month, and mean temperature of the warmest month). The purpose of this analysis is to examine the correlation between pelvic size/shape and climate in multivariate space.

Principal components analysis

The raw pelvic variables were subjected to principal components analysis based on the variance-covariance matrix (VCM). However, because the measurements were collected from archaeologically-derived collections, in several cases it was not possible to obtain all of the desired measurements from an individual due to postmortem damage, lost element(s), or a pathological lesion leading to an unusual pelvic morphology. For the following analyses, any individual who lacked a measurement was excluded from that analysis. On the first attempt at PCA of the complete dataset, many of the individuals were eliminated from the analysis due to missing values in the data. It was identified that there were two variables which were the most commonly missing due to damage to the sacrum, the AP outlet (Figure 2.2) and the posterior outlet (Figure 2.5). The analysis was therefore repeated excluding these two variables. This led to an increased sample size, an increased percentage of variance explained on the first two principal components, but did not change the underlying patterns of variance described in this chapter. This process resulted in a multivariate dataset with a large number of pelvic variables (29) and a robust sample size (473 individuals). The only other variables from the entire dataset that were excluded were long bone measurements (in order to focus the analysis on pelvic variation), and the angle measurements, which cannot be analyzed on a variance-covariance matrix. The remaining number of variables and resulting sample size is comparable to or larger than other multivariate studies of pelvic morphology (Steudel 1981; Tague 1986; Arsuaga and Carretero 1994; Bouhallier and Berge 2006).

The pelvic variables included for multivariate analysis are listed in Table 4.1. The eigenvector coefficients and percentage of the total variance explained are presented for the first five principal components. The first principal component accounts for 42% of the total variance. All of the eigenvector coefficients on PC1 are positive except for sacral width (-.096). The principal component (PC1) scores along this axis are highly correlated with the geometric mean ($r = 0.932$, $p < 0.000$), indicating that PC1 is a size component (see Figure 4.1). It should be noted that although the Andaman Islanders are the smallest data points on the plot, they do not appear to be scaling differently (i.e., are not removed from the regression line) compared to the data points for the other samples.

The second principal component accounts for 22% of the variance. PC2 almost completely segregates the sexes. As can be seen in Figure 4.2, almost all of the males have negative scores for factor 2, and almost all of the females have positive scores for factor 2. Overall there is an extremely clean separation between the sexes. It should also be noted that according to Figure 4.2 females appear to be more constrained in their pelvic shape than males. With regard to the signs of the eigenvectors, PC2 contrasts what can be characterized as “size” variables (biiliac breadth, acetabular dimensions, true pelvis depth, etc.) which load negatively with what can be characterized as “obstetric variables” (transverse pelvic inlet, transverse pelvic midplane, transverse pelvic outlet, linea terminalis, sciatic notch breadth, etc.) which load positively. These results are consistent with the findings of Arsuaga and Carretero (1994)**,** who conducted a multivariate study of the human pelvis in order to investigate patterns of sexual dimorphism (most of their measurements were utilized for this study). Arsuaga and Carretero (1994) also found a segregation of the sexes and a positive loading for obstetrical variables on PC2**.**

In this study, the scores for PC2 are statistically significantly correlated with the geometric mean ($r = 0.297$, $p < 0.000$), but with a much lower correlation coefficient compared to the first principal component (Figure 4.3). These results indicate that PC2 is in part a size component, but not nearly to the same extent as PC1.

The third and fourth principal components do not account for much of the remaining variance (5.8% and 4.3% respectively). The third principal component is not characterized by high factor loadings except for the “supra-acetabular auricular distance” (-0.581) and the “anterior inferior iliac spine to auricular surface” (-0.522). Both of these measurements are taken from the apex of the auricular surface to different points on the anterior inferior iliac spine (refer to Figure 2.11 in Chapter 2). Arsuaga and Carretero

(1994) found high loadings (but in the positive direction) for these same two variables on the third principal component. Arsuaga and Carretero (1994) also found high negative loadings for pubic length (-0.56) and for acetabulosymphyseal length (-0.43). They argue that PC3 is indicative of "morpho-functional constraints" involving the position of the acetabulae and sacro-iliac joint relative to pubic length. In effect, longer pubic bones are accompanied by a more anterior position of the auricular surface and sciatic notch relative to the acetabulae, while shorter pubic bones are accompanied by a more posterior position of the auricular surface and the sciatic notch with regard to the acetabulae. Although the data here indicate the opposite (in this case, positive) sign for the eigenvector loadings for pubic length variables, the loadings here (0.148 for pubic length and 0.050 for acetabulosymphyseal length) are not high enough to indicate the same type of morpho-functional contrast.

The fourth principal component is not characterized by high factor loadings with the notable exception of sacral width (0.799). This appears to be caused by the higher values for sacral width for the Point Hope and Kulubnarti samples, as discussed in the previous chapter.

Table 4.1: Principal components analysis on pelvic variables

Principal Components Analysis					
	Eigenvector Coefficient				
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Biiliac breadth	0.819	-0.174	0.163	-0.043	0.171
Transverse inlet	0.695	0.433	0.232	-0.208	0.247
Transverse midplane	0.285	0.776	0.377	0.069	0.233
Transverse outlet	0.221	0.731	0.420	0.056	0.104
Sagittal inlet	0.463	0.396	-0.367	0.317	-0.378
AP midplane	0.561	0.353	0.181	0.300	-0.442
Diagonal inlet	0.733	0.522	0.059	-0.194	0.032
Linea terminalis	0.690	0.630	-0.218	0.009	-0.076
Anterior midplane	0.754	0.298	0.200	0.056	-0.118
Posterior midplane	0.314	0.696	0.329	0.224	-0.112
Sacral width	-0.096	0.105	-0.100	0.799	0.366
Pubic length	0.819	0.219	0.148	-0.132	-0.087
Acetabulosymphyseal length	0.698	0.340	0.050	-0.207	-0.027
Arcuate chord	0.775	0.389	-0.282	0.122	-0.181
Arcuate line depth	0.229	0.679	-0.203	-0.222	0.230
Maximum iliac breadth	0.885	-0.199	0.019	-0.068	0.140
Iliac height	0.739	-0.387	-0.071	0.062	-0.030
Transverse acetabular diameter	0.713	-0.570	0.120	-0.064	-0.020
Vertical acetabular diameter	0.701	-0.579	0.087	0.039	0.038
Coxal height	0.784	-0.450	-0.011	-0.044	-0.055
Ischial length	0.774	-0.483	0.028	0.069	0.026
Articular ischial length	0.737	-0.546	0.073	0.198	0.089
True pelvis depth	0.763	-0.547	0.092	0.041	-0.017
Supra-acetabular auricular distance	0.657	0.270	-0.581	-0.073	0.117
Anterior inferior iliac spine to auricular surface	0.725	0.165	-0.522	-0.007	0.230
Anterior inferior iliac spine to greater sciatic notch	0.763	-0.384	-0.110	0.100	0.234
Auricular length	0.616	-0.339	0.286	0.134	0.011
Sciatic notch breadth	0.212	0.674	-0.124	-0.017	0.020
Sciatic notch height	0.605	-0.270	-0.046	-0.204	-0.313
% Total Variance	42.46	22.20	5.81	4.26	3.48

Figure 4.1: Scatter plot of the geometric mean vs. PC1

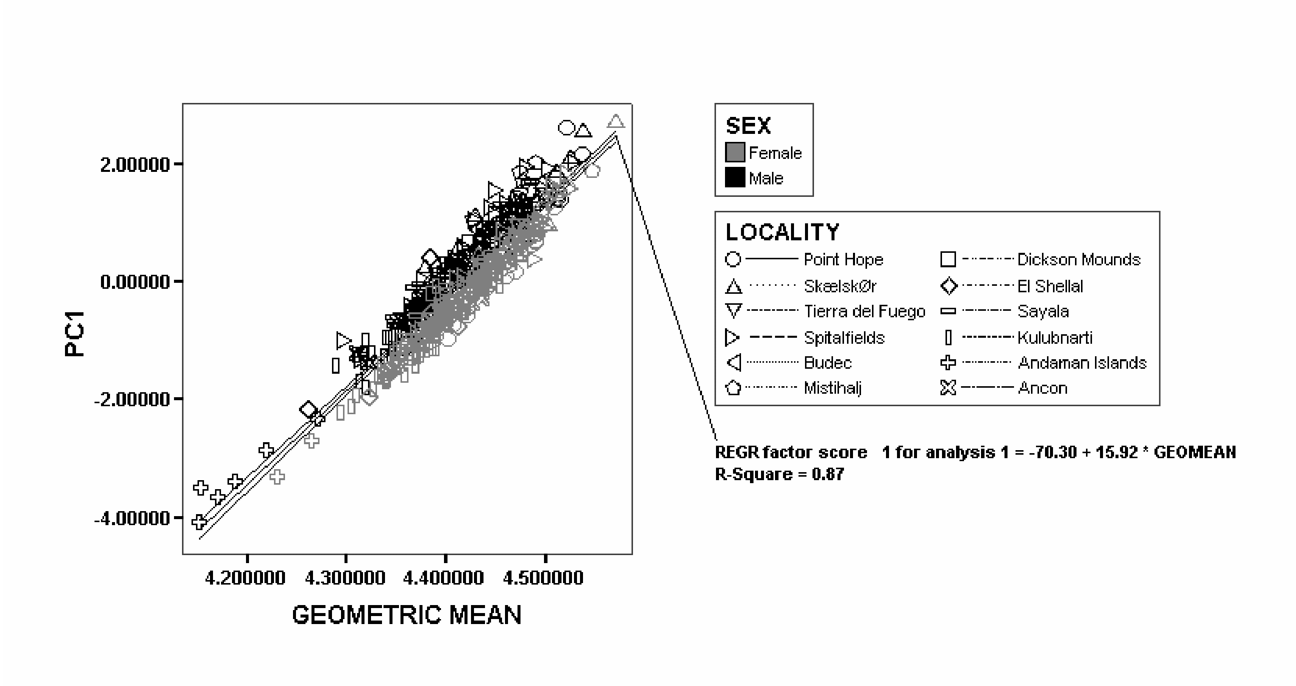


Figure 4.2: Scatter plot of PC1 vs. PC2

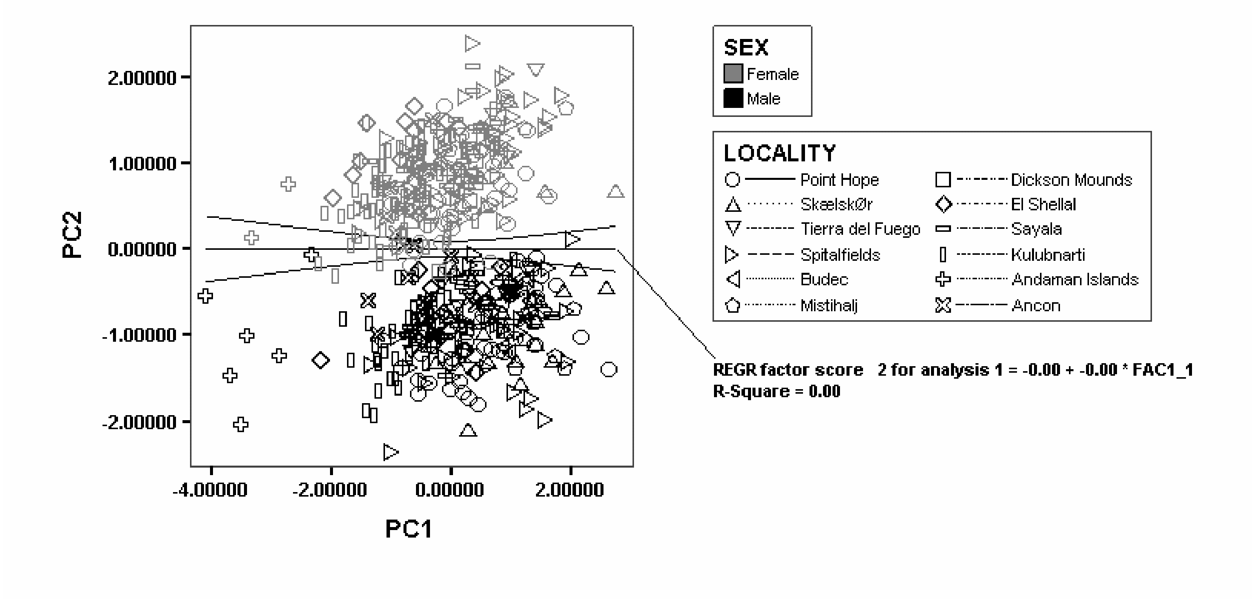
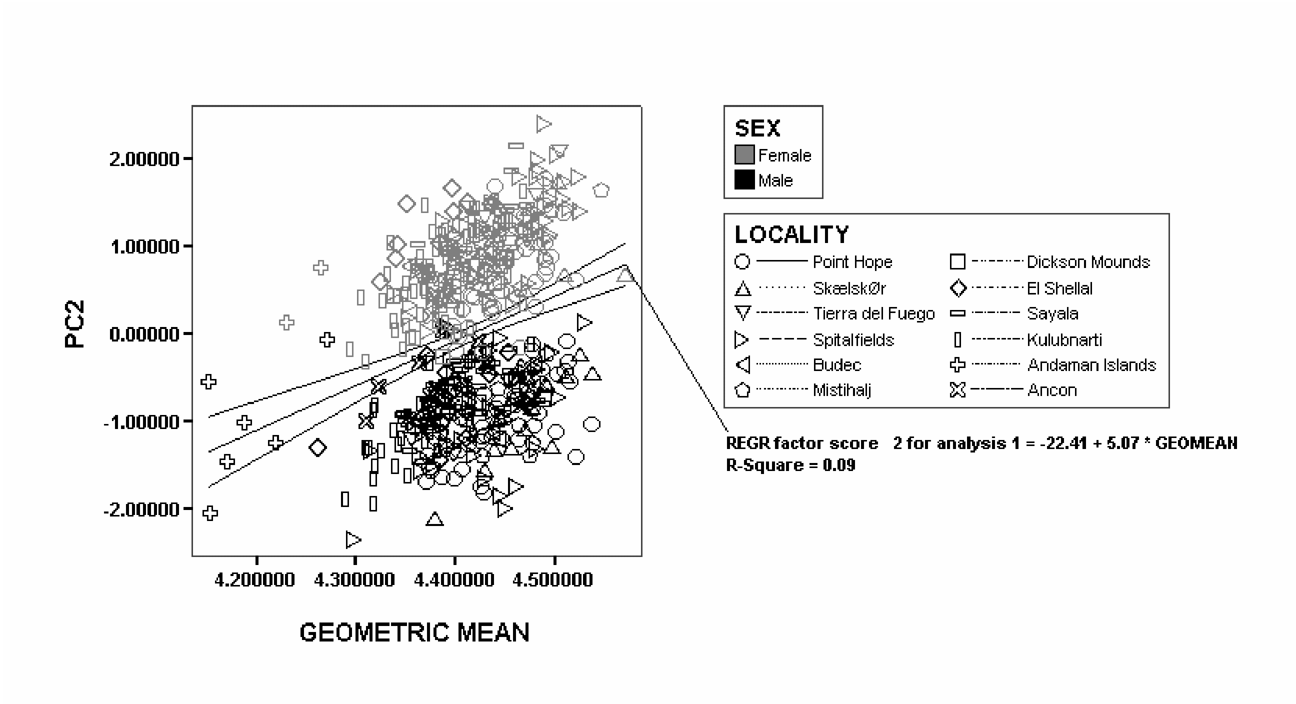


Figure 4.3: Scatter plot of the geometric mean vs. PC2



Principal component scores and climate

In order to further examine the relationship between pelvic variables and climate in multivariate space, the principal component scores were plotted against the same three measures of climate (latitude, mean temperature of the coldest month, and mean temperature of the warmest month) used in the previous chapter. For this analysis, the PC scores for males and females are plotted separately, but the scores were generated from the PCAs conducted on males and females together shown in Table 4.1.

Female results

Figure 4.4 displays the plot of the PC1 scores for females versus latitude. PC1 scores are statistically significantly correlated with latitude ($r = 0.488$, $p < 0.000$).

Results are similar when PC1 scores from females are correlated with mean temperature of the coldest month ($r = -0.407$, $p < 0.000$), and mean temperature of the warmest month ($r = -0.455$, $p < 0.000$). The plots for these can be seen in Figures 4.5 and 4.6**,** respectively. The Andaman Islanders individuals are outliers on the plots of PC1 vs. latitude, MTCM, and MTWM. It appears that the Andaman Islanders are outliers due to their lower PC1 scores, because the climatic variables are within the range of the other samples, but the PC1 scores are significantly lower than the other samples.

It should also be noted that in an analysis of birth weight and environmental heat load, Wells and Cole (2002) found that birth weight was statistically significantly correlated with heat index ($r = -0.59$, $p < 0.001$). Although heat index was not utilized here as a climatic measure, the correlation coefficient in that study is comparable to many of the correlation coefficients found here for PC1 scores and climate. This may indicate that selection on infant birth weight and adult body form is not only working in the same direction, but is of an equivalent magnitude as well.

When the PC2 scores are plotted against latitude (Figure 4.7)**,** no relationship is found. The PC scores are not statistically significantly correlated with latitude ($r = 0.017$, $p > 0.05$). PC2 scores are also not statistically significantly correlated with mean temperature of the coldest month ($r = .083$, $p > 0.05$) and mean temperature of the warmest month ($r = -.023$, $p > 0.05$). The latter two plots can be seen in Figures 4.8 and 4.9.

The first principal component is statistically significantly correlated with all three measures of climate (latitude, mean temperature of the coldest month, and mean temperature of the warmest month). As PC1 is the size component, this finding is consistent with the univariate results of the previous chapter. This finding also lends support to Bergmann's Rule and the cylindrical model (Ruff 1994). However, it is interesting that the PC2 scores, for which there are higher loadings for obstetric variables, are not statistically significantly correlated with any quantitative measures of climate. These results indicate that overall pelvic size, as represented by PC1, is statistically significantly correlated with climate, but the variables that capture the most variance for the obstetrical pelvis (represented in PC2) are not statistically significantly correlated with climate.

Figure 4.4: Latitude vs. PC1 (females)

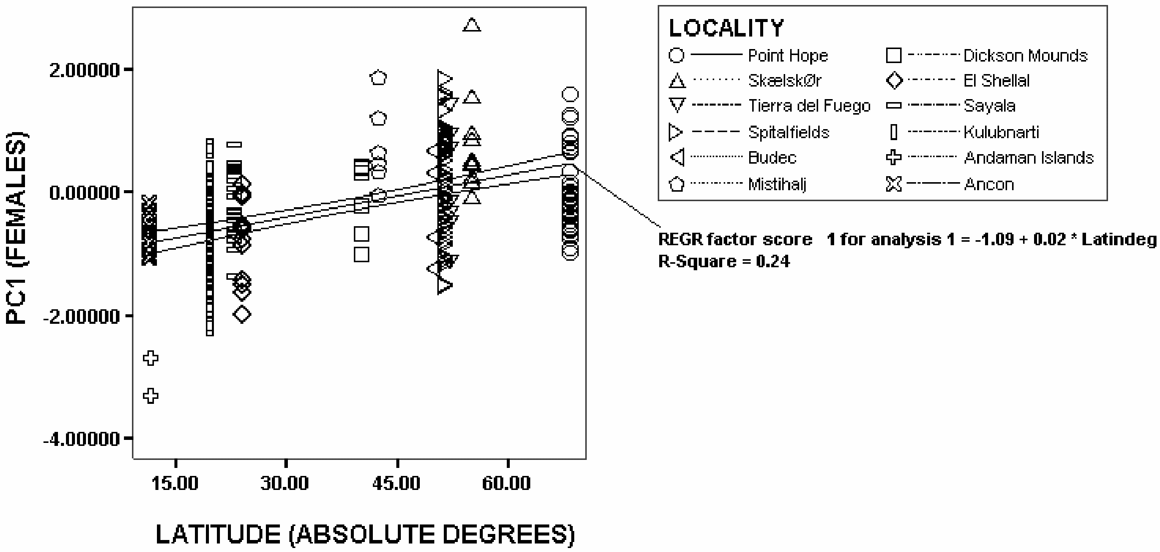


Figure 4.5: MTCM vs. PC1 (females)

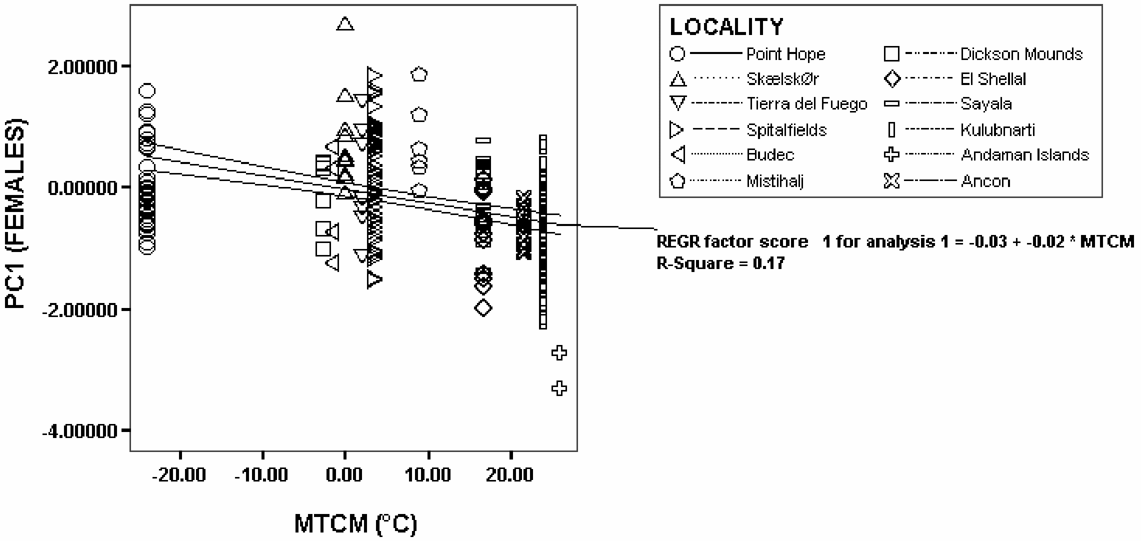


Figure 4.6: MTWM vs. PC1 (females)

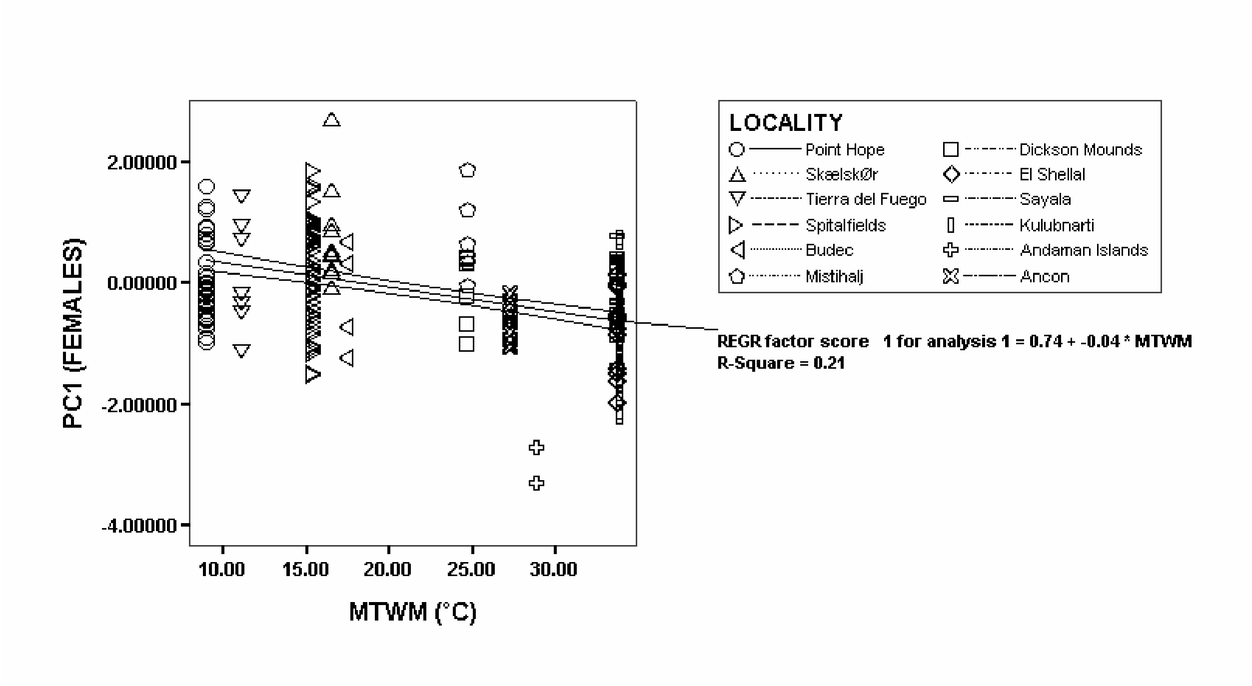


Figure 4.7: Latitude vs. PC2 (females)

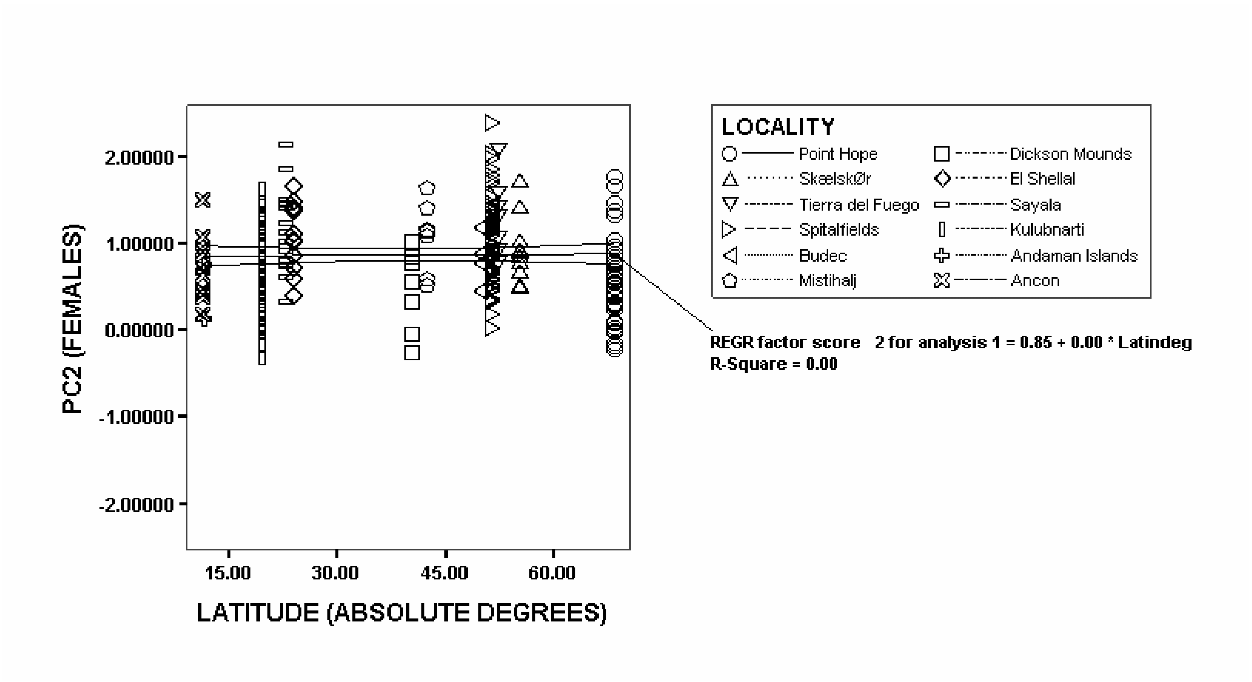


Figure 4.8: MTCM vs. PC2 (females)

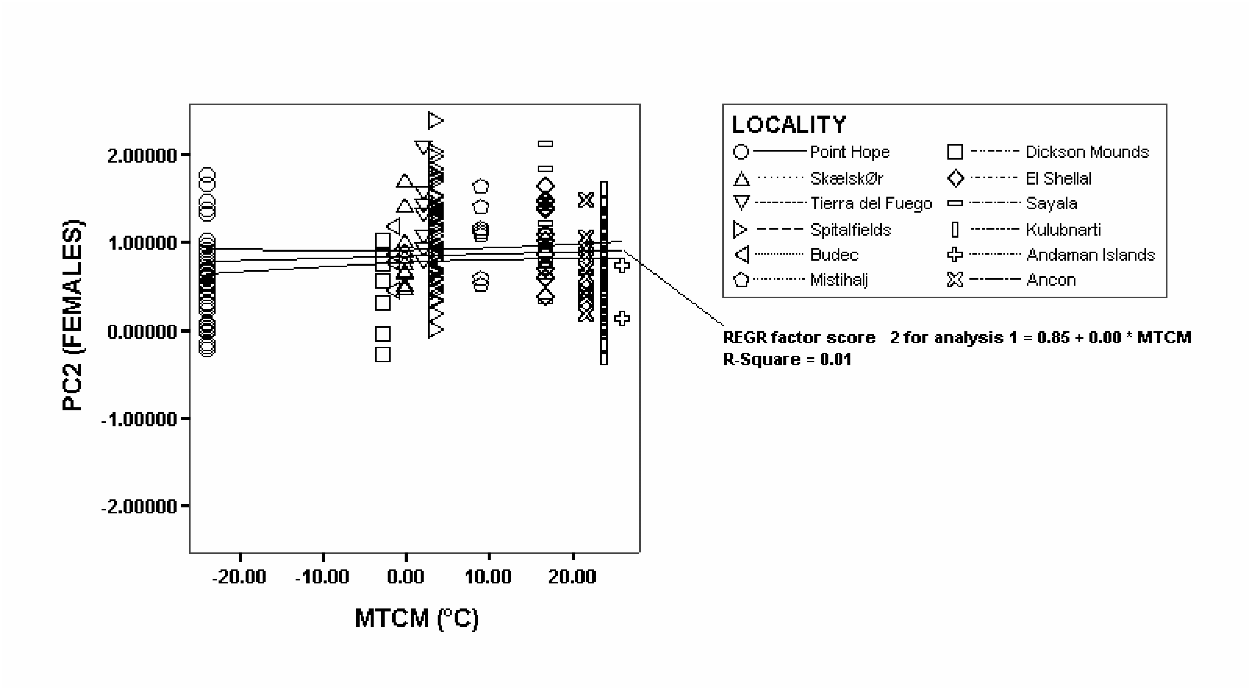
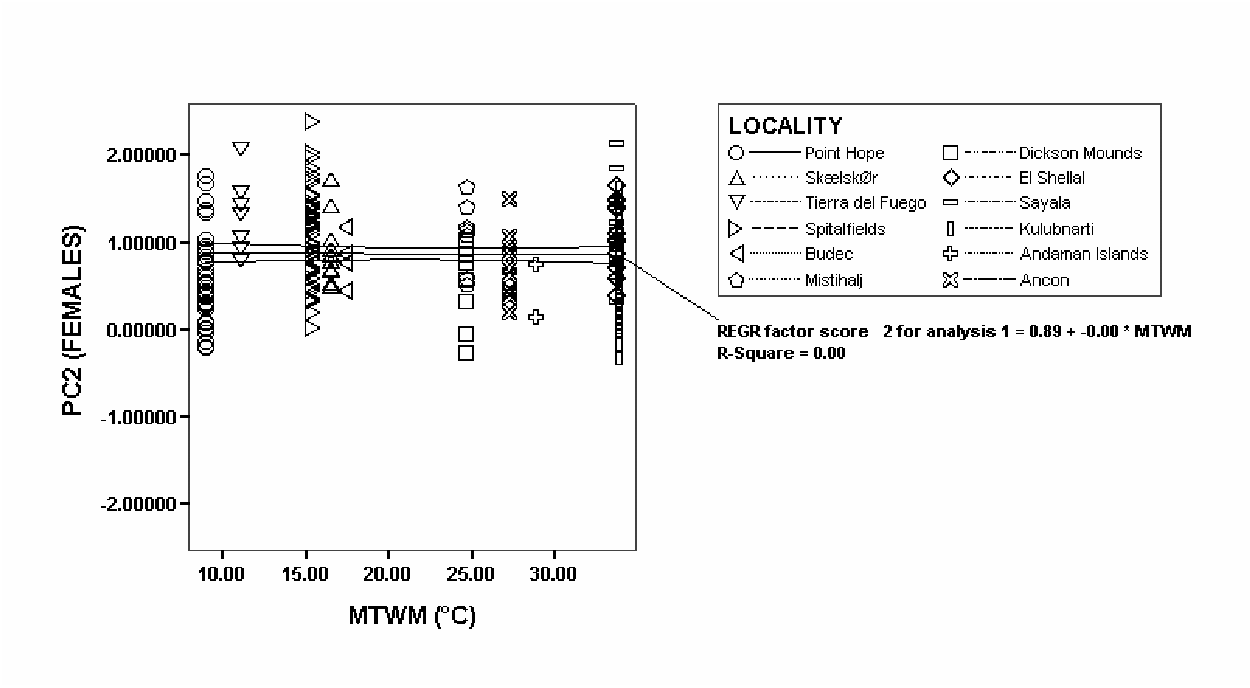


Figure 4.9: MTWM vs. PC2 (females)



Male results

The results for males parallel the female results. PC1 scores are statistically significantly correlated with latitude ($r = 0.478, p < 0.000$), mean temperature of the coldest month ($r = -0.409, p < 0.000$), and mean temperature of the warmest month ($r = -0.389, p < 0.000$). The plots for these three can be seen in Figures 4.10, 4.11, and 4.12, respectively. As with the female plots, the Andaman Islanders are an outlier on the plots of PC1 vs. latitude, MTCM, and MTWM, also due to the lower PC1 scores for those individuals.

The PC2 scores are not statistically significantly correlated with latitude ($r = -0.124, p > 0.05$), mean temperature of the coldest month ($r = 0.098, p > 0.05$), or mean temperature of the warmest month ($r= 0.102, p > 0.05$). The plots for these can be seen in Figures 4.13, 4.14, and 4.15, respectively.

As with the female results, overall pelvic size, as represented by PC1, is statistically significantly correlated with climate. However, PC2 scores, with high loadings for obstetric variables, are not statistically significantly correlated with any measure of climate.

Figure 4.10: Latitude vs. PC1 (males)

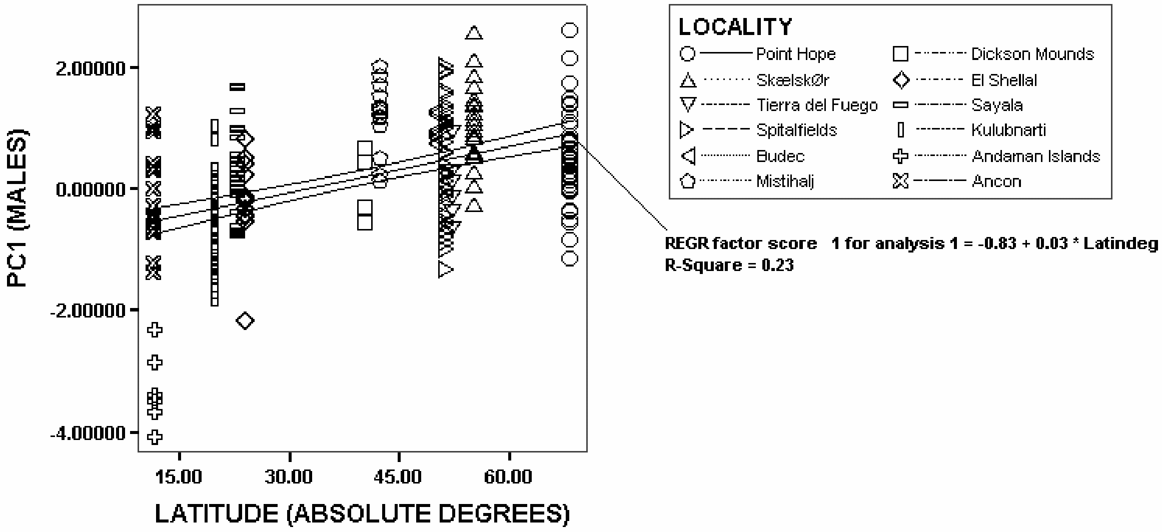


Figure 4.11: MTCM vs. PC1 (males)

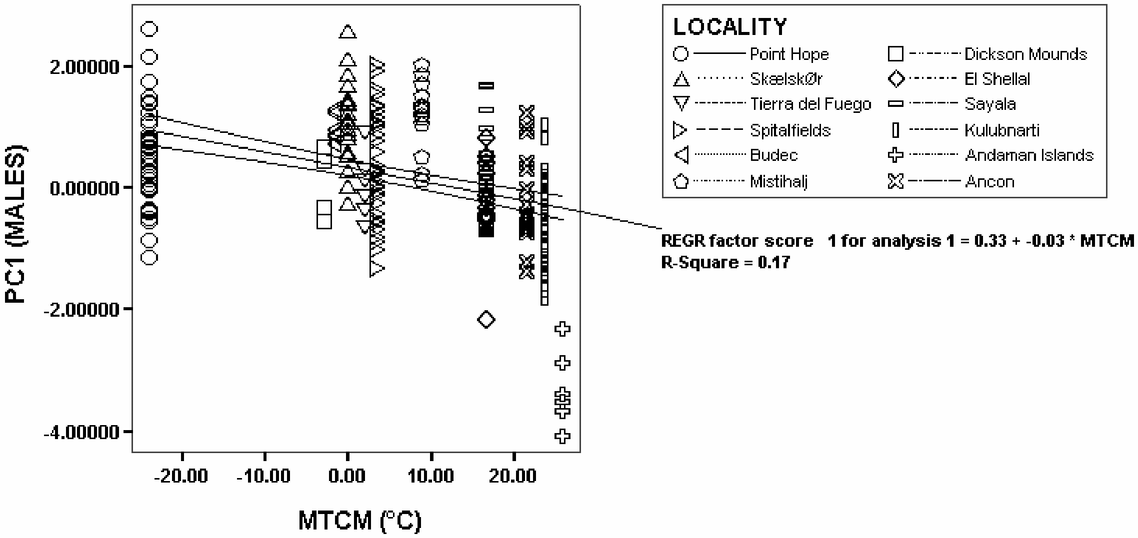


Figure 4.12: MTWM vs. PC1 (males)

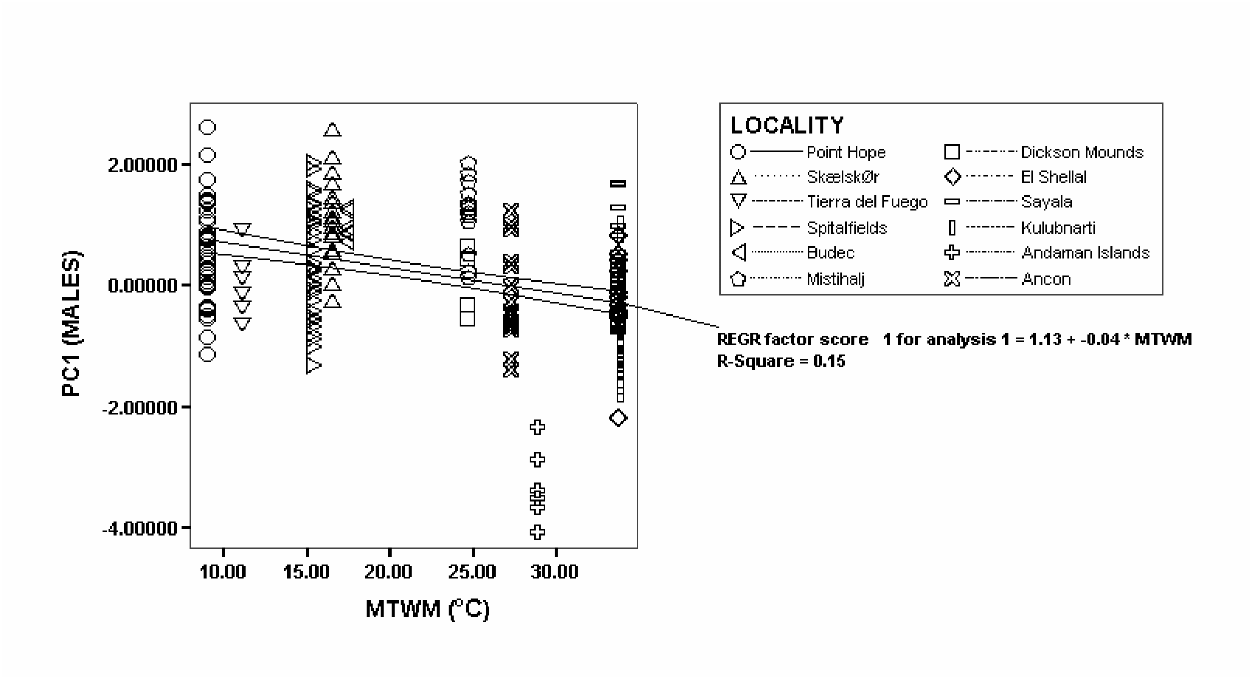


Figure 4.13: Latitude vs. PC2 (males)

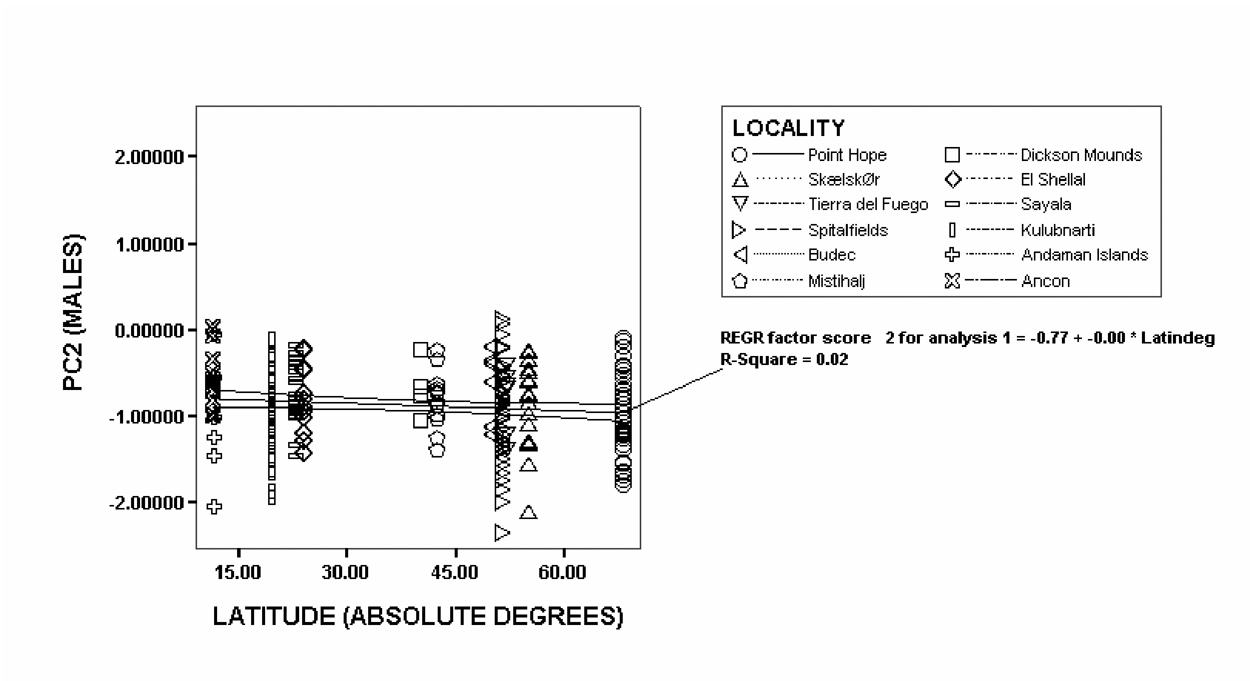


Figure 4.14: MTCM vs. PC2 (males)

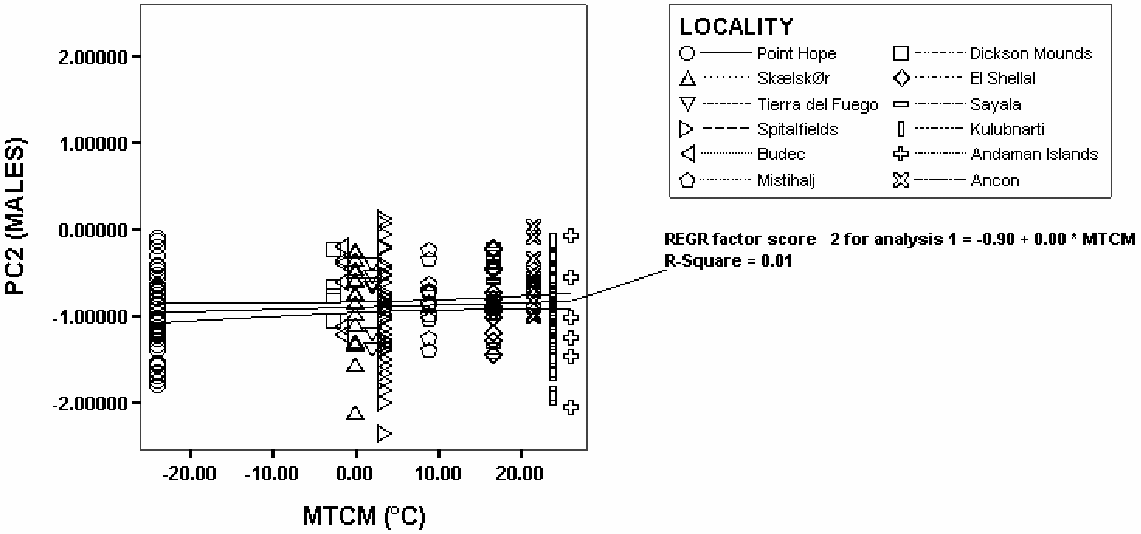
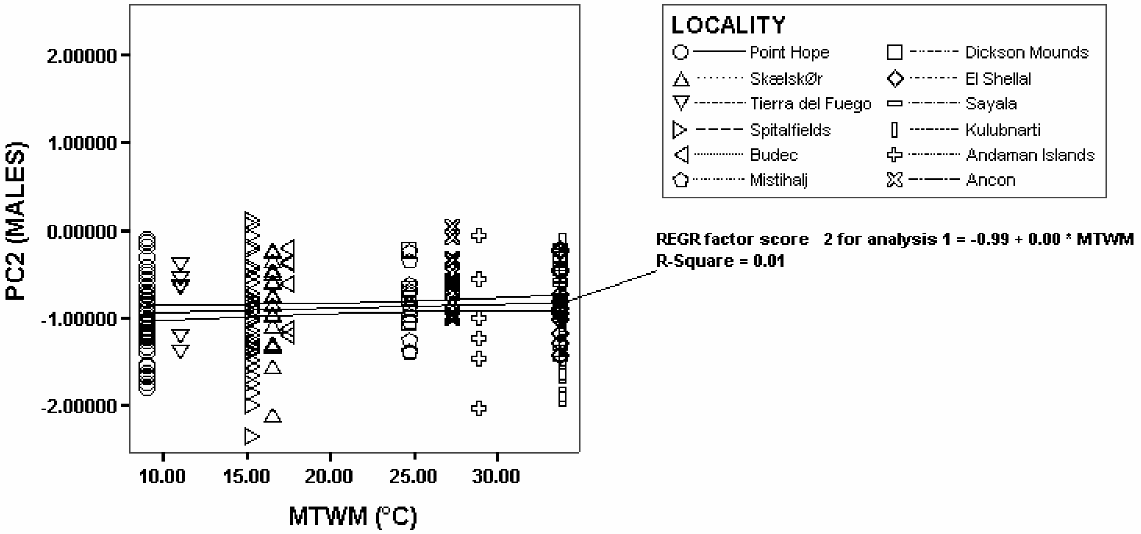


Figure 4.15: MTWM vs. PC2 (males)



Multivariate results summary

Principal components analysis was conducted on the raw pelvic variables collected in this study. The first principal component was the size component, having positive factor loadings for all of the variables. This was confirmed by a high correlation with the geometric mean.

The second principal component very clearly segregated the sexes, a finding that is consistent with previous multivariate postcranial skeletal studies (Arsuaga and Carretero 1994; Holliday 1997a). For the second principal component, the signs of the factor loadings separate into "size" variables and "obstetric variables," indicating a different pattern of variance for these two types of measurements, which is most likely related to sex differences and the unique obstetrical demands of the female pelvis. As the second principal component has high loadings for obstetric pelvic variables, it could be considered the "obstetric" component.

The third principal component was characterized by a high negative loading for supra-acetabular auricular distance, and the distance from the anterior inferior iliac spine to the auricular surface (Figure 2.11). The fourth principal component was characterized by a very high loading for sacral width (Figure 2.6). This is due to a higher mean value for sacral width for the Point Hope and Kulubnarti samples for both males and females, as noted in the previous chapter.

The uniqueness of the Andaman Islands sample is a pattern that has emerged with both the univariate and multivariate analyses. In univariate analyses, when pelvic variables are correlated with climate, the Andaman Islanders are not only the smallest in size, but are far removed from the regression line. These results indicate that the

Andaman Islanders have pelvic dimensions that are smaller than expected, even given the low latitude/hot climate locality of the sample. In multivariate analyses, the Andaman Islanders are also removed from the regression line when PC1 scores are plotted against different climatic measures (due to the lower PC1 scores for those individuals). Therefore, on plots that are related to size, the Andaman Islanders have a tendency to be outliers because they are so much smaller than individuals in the other samples. However, on the plot of PC1 versus the geometric mean (Figure 4.1), the Andaman Islanders are the smallest in size, but are still on the regression line. This result seems to indicate that the Andaman Islanders are smaller, but do not exhibit a pattern of allometric scaling that is different compared to the other samples studied.

Thermoregulatory explanations of the small-statured morphology were first put forward by Cavalli-Sforza (1986), who argues populations in extreme hot, humid environments are unable to dissipate heat through the evaporation of sweat from the skin (because such high humidity makes the evaporation of sweat ineffective). Instead, in order for small-statured populations to avoid overheating (most likely as a result of physical exertion) in an extremely hot and humid environment, the most efficient thermoregulatory adjustment is to reduce absolute body mass, and muscle mass in particular. Shea and Bailey (1996) argue that evolutionary thermoregulatory adaptations might not provide the best explanation for the morphology of small-statured populations, and that some of the changes seen in small-statured populations could be the result of genetic drift or other non-adaptive processes. It is also important to consider the role of island biogeography, as the Andaman Islanders were the only island population included in the study (Barton 1998; Whittaker 1998). However, as small-statured populations have been found all over the world in tropical regions, island-related evolutionary factors are probably not the sole causal influence. Any combination of these factors could explain the uniqueness of the pelvic morphology of the Andaman Islanders sample.

The second portion of this chapter examined the relationship between principal component scores and climate. The first principal component is statistically significantly correlated with all three measures of climate (latitude, mean temperature of the coldest month, and mean temperature of the warmest month) in both males and females. As PC1 is the size component, this finding is consistent with the univariate results of the previous chapter. This finding also lends support to Bergmann's Rule and the cylindrical model as it applies to the pelvis.

In contrast to the PC1 results, PC2 scores are not statistically significantly correlated with the three measures of climate employed here. This finding is initially surprising because PC2 has higher loadings for the pelvic variables considered the most important for obstetrics. These results are also surprising given the statistically significant correlations found between most of the obstetric variables and climate (when analyzed one variable at a time) in the previous chapter. What are the possible explanations for the differences between the univariate and multivariate results? First, despite the study cited earlier by Wells and Cole (2002), there has historically been strong stabilizing selection on infant birth weight (Beall 1981). Stabilizing selection on infant birthweight means that there is strong selection towards the mean (Karn and Penrose 1951). Mean birthweight does vary slightly from population to population. For the study cited, which was conducted in the United Kingdom, mean birthweight was between 7.5 and 8.5 pounds. In general, infants on the low end of this distribution (under

4.5 pounds) have a higher infant mortality rate due to complications related to underdevelopment. Infants on the high end of this distribution, over 10.5 pounds, also have a higher mortality rate (though not as high as the underweight infants) due to complications related to obstructed labor. It is possible that despite these differing climatic and obstetric pressures, infant birthweights are driven to be close to the mean, which lessens the impact of climate as an effect in this particular multivariate analysis. With the advent of industrialization, studies have shown that the intensity of stabilizing selection on birth weight has been relaxed (Ulizzi and Terrenato 1987; Ulizzi et al. 1998; Ulizzi 2002). However, that would certainly not have been the case for the pre-industrial populations under study for this project. It is possible that strong stabilizing selection on infant birthweight is a contributing factor to lack of statistically significant correlations between PC2 scores and climate variables.

Second, this project may provide great insight into the benefits of a multivariate study. The objective of multivariate analysis (especially PCA), is to study patterns of variance when several variables are examined simultaneously. There was clearly an obstetric signal in the data, as represented by PC2. It is possible that when all pelvic variables are analyzed simultaneously, a statistically significant correlation in univariate or bivariate space does not hold when the same data set is examined in multivariate space. However, the PC1 results, which *are* statistically significantly correlated with climate, do follow the hypotheses predicted in this study, indicating a larger pelvic size in higher latitudes/colder climates and a smaller pelvis in lower latitude/hotter climates. Therefore, the multivariate results are not in complete contradiction to the predicted hypotheses and the univariate results presented in the previous chapter. Rather, the PCA results provide some insight into why some variables have a strong climatic signal and others do not. It appears that the inconsistent correlations with climate found in obstetric variables in univariate analysis coincide with a principal component (PC2), found to be the “obstetric” component, which is not statistically significantly correlated with climate in multivariate space.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Summary of results

This study investigated the associations between obstetric dimensions and climate in human populations from a diverse range of geographic regions. The main hypothesis tested was that females in populations from high latitude/colder climates would require a larger obstetrical pelvis than females in populations from lower latitude/hotter climate populations. There were several reasons to expect associations between pelvic obstetrical dimensions and climate. First, there is selection on adult body form, indicating a wider body breadth in colder climates and a narrower body breadth in hotter climates. This particular type of selection has been studied most carefully in terms of examining the strong correlation between biiliac breadth and latitude, in keeping with the predictions of the cylindrical model (Ruff 1994). Although selection related to climate has been documented most extensively with body breadth as measured by the breadth of the false pelvis, it has the potential to affect the true pelvis diameters as well. In addition to selection on the pelvis due to climate-driven factors, there is selection on the true pelvis due to obstetrical pressures. Obstetrical pressures on the pelvis derive from two different sources. First, larger heavier females tend to have larger neonates, and smaller, lighter females tend to have smaller neonates, creating the need for the appropriate adjustment in birth canal size. Second, there is also selection on neonatal size, for larger infants in colder climates, for improved thermoregulation, and smaller infants in hotter climates, for reduced thermoregulatory stress on the mother (Wells and Cole 2002). Thus, there are several different types of selection pressures operating on the pelvis that would lead to the expectation of associations between the true pelvis and climate. In order to test this hypothesis, pelvic and long bone measurements were examined in adult human postcranial skeletal remains from a diverse range of geographic localities. The hypotheses were tested as follows: (hypotheses that were supported are in italics; hypotheses that were partially supported are in regular typeface):

Table 5.1: Table of hypotheses

Hypothesis (H_0)	**Hypothesis (H_A)**
1. Pelvic obstetrical dimensions are not statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)	1. *Pelvic obstetrical dimensions are statistically significantly correlated with climate, both* ***with and without*** *correcting for body size (a test of the cylindrical model)*
2. Male pelvic dimensions are not statistically significantly correlated with climate, with and/or without correcting for body size (a test of the cylindrical model)	2. *Male pelvic dimensions are statistically significantly correlated with climate, both* ***with and without*** *correcting for body size (a test of the cylindrical model)*
3. Pelvic obstetrical dimensions show no statistically significant correlation(s) with biiliac breadth	3. *Pelvic obstetrical dimensions show statistically significant correlation(s) with biiliac breadth*
4. Pelvic obstetrical variables in multivariate space are not statistically significantly correlated with climate	4. Pelvic obstetrical variables in multivariate space are statistically significantly correlated with climate

The first hypothesis investigated whether pelvic obstetrical dimensions were statistically significantly correlated with climate. The results of this study indicated that in females, the major transverse pelvic obstetrical dimensions (the diameters at the plane of the pelvic inlet, midplane, and outlet) were statistically significantly correlated with climate. These results were significant even when correcting for body size, and when different measures of climate (latitude, MTCM, and MTWM) were utilized. These variables covaried in the direction predicted, indicating larger obstetrical pelvic dimensions in high latitude/cold climate female individuals and smaller obstetrical pelvic dimensions in low latitude/hotter climate female individuals. The results for AP pelvic dimensions were not as consistent, with some AP obstetrical dimensions (AP outlet, posterior midplane, and posterior outlet) statistically significantly correlated with climate, but most AP pelvic obstetrical dimensions on the whole were not statistically significantly correlated with climate after body size correction. Also, the cases of statistical significance for AP measurements had a tendency to have lower correlation coefficients than statistically significant transverse pelvic dimensions. These results are consistent with the findings of previous studies (Weaver 2002), indicating a greater level of ecogeographic patterning in transverse pelvic measurements than in AP pelvic measurements. Weaver (2002) suggests that sagittal pelvic dimensions do not show as much ecogeographic patterning as transverse measurements because of biomechanical constraints. It has also been proposed by the author that because sagittal pelvic dimensions are on an oblique when the pelvis is in anatomical position (Figure 2.2), sagittal pelvic measurements do not have the same impact as a parameter of body depth that transverse measurements would as a parameter of body breadth, with regard to the cylindrical model (Ruff 1994).

Tague (2000) notes the importance of the pregnancy hormone relaxin, which alters the mechanical properties of pelvic ligaments, and can increase the area of the pelvic outlet by as much as 20-30% during delivery. This is because the relaxation of the sacrospinous and sacrotuberous ligaments allows the coccyx to be pulled back in a posterior direction, which increases the capacity of the AP pelvic outlet, and to some extent the AP pelvic midplane. Transverse pelvic diameters are also affected by relaxin, including loosening of the interpubic disc, which increases the distance between the pubic bones (Moore and Dalley 1999). Although all pelvic ligaments (and therefore potentially all obstetrical pelvic dimensions except the sagittal pelvic inlet) are affected by relaxin during pregnancy, the changes induced by the hormone appear to have the most impact on measurements affecting the distance between the inferior portion of the vertebral column and the pelvis. It is possible that the correlation of pelvic obstetrical dimensions with climate is inconsistent because of this differential degree of "malleability" allotted by the relaxation of pelvic ligaments.

The second hypothesis tested was essentially asking the same question with regard to the male pelvis. For males, the transverse pelvic midplane and outlet were statistically significantly correlated with all three measures of climate, but the transverse pelvic inlet was not statistically significantly correlated with any measure of climate after body size correction. These results are particularly suggestive of a relationship between obstetrics and climate with regard to females, because the pelvic inlet was statistically significantly correlated with both latitude and MTWM in females. With regard to AP pelvic dimensions and climate in males, some AP pelvic measures (AP midplane, AP outlet, anterior midplane, posterior midplane, and posterior outlet) were statistically significantly correlated with climate in males after body size correction. These results differ from the female results in that the AP and anterior midplanes were not statistically significant in females after body size correction. It is possible that these additional AP measurements were statistically significant in males because males do not have the same "obstetric" constraints as females, and therefore might be more responsive to climate-driven factors.

The third hypothesis investigated the relationship between biiliac breadth and the other transverse pelvic obstetrical diameters. The results indicated a particularly strong correlation of biiliac breadth with the pelvic inlet diameter, a less strong relationship with the pelvic midplane diameter, and a weaker correlation of biiliac breadth with the pelvic outlet diameter. However, the correlation of biiliac breadth with all three diameters was statistically significant. These results suggest that if selection related to climate is acting on biiliac breadth, this could in turn affect the other transverse diameters of the pelvis. Biiliac breadth was also statistically significantly correlated with AP obstetrical pelvic dimensions, albeit with a lower correlation coefficient compared to the transverse pelvic obstetrical dimensions.

The fourth hypothesis investigated the relationship between pelvic variables and climate in multivariate space. In order to do this, principal components analysis was conducted on the raw pelvic variables collected in this study. The first principal component was the size component, having positive factor loadings for all of the variables and a very high correlation with the geometric mean. The second principal component segregated the sexes, a finding in keeping with previous multivariate studies on human postcranial morphology (Arsuaga and Carretero 1994; Holliday 1997a). Most likely responsible for this segregation, the signs of the factor loadings on PC2 separated into negative loadings for “size” variables and positive loadings for “obstetric variables,” indicating a different pattern of variance for these two types of measurements. Another way to interpret PC2 is negative loadings for pelvic dimensions that tend to be greater in males, and positive loadings for pelvic dimensions that tend to be greater in females.

This study then investigated the relationship between principal component scores and climate. The first principal component was statistically significantly correlated with all three measures of climate (latitude, MTCM, and MTWM) in both males and females. As PC1 is considered the size component, this finding is not surprising, because with the univariate analysis many pelvic diameters (transverse pelvic diameters in particular) were statistically significantly correlated with climate.

When PC2 scores were correlated with climate, they were not found to be statistically significantly correlated with any measure of climate. This finding was initially surprising, because PC2 had high loadings for obstetric variables, and most obstetric variables (transverse diameters in particular) were statistically significantly correlated with climate in univariate analysis. A possible explanation for this pattern is strong stabilizing selection on infant birthweight (Beall 1981). Stabilizing selection on infant birthweight means that there is strong selective pressure towards the mean, about 7.5 to 8.5 pounds (Karn and Penrose 1951). These numbers are based on a study from the United Kingdom, and mean birthweight does vary slightly from population to population. However, in general infants that are on the low end of the mean birthweight distribution (less than 4.5 pounds) have a higher infant mortality due to complications related to underdevelopment. Infants on the high end of this distribution (greater than 10.5 pounds) also have a higher mortality rate (though not as high as the smaller infants) due to complications related to obstructed labor. It is possible despite these differing climatic pressures and pelvic sizes, infant birthweights are driven to be close to the mean, which lessens the impact of climate as an effect. Although the intensity of stabilizing selection on birthweight has relaxed with the advent of industrialization (Ulizzi and

Terrenato 1987; Ulizzi et al. 1998; Ulizzi 2002), that would certainly not have been the case for the pre-industrial populations included in this study. It is possible that strong stabilizing selection on infant birthweight is a contributing factor to the lack of a statistically significant correlation between PC2 scores and climatic variables.

Second, part of the purpose of multivariate analysis is to be able to examine several variables simultaneously with the goal of identifying patterns of variance that might not be apparent in univariate analysis. It is possible that when all of the pelvic variables were analyzed simultaneously, a statistically significant correlation in univariate or bivariate space does not hold when the same relationship is examined in multivariate space. However, it should be noted that the PC1 scores, which were statistically significantly correlated with climate, did follow the hypotheses predicted in this study, indicating a larger pelvic size in high latitude/colder climate individuals and a smaller pelvic size in lower latitude/hotter climate individuals. Furthermore, an examination of brachial and crural indices found that although both brachial and crural indices were statistically significantly correlated with climate, crural indices were more highly correlated with climate than brachial indices. The crural index results provide additional support that the lower trunk region is particularly responsive to climate. In the univariate analysis, many obstetrical pelvic dimensions had a strong climatic signal, but there were some variables (primarily AP obstetrical dimensions) that did not. It appears that the inconsistency of these results coincides with the multivariate results, where PC2, found to be the “obstetric” component, was not statistically significantly correlated with climate. However, it is also worth noting that there were many pelvic variables included in the PCA that were not by definition, “obstetric” variables. Pelvic dimensions that were measurements of overall pelvic or coxal size (coxal height, iliac height, iliac breadth, etc.) were included in the PCA, but are not considered critical measurements in terms of the birth canal and obstetrics. It is possible that these variables created too much noise in the multivariate analysis and made it too difficult to decipher a clear obstetric signal.

A pattern that emerged in all analyses conducted was the uniqueness of the Andaman Islands sample. In univariate analysis, when pelvic variables were correlated with climate, the Andaman Islands sample was not only the smallest, but also usually removed from the regression line. In multivariate analysis, when PC1 scores are plotted against climate, the Andaman Islands sample was also removed from the regression line (due to the significantly lower PC1 scores for Andaman Islanders compared to the rest of the data set). However, when PC1 is plotted against the geometric mean, the Andaman Islanders were still the smallest values, but were not removed from the regression line. These results suggest that despite the smaller size of the Andaman Islanders, they do not exhibit a pattern of allometric scaling that is different from the other samples under study.

There are several possible explanations to explain the uniqueness of the Andaman Islands sample. Cavalli-Sforza (1986), argues that populations in extreme hot, humid environments are unable to dissipate heat effectively through the evaporation of sweat from the skin (because of such high humidity). Instead, in order for small-statured populations to avoid overheating during bouts of physical exertion, reducing overall body mass, and muscle mass in particular, is the most effective strategy. However, Shea and Bailey (1996) note that it is important to consider the role of genetic drift or other non-adaptive processes in addition to evolutionary thermoregulatory explanations. The Andaman Islanders were the only island population included in this study, and therefore the role of island biogeography should also be considered. Island populations are more likely to be subjected to evolutionary forces such as genetic drift, the founder effect, and genetic bottlenecks (Barton 1998; Whittaker 1998).

Conclusions

This study sought to investigate the relationship between climate and the obstetrical dimensions of the human bony pelvis. It was predicted, because of selection on adult body form and on infant size at birth, that females from high latitude/cold climate populations would have a larger obstetrical pelvis than females from low latitude/hot climate populations. This hypothesis was based on Bergmann's Rule (1847), the predictions of the cylindrical model Ruff (1994), and the predictions from the obstetric literature citing the strong correlation between maternal body weight and infant birth weight (Kirchengast and Hartmann 1998; Kirchengast et al. 1998; Pickett et al. 2000).

Bergmann's and Allen's Rule have been taken to be the cornerstone of how to explain clinal variation in human body size and shape across different geographic regions. The underlying assumption tied into Bergmann's and Allen's Rule is that improved thermoregulation with a particular morphology in a given climate leads to a significant adaptation for that individual. However, it is readily apparent upon closer examination that this variation is not always consistently present, and finding the cause of the underlying adaptation can be problematic (Steegmann 2007). Other inconsistencies in Bergmann's Rule have been previously identified (Hiernaux and Froment 1976; Stinson 1990). The Andaman Islanders included in this study are an example of a population with a unique morphology compared to the other samples, but the specific explanations to the variation and [assumed] adaptation with this sample are unclear, or at the very least likely related to several factors.

This study corroborated the findings of Ruff (1994) with regard to the strong correlation between biiliac breadth and climate. In addition, a statistically significant correlation was found between the transverse obstetrical dimensions of the birth canal and climate, especially in females. These results remain significant even after accounting for body size. These results could be indicative of selection related to climate affecting the true pelvis in addition to the false pelvis, or it could be that obstetrical pressures are driving an optimum true pelvis size in a given climate. Both Chapter 1 and the beginning of this chapter addressed the multitude of selective pressures that could be responsible for associations between obstetrics and climate. It is not possible to parse the individual selection pressures to find which one or which combination of pressures is responsible for the correlations found in this study. However, a direction for future research could be an attempt to separate climatic and obstetrical selection pressures on human pelvic morphology. In any case, the statistically significant correlation between pelvic obstetrical dimensions and climate may prove to be part of the puzzle that determines the underlying selective pressures that determine pelvic (and overall trunk and lower limb) morphology.

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