CAUSES AND CONSEQUENCES OF RISING CESAREAN RATES IN YUCATEC MAYA FARMERS

by

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A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Anthropology

West Lafayette, Indiana

December 2019

THE PURDUE UNIVERSITY GRADUATE SCHOOL
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To my family, local and extra-local.

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ABSTRACT

This project is concerned with obstetric complications and cesarean births in a Yucatec Maya community that has only recently began interacting with global market economies and Western biomedicine. This research engages with maternal health, reproductive biology, colonial histories, and the global trend of increasing cesarean section [CS] births. The Maya of Campeche, Mexico, are a short statured population [average adult female height 2010 = 143.2 cm] with historically low obstetric complications and maternal mortality. In the last 30 years, CS rates have risen to account for 25% of all births in this community. Over 70% of births currently take place in the hospital. Because extreme short stature for population has been linked to obstructed labor and birth complications, this project was designed to determine if stature is impacting the rising rate of CS. Reproductive outcomes and obstetric complications were modeled against height in three age cohorts of mothers using one-way ANOVA with a Bonferroni-post hoc test and univariate general linear models. No statistical evidence was found to indicate that stature is related to reproductive outcomes or obstetric complications; however, there is an association between short stature and likelihood of cesarean birth. This study employs a longitudinal dataset that represents over 50 years of reproductive histories though limited in statistical power. The dramatic change in birth mode in this population may be attributed to increased availability of biomedical resources, doctor-driven perceptions of indigenous women, and low capacity of rural public hospitals to serve numerous patients in labor. More data is needed on Yucatec Maya health, demography, and birth experiences as well as medical accounts of birth in Mexican hospitals.

INTRODUCTION

Since around the mid-twentieth century, cesarean sections have become increasingly more common worldwide, to the point where they account for over 50% of births in some areas (Mariani & Vain, 2019; Rutherford, Asiodu, & Liese, 2019; Sakala, 1993; Wolf, 2018). The rate of increase has been especially dramatic in some regions of Latin America. The motives for rapid acceleration in some areas may be connected to changing maternal biology due to nutritional and energetic transitions. Several researchers have found a correlation between cesarean delivery and features of maternal biology including short stature and obesity (Ferreira et al., 2009; Möller & Lindmark, 1997; Sheiner, Levy, Katz, & Mazor, 2005; Toh-adam, Srisupundit, & Tongsong, 2012). It is important to understand why cesarean deliveries are rising so rapidly, and if they are indeed medically necessary in every instance. Maternal-child health costs of unnecessary cesareans are potentially quite high. These costs have mainly been documented in industrialized settings (Keag, Norman, & Stock, 2018; Lyerly et al., 2009; Reyes & Rosenberg, 2019; Sheiner et al., 2005; Wolf, 2018), yet it is plausible that they manifest differently in poor and rural environments. Under these conditions, some of the negative outcomes associated with unnecessary cesareans may be exacerbated in terms of maternal health. For example, low-income women who have had cesarean deliveries may lack the resources to pay for prolonged postnatal hospital care, or may experience limited sanitary infrastructure where they live, increasing the risk of maternal infection after surgery (Jordan, 1993; Sakala, 1993).

This project is concerned with biological fitness, obstetric complications and cesarean births in a short-statured Yucatec Maya community that has only recently began interacting with global market economies and heath care systems. Since that time, the cesarean birth rate for this community has increased to 25% of all births [32% of hospital births]. The Maya of Campeche, Mexico, are a short statured population [average female height = 143.2 cm] with historically high fertility and low obstetric complications and maternal mortality. In the last 20 years, prevalence of obesity and diabetes has increased in this population along with stature, though average height remains lower than 150 cm. These changes may partially explain the concurrent upsurge in cesarean births. To understand the extent to which stature is driving the trend of rising cesarean births, this project engages with several bodies of literature on maternal health, reproductive biology, colonial histories, and the global rate of increasing cesarean sections. Theoretical foundations of this paper come from evolutionary ecology and the allocation of energy to reproduction over the life course. This informs potential changes to maternal biology and birth in the Yucatec Maya. The study community has experienced accelerated modernization since the 1990s, resulting in changes to diet, daily energy expenditure, and biomedical access. Hospital and cesarean births have become normalized in the last decade, which has changed local perceptions of birth. Many individuals have observed that birth is more difficult for women today and some even conclude that women are not as strong as they used to be.

In the Yucatec Maya, it is possible that modifications to birth and pregnancy are the result of both biological and cultural changes in the last quarter century. The purpose of this project is to parse out factors contributing to biological fitness, obstetric complications, and rising c-sections in a population that began experiencing the nutritional transition and medicalization of birth in the last 30 years. This investigation delves into historical demographic data to see if birth was always difficult for shorter mothers or if this is a recent phenomenon driven by biocultural factors. This includes the impact of social change on individual health, which is apparent in phenomenon like increased obesity and diabetes as a result of the nutritional transition. Hospital overcrowding and the replacement of traditional birth by biomedical systems can also be viewed from biocultural perspective as Yucatec Maya women are increasingly encouraged to seek hospital care while pregnant and in labor. Eugenic perceptions of indigenous women by Mexican medical institutions may also have an impact on maternal health in the form of demeaning behavior (Braff, 2013; Smith-Oka, 2015). This project sought to understand what is causing rising cesarean rates in the Yucatec Maya and if they are caused by maternal short stature. It was posited that birth and labor complications, requiring surgical intervention, are the result of recent modernizing influences including the nutritional transition and the medicalization of birth.

CHAPTER 1. THEORETICAL FOUNDATION

In order to understand reproductive biology, modernization, and rising cesarean section [CS] rates in the Yucatec Maya study community, I integrate scholarship from biocultural anthropology, evolutionary biology, and Mexican sociocultural history. The theoretical foundation of this project utilizes life history theory and human reproductive ecology to describe human energetic investment in reproductive effort over the life course. Recent work on the biocultural synthesis is employed to describe changes to health and biology as the result of changing social institutions and the nutritional and energetic transitions. Birth is then described from an evolutionary perspective, influenced by selective pressures like bipedal locomotion, large-bodied infants, and obligate midwifery. Recent global changes to birth mode and a shift toward medicalized birth have prompted a reevaluation of reproductive health and biology and the impact that medicalized changes have on maternal-child health. Increased prevalence of CS, especially in Latin America, represents one of the greatest changes to birth since the mid 20th century. The connection between obstetric biology, medicalization, and Mexican socio-historical conceptions of indigenous women is explored as well in connection to the Yucatec Maya study community. Each of these resources are instrumental in developing comprehensive conclusions and in explaining apparent patterns that become visible in future results.

1.1 Life History Theory

Before unpacking recent changes to reproductive health and biology occurring within a specific population, it is necessary to contextualize human reproduction and the life course in natural selection. This includes adaptive pressures placed on individual reproduction and survival. Life history theory [LHT] is an evolutionary-ecological framework that seeks to understand the evolution of different life history traits, within and across animal and human taxa, by examining the allocation of energy throughout an individual's life span. The traits include the timing of birth, breastfeeding and weaning, reproductive schedules, number of offspring, patterns of parental investment, and senescence. Life history traits tend to be correlated. For example, primates, especially the great apes, take longer to reach reproductive maturity than most other mammals. They invest in growing larger bodies early in life and continue to invest in somatic maintenance, which results in greater longevity. Great apes also produce a small number of larger, higher-quality offspring, which receive high levels of maternal investment (Charnov & Berrigan, 1993; Hawkes & Paine, 2006; Hill & Hurtado, 1996).

According to LHT, organisms may utilize the time and energy allotted over their lifespan to optimize reproductive success. In this context, reproductive success refers to the amount of offspring that survive to adulthood and who themselves reproduce, which leads to greater genetic representation in future generations (Bogin & Smith, 1996; Ellison, 2001; Hawkes & Paine, 2006; Hill, 1993). In LHT literature, discussions of energetic investment strategies use economic language to create an analogous comparison. Energy harvest and utilization, in the form of calories, are discussed in terms of capital, investment, gains, and returns (Aiello & Wells, 2002; Kaplan, Hill, Lancaster, & Hurtado; Wells, 2010). As such, fat stores in the body serve as energetic reserves and potential capital, which may be invested in future demands made on the body. The energetic demand and equilibrium of the key life history functions, growth, maintenance, and reproduction, are fundamental to LHT and energetic investment strategies observed in various species and populations. Some newer models of energetic investment treat brain growth as separate from other somatic life history functions and investment pools, since brain growth and cognition require between 44% and 87% of resting metabolic rate during infancy, childhood, and adolescence (Barton & Capellini, 2011; Isler & van Schaik, 2012; Kuzawa et al., 2014; Wells, 2012). Energy can be invested in one life history function but not another, representing a trade-off between growth, maintenance, and reproduction (Hill & Kaplan, 1999). In LHT, "trade-offs" refer to energetic investments that are beneficial for one function, but detract energy from others because energy budgets are limited (Stearns, 1989). For example, a very young pregnant female, who is still growing herself, may be caught between the energetic demands of the developing fetus and her own growth and maintenance (Kramer, 2017; Kramer & Lancaster, 2010). Another example would be growth-maintenance trade-offs for juveniles living in energetically or epidemiologically challenging environments, in which immune system upregulation can detract from growth (Blackwell, Snodgrass, Madimenos, & Sugiyama, 2010; McDade, Rutherford, Adair, & Kuzawa, 2009).

Since the mid 20th century, LHT has been widely applied by anthropologists to describe evolutionary adaptations in humans (Eveleth & Tanner, 1976; Frisch, 1984). Much research in LHT and other fields concerned with human biology has focused on natural fertility populations. This describes people groups that lack access to medical contraception, have relatively high fertility, and typically practice traditional subsistence strategies like hunting and gathering and/or small-scale agriculture (Blurton Jones, 2006; Ellison, 2011; Valeggia & Núñez-de la Mora, 2015). Scholarship produced with these groups forms much of the current foundational knowledge regarding the evolution of the human life course and reproductive investment strategies. In natural fertility populations, energetic trade-offs between female growth, maintenance, and reproduction are evident, especially in resource-scarce settings, though human social organization can render them more flexible than as would be the case for other great apes (Kaplan, Hooper, & Gurven, 2009). For example, gestating or lactating women may receive nutritional and childcare support from male partners and other kin, alleviating energetic trade-offs to some extent (Gurven & Walker, 2005; Hawkes, O'Connell, Jones, Alvarez, & Charnov, 1998; Quinlan & Quinlan, 2008).

The Yucatec Maya community located in Campeche were a natural fertility population until about the mid 1990s. They have historically practiced small-scale agriculture on family plots, or *milpas*, and they raise domesticated farm animals and hunt small game in the surrounding forest (Kramer, 2005; Kramer & McMillan, 1998). Only recently has the community gained access to market foods and clinical medicine, which have improved energetic and epidemiological access. Many food items that were previously inaccessible, like processed goods high in salt and sugar, can now be bought cheaply at any of the handful of small convenience stores in town. The local clinic, built in the late 1990s, is staffed with a health promoter and a physician that visits every two months (Veile & Kramer, 2018). These events are likely to alter the nature of growth-maintenance-reproduction trade-offs for women, who are now heavier. Prior, women were reproducing without contraception under conditions of environmental and nutritional stress, though maternal and infant mortality were historically quite low. In the last 20 years, since the alleviation of some energetic stress, age at first birth has decreased by just a couple years (Kramer & McMillan, 2006). The interaction between energetic demands and sociocultural change following this phenomenon will be examined in a later section.

The presence of environmental stress, defined here as external forces that place strain on physiological systems, can manifest as nutritional, social, ecological, and even atmospheric constraints that increase disease susceptibility and otherwise negatively impact growth and reproductive success (Bogin, 2006; Bogin, Smith, Orden, Varela Silva, & Loucky, 2002; Hoke & Leatherman, 2018; Krieger, 2005; Wells, 2016). In response to stressful environments, humans display remarkable plasticity, or adaptive flexibility, on the genetic and phenotypic level to acclimate to challenging or suboptimal conditions (Beall, 2007). It has become increasingly evident in the last 20 years that individuals are particularly sensitive to environmental information during critical windows of development, specifically through the fetal, infant, and childhood stages of life (Barker, Osmond, Golding, Kuh, & Wadsworth, 1989; Bogin & Loucky, 1997; Gluckman, Hanson, & Beedle, 2007; Kuzawa & Quinn, 2009; Wells, 2011, 2016). Stunting [short height for age] and wasting [low weight for age] have been observed in populations where energetic stress is high and nutritional access is limited (Bogin, 2006; Eveleth & Tanner, 1976; Martorell, 1989; Martorell & Young, 2012). Past studies indicate that early life conditions can impact metabolic function and adult body size (Bogin et al., 2002; Wells, 2016).

To illustrate this phenomenon, Bogin and colleagues studied Guatemalan Maya immigrant children living in the Unites States, who were up to 11.54 cm taller than their Maya peers still living in Guatemala (Bogin & Loucky, 1997; Bogin et al., 2002). Birthplace of immigrant children, whether in Guatemala, Mexico, or the United States, did not have a significant effect on comparative height (Bogin & Loucky, 1997). The difference in height between the two cohorts appears to be a product of relatively abundant caloric resources and a low-stress environment compared with rural Guatemala, even though the US cohort lived at or below the poverty line (Bogin et al., 2002). Poorer conditions early in life have typically been linked to smaller body size, however recently there is also a greater trend towards diabetes and obesity. In a follow-up study, Bogin and colleagues found that the same population of Guatemalan Maya immigrants in the United States had increased incidences of obesity due to effective assimilation to high energy diets and low levels of daily physical activity (Smith, Bogin, Varela-Silva, & Loucky, 2003).

Research has also been conducted on child growth in the Yucatec Maya in Mexico, another short-statured population (Azcorra, Dickinson, Bogin, Rodríguez, & Varela-Silva, 2015; Dickinson et al., 2018; Kramer, Veile, & Otarola-Castillo, 2016; Varela-Silva, Azcorra, Dickinson, Bogin, & Frisancho, 2009; Veile & Kramer, 2016). In the same study community as the current project, children under 5 were found to have healthy body mass indices despite being stunted according to recommendations of the World Health Organization [WHO] (Kramer et al., 2016). Childhood obesity rates are low, but recent research has shown that children delivered via CS have higher body mass indices compared to vaginally delivered children (Kramer et al., 2016; Veile & Kramer, 2016). Veile and collaborators (2019) have suggested that cesarean delivery may alter growth-maintenance trade-offs, either through modifications in the infant's intestinal microbiome, or alterations in infants' diets, or both. Children born vaginally are exposed to microbial cultures, which become part of the infant's intestinal flora (Azad et al., 2016; Dominguez-Bello et al., 2010; Dominguez-Bello et al., 2016). Breastfeeding is also important for development of the infant microbiome as well as improved childhood immunity (Azad et al., 2016; Castanys-Muñoz, Martin, & Vazquez, 2016; Mueller, Bakacs, Combellick, Grigoryan, & Dominguez-Bello, 2015; Veile & Kramer, 2016). However, CS birth does not bring the infant into contact with the same diversity of microbial cultures as vaginal birth, unless the infant is exposed via swabbing (Dominguez-Bello et al., 2016). CS is also associated with negative breastfeeding outcomes due to the immediate isolation of the infant after surgery (Kearney, Cronenwett, & Reinhardt, 1990; Zanardo et al., 2010). With the rising rate of CS in this population, it will be important to track the potential impacts of birth mode on long term growth trajectories and health outcomes over the entire life course.

1.1.1 The Human Life Course

The human life course is characterized by different stages based on energetic demands and investment in different life history functions. The earliest stage of life, the fetal stage, refers to the time spent gestating in the womb. This stage typically lasts from conception until birth after around 9 months of gestation (Shibley-Hyde & DeLamater, 2000). Gestation is divided into three trimesters, each corresponding to different stages of fetal growth and development (Bogin, 2006; Shibley-Hyde & DeLamater, 2000). In the first two trimesters, organ differentiation and fetal growth occur, supported by maternal nutritional resources (Shibley-Hyde & DeLamater, 2000; Trevathan, 2015). In the last trimester, from month 7 to 9, the fetus rapidly increases in length and weight, accumulating subcutaneous fat deposits that will aid extrauterine growth and development (Shibley-Hyde & DeLamater, 2000; Trevathan, 2015).

The total energetic cost of pregnancy is fairly consistent across study populations. For European women, pregnancy costs have been estimated at an additional 10% on top of somatic maintenance costs (Dufour & Sauther, 2002). Thai women were estimated in the same study to require an 8% increase in energetic costs during pregnancy, while Philippine and Gambian women were estimated to require a 9% increase (Dufour & Sauther, 2002). Pregnancy costs have not been calculated for Yucatec Maya women, however with the advent of labor-saving technology beginning in the late 1970's, it has become easier to meet the energetic demands of pregnancy (Kramer & McMillan, 1998, 2000; Veile & Kramer, 2016). Though women typically gathered water from the well in the center of town, a gas-pump was installed in 1978 followed by a pipe system in 2000 (Veile & Kramer, 2018). Despite alleviating stress, many villagers report that birth was easier for women prior to the installation of a water pump, stating that the arduous physical labor was beneficial to the birth process and facilitated an easier labor. Many older women claim that manually gathering water from the well, which required moving the hips in a circular motion while pulling up heavy buckets by a rope, was beneficial for settling the fetus into delivery position prior to labor (Kramer & McMillan, 1998 2005; Veile & Kramer, 2018).

Women who give birth before they have reached full maturity, as is the norm in some natural fertility populations, may be under additional energetic strain, though cooperative labor, food sharing, and social networks can improve infant and maternal health outcomes (Hill & Hurtado, 1996; Howell, 2010; Kramer, 2017; Kramer & Lancaster, 2010; Reiches et al., 2009). Many natural fertility populations encourage and value early motherhood (Hill & Hurtado, 1996; Howell, 2010; Kramer, 2017). By contrast, many industrialized populations view teen pregnancy as a public health concern (Kramer, 2017). It appears that age at sexual maturity is dependent on numerous environmental factors including energetic stress, healthcare, and life expectancy. More stressful environments with lower life expectancies are associated with accelerated sexual maturation (Cooper, Kuh, Egger, Wadsworth, & Barker, 1996; Hill & Kaplan, 1999; Kramer, 2008, 2017). In the Yucatec Maya, young women live and work with their parents until they marry, after which they typically live with their spouse's family until the couple can afford their own home and *milpa* allotment (Kramer & McMillan, 1998). Thereafter, these households are linked in terms of energetic production and consumption. Even if the young woman becomes pregnant before she has finished growing, she is supported by this household network, to which she also contributes. Maternal age at first birth has varied considerably over the last 20 years, becoming younger with modernization and the nutritional transition, but increasing once medical contraception became available in the early 2000s (Kramer & McMillan, 1998, 2006; Veile & Kramer, 2018).

After birth, the infancy life stage begins when the neonate is entirely dependent on its parents for food and care (Bogin, 2006; Bogin & Smith, 1996). Some consider this stage to be extension of the fetal stage that simply takes place outside the womb (Trevathan, 2015). The energetic demands of the infant increase during this stage as brain and body growth reach the fastest rates they will ever be after gestation (Bogin, 2006; Bogin & Smith, 1996). Human breastmilk is high in fats, sugars, growth hormones, and immune factors necessary for somatic growth, development, and pathogenic protection. This is vital for infants who do not have fully functioning digestive tracts, teeth, or immune systems. Breastfeeding is also a more efficient way of transferring nutrients to the infant than via the placenta (Bogin & Smith, 1996; Sellen, 2006; Trevathan, 2015). However, the energetic costs of lactation are much higher than pregnancy; for a woman who requires around 1950 kcal per day at basal metabolism, lactation adds a 26% increase in energetic costs on top of somatic maintenance (Dufour & Sauther, 2002). These costs are alleviated when complementary foods are added to the infant diet, typically at 4-6 months of age in most human populations (Sellen, 2006; Veile & Kramer, 2015). It has been proposed that complementary feeding during nursing reduces stress put on the mother by decreasing the infant's dependency on breastmilk and distributing the responsibility of feeding the infant amongst kin and other group members (Howell, 2010; Sellen, 2006). Infancy in humans is often defined as the period from birth until the child is fully weaned from breastmilk, but weaning age varies dramatically across and within human populations (Bogin, 2006; Hill & Hurtado, 1996; Howell, 2010; Veile, Faria, Rivera, Tuller, & Kramer, 2019). For example, Yucatec Maya women continue to breastfeed for long durations of time, often up to or beyond the second year of their infant's life (Veile, Faria, et al., 2019).

Childhood is the life stage immediately following weaning when the individual is still reliant on adults for food and protection, but has improved motor function and sociality (Bogin, 2006; Bogin & Smith, 1996). Though still relatively high, nutrient and energetic requirements for brain and body growth reduce after infancy. Brain growth continues during this stage, eventually reaching its full size by about age 7, though brain development continues well into adulthood. The mid-growth spurt also occurs around age 7 for both females and males as skeletal and muscle tissue rapidly accumulate (Bogin, 2006). Children are also susceptible to disease at this life stage, which can slow or stunt growth. Immunological insults, particularly those that hinder the body's ability to digest and absorb food, can result in reduced body size and even be fatal in extreme cases (Black et al.; Bogin, 2001; Martorell et al., 1975; Martorell & Young, 2012). Undernutrition and disease burden can have drastic impacts on future morbidity and height since maximum stature is permanently set once the long bones fuse (Bogin, 2001; Eveleth & Tanner, 1976; Martorell; Martorell & Young; White & Folkens, 2005). The eruption of the permanent molars and incisors mark the transition from childhood to juvenility (Bogin; Bogin & Smith, 1996; White & Folkens, 2005).

In some societies, children are able to contribute to infant care, food production and procurement, and other tasks that benefit group survival, as has historically been the case with the Yucatec Maya study community (Hill & Hurtado, 1996; Howell, 2010; Jasienska, 2013; Kramer, 2005). The juvenile stage between childhood and adolescence marks the period just before reproductive maturation as denoted by puberty. Juveniles are no longer dependent on adults for survival and will have lost deciduous teeth in favor of permanent dentition by age 12 (Bogin, 2006; Bogin & Smith, 1996; White & Folkens, 2005).

During adolescence, an individual undergoes puberty and an accelerated period of skeletal and muscle growth (Bogin, 2006; Bogin & Smith, 1996; White & Folkens, 2005). Ultimately, energetic allocation transfers entirely from somatic growth to reproduction of offspring. Adolescent females may experience their first menses as early as age 10 depending on available energy stores, but typically begin menstruating between ages 12 and 15 (Eveleth & Tanner, 1976; Shibley-Hyde & DeLamater, 2000; Vitzthum, 2009). Male puberty is not as immediately obvious as in females, but can be indicated by the descent of the testes and accumulation of muscle mass (Bogin, 2006; Bogin

& Smith, 1996). While adolescence is significant for reproductive development, this is also the life stage when individuals begin to take on adult roles in their society and may be partnered for marriage. Though males are fertile by their mid-teens when they begin producing large quantities of sperm, females are not able to successfully reproduce until 1-3 years following menarche when the ovaries finally release a mature egg (Bogin, 2006; Bogin & Smith, 1996; Kramer, 2017; Shibley-Hyde & DeLamater, 2000). Parenthood in many populations begins immediately after reproductive maturity. Yucatec Maya adolescents may marry and live with family before independently cultivating their own plot of land (Kramer, 2005). Historically, young men also participated in wage labor, however recently young women are starting to enter the wage labor economy and are now slightly more likely to continue their education past primary school (Kramer, 2005; Veile & Kramer, 2018). Age at first birth in this community has increased slightly over the last 60 years. The average age at first birth between 1950 and 1977 was 19.8, while the average from 2000 to 2017 increased to 21.8.

Adulthood is the human life stage that signifies full emotional, social, and reproductive maturation. Age of adulthood, and the onset of reproduction, is variable across human populations. Generally, somatic growth halts by around age 20 and most bones have fused by the time an individual reaches their mid-to-late 20s, cementing their maximum stature (White & Folkens, 2005). Energy is thereafter allocated to maintenance and reproduction, though the energetic demands of reproduction differ between females and males. Ovulatory cycles in females can be disrupted by stressful environmental conditions where energetic resources become scarce. This is likely a buffer against unsustainable pregnancies that would forego the energetic needs of the mother's own body (Jasienska, 2011; Jasienska & Ellison, 1998; Vitzthum, 2009, 2011). While females invest high amounts of energy in ovulation, pregnancy, and lactation, the costs of male reproductive systems are comparatively inexpensive (Bribiescas, 2011; Ellison, 2001; Valeggia & Núñez-de la Mora, 2015). Unlike ovulation, spermatogenesis is an economical process and can be sustained under a variety of stressful environmental conditions. In fact, though it is only a secondary sex characteristic, the musculoskeletal system is the most energetically demanding reproductive tissue in adult males (Bribiescas, 2011; Campbell, 2011; Shibley-Hyde & DeLamater, 2000). Males also contribute significantly to the reproductive effort by providing child care and resource provisioning in many, but not all, populations (Bribiescas, 2011; Hill & Hurtado, 1996; Howell, 2010). Traditionally, Yucatec Maya men and women in the study community both contributed to provisioning efforts. Typically, men grew corn, squash, peppers, and other plants on *milpas* and hunted small game while women processed the food at home and tended to domesticated animals like chickens, turkeys, ducks, and pigs (Kramer, 2005; Veile & Kramer, 2018). During periods of seasonal harvest, women and children would accompany men to the *milpas* and help collect crops. This pattern of labor is still observed in the study community, though men and women also participate in wage labor and market economies (Kramer, 2005; Veile & Kramer, 2018). Early reproductive cessation has become more common in the Yucatec Maya as women take advantage of sterilization procedures, like tubal ligation, to prevent future pregnancy. This topic will be revisited later in this thesis.

Somatic deterioration and the end of the reproductive phase for females marks the beginning of senescence. Women undergo menopause when their supply of eggs is depleted and the ovaries cease to produce estrogen (Beyene, 1997; Leidy-Sievert, 2011; Shibley-Hyde & DeLamater, 2000). Men do not undergo a similarly definitive end to their reproductive careers, though the amount of sperm produced does diminish in old age (Bribiescas, 2011; Shibley-Hyde & DeLamater, 2000). In many cultural contexts, women and men gain even higher social status as community elders (Beyene, 1997; Ellison, 2001). Though older individuals can no longer directly improve their reproductive success, senescence and menopause are argued to have adaptive benefits, as elders continue to be reproductively successful by caring for children and grandchildren, and by sharing cultural and environmental knowledge, thereby ensuring the survival of their genetic lineage (Hawkes et al., 1998). Grandparental support is an important benefit for young women who begin their reproductive careers earlier in the life course and may not have the social or environmental knowledge required to successfully raise and feed a child (Hawkes et al., 1998; Kramer, 2017). For the Yucatec Maya, older women and men continue to work and contribute to their household until they are physically unable (Kramer, 2005). In recent years, diabetes has become a more common morbidity associated with old age. Our knowledge of diabetes prevalence in this population comes almost exclusively from interview data as a dataset of diabetes incidence does not currently exist.

Reproductive effort and investment throughout the life course is central to understanding the timing of certain physiological and social events like puberty, adulthood, and old age. A substantial proportion of the current work on energetic investment and human adaptation focuses completely on reproduction. This body of work, termed human reproductive ecology, is constructive in understanding changes in birth mode in the Yucatec Maya independent of other facets of LHT.

1.2 Human Reproductive Ecology

Often folded into LHT, human reproductive ecology [HRE] is a framework for describing female and male reproductive biology in the context of ecological selective pressures (Ellison, 2011; Vitzthum, 2009). While LHT is focused on variation in life histories, HRE deals with variation in reproductive function, adaptations, and behavior across populations. HRE initially grew as a collaboration between human demographers and reproductive biologists in the animal sciences (Ellison, 1990; Valeggia & Núñez-de la Mora, 2015). HRE assumes that natural selection shapes variation in female and male reproductive biology and that different populations may vary based on environmental conditions and cues (Ellison, 2011; Valeggia & Núñez-de la Mora, 2015). Interest from biological anthropologists, who seek to connect human biology with evolutionary theory and environmental pressures, have contextualized their work within multiple cultural settings in order to observe the effect of ecological adaptations on human reproductive biology (Ellison, 1990, 2001; Valeggia & Núñez-de la Mora, 2015; Vitzthum, 2009). Traditionally, this work has been conducted with natural fertility populations.

Similar to LHT, HRE research with natural fertility populations has served as the basis for understanding human physiological function and adaptation under relatively resource-scare conditions with limited medical intervention (Blurton Jones, 2006; Ellison, 2011; Hill & Hurtado, 1996; Howell, 2010; Kaplan et al., 2000; Konner & Worthman, 1980; Valeggia & Núñez-de la Mora, 2015). By working with natural fertility populations, anthropologists have been able to situate the timing and physiological processes underlying female and male reproductive maturity, function, and expiration in ecological context, while acknowledging that these processes vary cross-culturally (Allal, Sear, Prentice, & Mace, 2004; Ellison, 2001; Hrdy, 2011; Jasienska, 2009). For example, research conducted with the Lese of central Africa (Ellison, 1990, 1994, 2001) established a basic understanding of the impact that nutritional fluctuation can have on ovulatory regulation and energetic resources, while contemporaneous work in rural Nepal (Panter-Brick, 1993) disclosed the high energetic demands of lactation and pregnancy. Natural fertility populations are distinct from settings where medical intervention is common and energetic stress is minimized, as might be the case in industrialized populations. In clinical studies that utilize industrial populations, it may be difficult to control or account for individual factors like environment, early development, medication, and stress load, which can warp the application of biological functions over multiple populations and cultures. In industrialized settings, reproductive patterns [e.g., late reproduction and low fertility] diverge substantially from ancestral conditions, making it challenging to draw meaningful conclusions regarding reproductive adaptations. Natural fertility populations, and especially modern-day foragers, provide an opaque lens into human ancestral conditions (Gurven et al., 2016).

Much of HRE focuses on the energetic costs of reproducing and raising offspring. As previously described, the demands of pregnancy and lactation make female reproductive efforts more energetically expensive than male reproductive effort. As a result, much of HRE scholarship is centered on female reproductive biology among human populations including their unifying features and differences. For example, studies show that women who practice traditional, labor-intensive subsistence strategies, like farming or hunting and foraging, experience dramatic seasonal differences in ovulation (Ellison, Peacock, & Lager, 1989; Jasienska, 2011; Jasienska & Ellison, 1998; Panter-Brick, 1993). Studies in a Polish farming community have shown that seasonal variation in work load and subsequent energy expenditure result in suppressed ovulation for women, despite maintaining stable weight and nutritional status throughout the year (Jasienska, 2011; Jasienska & Ellison, 1998). This suggests that ovulation and energetic status are linked; ovulation suppression during periods of high energetic stress effectively protects women from the costs of pregnancy and lactation (Jasienska, 2011; Jasienska & Ellison, 1998; Vitzthum, 2009, 2011).

Energetic demand and availability might also describe the timing of birth. From an energetic perspective, there appears to be a threshold at which the fetus becomes too expensive to sustain through gestation and too big for delivery. The energetics of gestation and growth [EGG] hypothesis posits that the metabolic demands of pregnancy will eventually become too great to support and the baby is subsequently born (Dunsworth, Warrener, Deacon, Ellison, & Pontzer, 2012; Ellison, 2001). In fact, anthropologists and biologists have noted that in many populations women do not become pregnant again until they have finished lactating (Hill & Hurtado, 1996; Howell, 2010; Valeggia & Ellison, 2004). In the Q'om/Toba of Argentina, well-nourished, postpartum women who practiced on-demand breastfeeding only resumed menstruation once they had regained sufficient fat reserves (Valeggia & Ellison, 2004). This indicates that the energetic demands of lactation may limit overall fertility in certain environmental contexts. In natural fertility contexts, the interbirth duration is often determined by energetic resources mitigated by the costs of lactation, which vary across populations.

To account for observations of variability in human reproductive biology, Vitzthum has proposed the flexible response model, to describe different reproductive strategies in energetically stressful or unpredictable environments (Vitzthum, 2011). This model assumes that considerable variation exists in reproductive functioning within and between populations and that human physiology is plastic in response to environmental conditions and subject to natural selection (Vitzthum, 2011). In energetically unpredictable environments, there are adaptive benefits to perceive current and even future environmental conditions and to delaying reproductive efforts if it seems conditions will improve (Vitzthum, 2011). This delay may be the result of physiology [e.g. ovulatory cycle regulation] or behavior [e.g. abstinence from intercourse]. Delayed reproduction is a more beneficial and energetically efficient reproductive strategy than obligatory reproduction in any environment, whether or not conditions are favorable. Spontaneous abortion can be viewed under the flexible response model as a protective mechanism enacted by the gestating body in response to unfavorable environmental conditions (Hill & Hurtado, 1996; Vitzthum, 2009, 2011). Supporting offspring up through childhood also places energetic demands on the parents, but in small-scale societies this burden is frequently distributed amongst family and group members (Hawkes et al., 1998; Hrdy, 2011; Kramer, 2005). Maternal-child outcomes during pregnancy and lactation improve with alloparenting support from partners, parents, kin, and other group members (Hawkes et al., 1998; Hrdy, 2011). This may take the form of food provisioning to the mother or distributing the burden of childcare to others.

Increasingly, global changes in labor, food acquisition, and healthcare access have transformative impacts on reproduction and development through the life course (Valeggia & Núñez-de la Mora, 2015). Accelerated globalization in the last century has prompted investigations of subsequent transformations in human biology and reproduction. In communities with greater access to healthcare, global connectivity, and highly processed foods, we see trends of both positive and negative health outcomes (Hoke & Leatherman, 2018; Veile & Kramer, 2016). Rates of maternal mortality have decreased while incidence of certain metabolic diseases, like diabetes and obesity, have increased (Alkema et al., 2016; Clausen et al., 2005; Shen & Williamson, 1999). Worldwide, the age at first menses, which is connected with fatness in adolescent girls, has progressively become younger and younger as a result of access to highly caloric, readily available food and decreases in energy expenditure (Wells, 2016). The investigation of breastfeeding in the Q'om/Toba even suggested that the recovery of fat reserves had become easier for women because of recent changes to diet and lifestyle (Valeggia & Ellison, 2004). Specifically, women were urbanized and more sedentary than previous generations, their diet was lower in protein and higher in fat, and the age at first birth was older than previous generations.

These changes are consistent with many other modernizing populations, including the Yucatec Maya community. The introduction of labor-saving technology in the 1990s gave women more free-time in which to relax and socialize (Kramer & McMillan, 1998, 2000, 2006). It was also found that women began having children earlier once this technology was introduced. Medical interventions and access to contraception have decreased fertility rates since the 1990s and pushed back the age at first birth. Metabolic diseases like diabetes and obesity are more common for adults in this population while maximum adult stature has not changed significantly between generations (Tuller, Veile, & Kramer, 2019; Veile, Valeggia, & Kramer, 2019). The increase in obesity and diabetes is understood from interviews with participants who have been medically diagnosed with either morbidity. A longitudinal dataset on diabetes and obesity prevalence does not currently exist for this sample, but is needed to make definitive claims about the impact that each has on individuals and the greater community. This is especially relevant as diabetes and obesity put pregnant women at higher risk for obstetric complications like gestational diabetes, preeclampsia, hypertension risk, and obstructed labor (Clausen et al., 2005; Ferreira et al., 2009; M. S. Harrison et al., 2015; Wells, 2017).

1.3 Biocultural Anthropology

It is useful to apply a biocultural lens when examining potential changes to reproductive biology made by social and economic forces. While researchers have discussed interactions between culture and biology for decades, the biocultural synthesis was formally proposed in the 1990's and 2000's as a way to examine recent biological changes in human populations through a sociocultural and environmental lens (Dufour, 2006; Goodman & Leatherman, 2001; Zuckerman & Armelagos, 2011). By recognizing the impact that social systems like poverty, racism, and beliefs have on human biology, anthropologists gain a broader understanding of human adaptive capacity (Dufour, 2006; Goodman & Leatherman, 2001). Though prevailing, biocultural anthropology has often focused on human health and biology, broadly considering "culture" to be any structure that is created and upheld by people (Dressler, 2005; Dufour, 2006). Biocultural perspectives on human health are especially useful in populations experiencing rapid modernization and a transition away from traditional lifeways. In this context, modernization refers to prolonged exposure to different social tenets, institutions, and technologies associated with mainstream Western society (Sam & Berry, 2010; Veile & Kramer, 2015). Modernization in this sense describes changes that many populations undergo when encountering exposure to market economies, formalized educational systems, Western biomedicine, and neoliberal values, but does not mean to label the population as "primitive" or "backward" or to give a value to its perceived level of "modernity."

The biocultural synthesis initially gained prominence in archaeological and bioarchaeological research, which is concerned with human biological remains in archaeology (Goodman, 2001). Investigations of past populations, their biology, and culture, frequently combine multiple lines of evidence to make inferences on populations and individuals in the ancient past. Excavation and treatment of human remains has evolved with the field over the past 20-30 years to incorporate an understanding of the osteological material as representative of a once living person (Agarwal & Glencross, 2011; Blom, 2005; White & Folkens, 2005; Wood et al., 1992). Bones and the archaeological remains of an individual can reflect the health, cultural, political, and environmental experiences of that person. Unequal treatment and access can also be assessed in bioarchaeology using osteological indicators of growth, trauma, and even disease in some contexts (Goodman, 2001). Frequently, bioarchaeologists examine hypoplastic lesions, which present as striations in dental enamel or long bones when growth was stopped or stunted during childhood (Goodman, 2001; White & Folkens, 2005). This has been used to infer nutritional access in early life, which can sometimes indicate an individual's status within a social hierarchy (Rothschild, 1979).

Restricted nutritional access is a common proxy for social status in biology and archaeology because it can reflect other cultural structures and institutions that subsequently restrict food access. Poverty and malnutrition can have major repercussions for health and disease patterns across generations (Dufour, 2006; Thomas, 2001; Wells, 2010). Poverty is often described as a difficult cycle to break as its conditions and social stigmas are frequently institutionalized and passed on between generations (Thomas, 2001). The undue stress place on affected individuals can manifest as chronic morbidities such as hypertension, diabetes, and cardiovascular disease (Gravlee, 2009; Krieger; Wells, 2010). These and other experiences of energetic stress may also be imprinted on future generations via fetal programing and epigenetics (Kuzawa, 2005; Kuzawa & Quinn). A proposed reason for why Yucatec Maya populations are characteristically quite short incorporates bioarchaeological and historical evidence. Declining health during the Late Pre-Classic age of Maya civilization, compounded by Spanish colonialism, may partially explain stature losses due to poor health and high stress (Anderson, 2005; McCullough, 1982). The intergenerational effects of short stature are also visible in contemporary populations that continue to live under conditions of poverty and low resource accessibility (Dickinson et al., 2018).

Less visible in archaeological populations, but discernable in contemporary ones, is the impact of social norms and behavior on individual and population health. Birth, also called parturition, is an excellent example of a biologically universal human life history event that can be culturally managed in a variety of ways. Birth remains a significant, universal experience, though how it proceeds and who participates in the process has changed in the last half century in many parts of the world (Jordan, 1992; Rutherford et al., 2019; Trevathan, 2010; Wolf, 2018). Traditionally in many human populations around the globe, birth is attended by a midwife to help deliver the infant and tend to the person in labor (Jordan, 1992; Stone, 2016). Family members may also participate in the birthing process, which can take hours or days in extreme cases, and be potentially dangerous to the infant and the person in labor. Parturition is highly stressful in humans to the point where assisted birth is observed in nearly all cultures (Ellison, 2001; Hill & Hurtado, 1996; Howell, 2010; Rosenberg & Trevathan, 2002).

Using the Yucatec Maya as an example, young women reach menarche between ages 13 and 15 (Beyene, 1997; Eveleth & Tanner, 1976; Kramer, 2005) but do not start having children until they reach their twenties. Yucatec Maya mothers continued to have children until they reached menopause around age 45 (Beyene, 1997; Kramer, 2005; Kramer & McMillan, 2006; Veile & Kramer, 2018). Total fertility rates reached 7 or 8 children per mother in the past 50 years, but today the average is between 2 and 3. Pregnancy outside of marriage is rare in this community and the husband typically is present during parturition. Though many women now may give birth in a hospital with a physician, some women still prefer to give birth in a familiar setting, such as their home, attended by a midwife (Tuller et al., 2019; Veile & Kramer, 2018). This reflects human evolutionary history, wherein birth was likely attended by another person to help support the laboring person and successfully bring the infant out into the world.

1.4 Evolution of Birth

Aspects of human reproductive physiology and life history have changed since our evolutionary divergence from our closest living relatives, chimpanzees [*Pan troglodytes*] at around 7 million years ago (Klein, 2009). Significant changes include bipedality, tripling in brain size, larger infant size, female pelvic widening, lengthening of the childhood and juvenile phases that include "an exaggerated growth spurt" in anticipation of reproductive maturity, increased fat deposition combined with decreased muscle mass in both sexes, shorter birth intervals, and increased total longevity (Ellison, 2011). Though no fossil evidence currently exists, anthropologists infer that the human-chimp last common ancestor [LCA] who lived as recently as 5 million years ago in central Africa likely did not adhere to seasonal breeding restrictions, had long birth intervals, and experienced long periods of early development (Ellison, 2001). Inferred energetic costs of maintenance, growth, and reproduction for human ancestors show an increase in energy requirements as hominids became large bodied and large brained (Aiello & Key, 2002; Aiello & Wells, 2002).

Humans share some features of pregnancy and labor with chimpanzees, including physiology of the placenta, a similar hormonal cascade at birth, and overlapping ranges of gestation length, though humans gestate for about 50 days longer than chimps (Hirata, Fuwa, Sugama, Kusunoki, & Takeshita, 2011; Trevathan, 2015; Wildman et al., 2011; Wislocki, 1933). During human birth, high levels of steroids, estrogen, progesterone, and oxytocin are produced to dilate the cervix, reduce sensitivity to pain, facilitate uterine contractions, and deliver the neonate and placenta (Shibley-Hyde & DeLamater, 2000; Trevathan, 2015). The fetus and laboring person engage in oxytocin exchange via the umbilical artery and umbilical vein during the delivery process (Ellison, 2001; Trevathan, 2015). In the final stage of birth, increased oxytocin production facilitated by breastfeeding the infant may expedite delivery of the placenta (Ellison, 2001). Potential triggers for labor and birth include hormonal signals from pregnant person or fetus, maximal fetal maturation, pressure of the descending fetus at the base of the uterus, and increases in environmental stress (Ellison, 2001; Shibley-Hyde & DeLamater, 2000; Trevathan, 2015). The need to birth larger infants also seems to have shaped some differences in human female reproductive physiology when compared to chimpanzees. Chimps have long, narrow pelvic bones that are much more accommodating to infant brain and body size than human pelvic morphology. Infant chimps are also smaller and do not exhibit the extreme encephalization of humans (Rosenberg & Trevathan, 1995; Trevathan, 2015).

1.4.1 Obstetric Dilemma: Classic Theoretical Presentation

A central contributing theory to the difficulty of human birth has to do with the size of the infant's head and the mother's pelvic opening, which was originally described as "the obstetrical dilemma" [OD] by Washburn (1960). The OD states that female pelvic morphology represents a trade-off between reproduction of large-brained infants and bipedal locomotion, which selects for a compact pelvis to maintain the center of gravity while walking (Rosenberg & Trevathan, 1995; Washburn, 1960). Humans have short, broad pelvic bones in comparison to chimpanzees because bipedal posture places the weight of the upper body on the hips. The pelvic inlet and outlet, which form the birth canal, are widest in opposing planes and narrow where they meet (Rosenberg & Trevathan, 1995). Not only do human infants have large brains, but also broad shoulders, which force the infant to rotate as it passes through the chute-like birth canal (Rosenberg & Trevathan, 2002; Trevathan, 2010, 2015). These features combined make vaginal birth relatively difficult for humans and, by extension, other members of our lineage who would also have faced constraints of birthing large infants from a bipedal pelvis.

It is theorized that assistance was required during birth as far back as 1.5 million years ago with the appearance of *Homo erectus* and accelerated brain growth, or encephalization (Trevathan, 2010, 2015). Assisted birth, or obligate midwifery, may have been an important behavioral adaptation that not only reduced fear and anxiety of the person in labor, but also improved maternal and infant survival outcomes (Rosenberg & Trevathan, 2002). In a normal vaginal birth, the infant is born facing away from the mother, making it difficult for her to reach down and pull the infant free without causing it harm (Rosenberg & Trevathan, 2002). It is therefore important to have someone present to "catch" the infant as it is born. Obligate midwifery has been described as a uniquely human activity, required to more safely deliver large infants that cannot easily pass through the narrow birth canal. Non-human primates, including chimpanzees, do not engage in these behaviors and have more spacious pelvic openings to facilitate birth. However, recent observations of chimpanzee birth indicate that some infant rotation is taking place (Hirata et al., 2011) and primatologists have also witnessed and recorded an assisted birth in white-headed langurs (Pan et al., 2014). This calls into question how unique assisted birth and rotating infants may be in humans, though more research is needed in this area. There have also been challenges made to OD that argue for the importance of phenotypic variation, environmental plasticity, and basic adaptive reasoning.

1.4.2 Obstetric Dilemma: New Perspectives

Recently, scholars have critiqued and expanded the OD hypothesis to incorporate new research and address inconsistencies. Many have challenged its evolutionary logic (Betti, 2017; Stone, 2016; Wells, 2015). For example, Wells and colleagues (2012) questioned why natural selection would produce a trait that could be potentially fatal to mother and offspring, and suggest that complications at birth are more likely the result of contemporary environmental conditions. This assertion will be discussed at length in the next section of this paper. Others have argued that pelvic width does not reduce locomotive efficiency. Theoretically, bipedal locomotion would select for narrow pelvic morphology to keep the center of gravity centralized while walking and subsequently spending a good amount of time balanced on one leg (Betti, 2017; Schmitt, 2003).

Typically, female pelvic openings are wider and round than in males and female sacra are smaller and flatter (Betti, 2017; White & Folkens, 2005). This is assumed to accommodate not only muscular support and the distribution of internal organs, but also birthing large infants. However despite historical arguments of antagonistic selection between the competing demands of bipedal efficiency and birthing large-brained infants, Warrener and colleagues (2015) found no significant additional energetic costs to having a wide pelvis while engaging in bipedal locomotion. It is also apparent that female pelvic dimensions change over the life course, becoming wider after puberty and then aligning more closely with male dimensions after age 40 (Huseynov et al., 2016). Furthermore, pelvic canal dimensions in human populations from the paleontological and archaeological record show high variability, indicating that human females share do not all share a universal birth canal shape (Grabowski, 2013; Kurki, 2013; Wells, 2015).

Environmental conditions and nutritional availability also appear to have a greater effect on development and variation in pelvic dimensions than previously thought. For example, early-life malnutrition can result in smaller overall body size at adulthood (Bogin & Loucky, 1997; Bogin et al., 2002; Eveleth & Tanner, 1976; Martorell, 1989). Wells (2015); (2012) and his collaborators posit that maternal pelvic dimensions, and fetal cranial and body size, are both influenced by external ecological and energetic conditions. Fetal growth is especially sensitive to external cues from the immediate environment, which are experienced and conferred by the mother (Kuzawa, 2005; Kuzawa & Quinn, 2009; Rutherford, 2013; Wells, 2015). Importantly, the mother's fetal environment may have been very different from that of her own fetus, meaning they undergo different adaptive responses in reaction to different environmental cues. This encompasses both ecological and social factors that may impede optimal development and birth outcomes. For example, many populations globally are experiencing a nutritional transition, where traditional foods and practices are replaced by highly processed market goods and energy expenditure decreases (Popkin, 2011; Sam & Berry, 2010). The effects of these dramatic changes to food access and nutrition thus have broader and more dramatic impacts on maternal-child health (Azcorra et al., 2013; Ferreira et al., 2009; Wells, 2010). Health conditions associated with the nutritional transition like increased incidence of obesity, diabetes, and cesarean sections [CS] will the discussed in the following sections.

1.4.3 Evolutionary Biology & Obstetric Complications in Contemporary Populations

Whether or not the OD is a significant pressure on maternal and fetal physiology has not been clearly established. Even so, obstructed labor remains a risk for birth and accounted for 6% of maternal deaths in the year 2000 (Dolea & Abou Zahr, 2003; M. S. Harrison et al., 2015). In the postpartum phase, maternal morbidity due to obstructed labor can extend to musculoskeletal injury, vaginal scarring, fistula, severe anemia, and secondary infertility. The majority of all maternal deaths occur in countries and regions with limited reproductive healthcare resources and education. A Nigerian study found that obstructed labor occurred in 120 of 4,521 observed births in a public teaching hospital, and that the majority affected women who occupied the lowest social class and had little or no formal education (Nwogu-Ikojo, Nweze, & Ezegwui, 2008). Cephalopelvic disproportion was reported to account for over 50% of obstructed labor cases at this hospital. A global comparison found that women who experienced obstructed or prolonged labor were more likely to have BMI's over 25 kg/m^2 and give birth to infants over 3500g (M. S. Harrison et al., 2015). Of all the global regions compared, Pakistan had higher instances of obstructed or prolonged labor, due to either poor healthcare or inconsistencies in how parameters are defined (M. S. Harrison et al., 2015). An investigation of maternal mortality in Thatta, Pakistan found that rates of maternal and infant mortality were indeed higher when compared to five other global regions (Pasha et al., 2015).

Numerous studies of global maternal mortality have made direct connections between maternal outcomes, the quality of care received, and level of development available to women in that region or country (K. A. Harrison, 1985; M. S. Harrison et al., 2015; Nwogu-Ikojo et al., 2008; Pasha et al., 2015; Shen & Williamson, 1999; Stone, 2016). In both the previously discussed investigations of Nigerian and Pakistani hospitals, the lack of women's education and social empowerment were connected to maternal outcomes in terms of decision-making power (Nwogu-Ikojo et al., 2008; Pasha et al., 2015). A Mexican study also found that women's education and economic status did indeed impact maternal health outcomes, but that competent delivery was a major predictor of maternal and infant outcomes (Romero-Gutiérrez, Espitia-Vera, Ponce-Ponce de León, & Huerta-Vargas, 2007).

Acquiring adequate nutrition is also connected to maternal health outcomes. It is well-known that malnutrition and vitamin deficiency during pregnancy can result in fetal congenital deficiencies, on top of placing energetic stress on the gestating person (Abu-Saad & Fraser, 2010; Casanova et al., 2019; Jasienska, 2013; Trevathan, 2015). This is of course linked to limitations of access in terms of energetics, economics, and care, which has already been established as a major burden on maternal health outcomes. To restate from above, reduced nutritional access throughout life can also impact growth trajectories and stature attained at adulthood. Short stature is the subject of recent research on obstetric complications in a variety of global settings and may also be affecting the Yucatec Maya study community.

1.5 Stature, Reproductive Outcomes & Obstetric Complications

Stature has been described as an indicator of health, stress, and/or biological fitness across human populations. Eveleth and Tanner (1976) documented global patterns in growth and development, referring specifically to stature as an indicator of early nutrition and resource accessibility in some populations. It has been stated that stature also differs geographically in accordance with changes in temperature, biodiversity, and precipitation (Eveleth & Tanner, 1976; Migliano & Guillon, 2012; Wells, Saunders, Lea, Cortina-Borja, & Shirley, 2019). Bergmann (1847) and Allen (1877) are the main contributors to the prevailing hypothesis that humans tend to be tall and slender in hot climates but short and stout in colder ones, which corresponds to the amount of exposed surface area of an individual's body and their ability to thermoregulate. Recently, it has been found that both lean mass, including internal organs, and fat mass change in response to resource availability in hot and cold climates, which may complicate Bergmann and Allen's hypotheses (Wells et al., 2019). There are also many short populations that live in hot climates with high precipitation and dense forestation, including the Maya of southern Mexico and Central America. Several theories have been presented to provide an adaptive explanation to this phenomenon including nutrient and carbohydrate deficiency (Dietz, Marino, Peacock, & Bailey, 1989), reduced need for thermoregulation (Cavalli-Sforza, 1986), and easier mobility in dense brush (Migliano & Guillon, 2012; Turnbull, 1986). It has also been noted that many smaller species of larger animals, like elephants, are found in dense forests (Migliano & Guillon, 2012; Morgan & Lee, 2003). Despite this body of work, there is not a unifying theory to explain why so-called "pygmy" groups exist in hot, humid areas of the world. Population-specific histories and adaptive pressures may provide a better explanation of this phenomenon.

Investigations of stature with Maya populations in Mexico and Guatemala have focused on nutritional access and energetic stress experienced before adult stature is attained (Azcorra et al., 2015; Bogin & Loucky, 1997; Bogin, Varela Silva, & Rios, 2007; Varela-Silva et al., 2009) and the influence of colonial oppression on Maya health and biology (Anderson, 2005; Bogin et al., 2007; McCullough, 1982). As previously mentioned, osteological evidence indicates that adult male stature has steadily decreased due to declining health since the Late Pre-Classic era of Maya society (McCullough, 1982). The impact of Spanish colonialism likely preserved Maya short stature as many suffered extreme stress during their lifetime due to slavery, subjugation, and colonial dispersion of Yucatec Maya populations to remote areas (Anderson, 2005; Bogin & Loucky, 1997; Bogin et al., 2007; McCullough, 1982). These effects are still observable in contemporary populations that continue to live under conditions of urban poverty and low resource accessibility (Dickinson et al., 2018). While biocultural structures of historical oppression and poverty may not entirely explain why the Maya are distinctively short, it has been shown that changes to early life developmental conditions do have positive effects on Maya height and body size (Bogin & Loucky, 1997; Bogin et al., 2007). In 2010, after the initiation of the energetic and nutritional transition in the Yucatec Maya study community, average adult stature was 156.1 cm for males and 143.2 cm for females, nearly 4 cm taller than adult averages from 40 years before (Tuller et al., 2019).

Stature also has implications for female reproductive outcomes based on biological indicators such as age at menarche and completed fertility. Short stature, here referring to an adult height less than 150 cm, has been found by some researchers to be associated with early sexual maturation, or menarche (Georgiadis, Mantzoros, Evagelopoulou, & Spentzos, 1997; Onland-Moret et al., 2005). This is related to the finding by Migliano and Guillon (2012) that short stature in the Efe, a pygmy group living in the Ituri rainforest of the Democratic Republic of Congo, is associated with faster life histories and earlier maturation, suggesting a trade-off between somatic growth and reproduction. Work with the Efe did not account for nutritional access or epidemiological burden, which can impact growth trajectories early in life. Shortness has been linked to varying levels of positive or negative reproductive outcomes depending on environmental conditions and access to resources (Allal et al., 2004; Ferreira et al., 2009; Hernandez-Diaz et al., 1999; Martorell, Delgado, Delgado, Valverde, & Klein, 1981). However, shortness independent of energetic or epidemiological burdens, has been associated with obstetric complications and increased CS rate (Kirchengast & Hartmann, 2007; Sheiner et al., 2005).

Short stature is also frequently associated with obstructed labor, whether manifested as cephalopelvic disproportion or fetal macrosomia (Dewey & Begum, 2011; Möller & Lindmark, 1997; Omole-Ohonsi & Ashimi, 2007; Toh-adam et al., 2012). This has been linked back to the OD and the possible trade-off between large brains and bipedal anatomy, as smaller bodies are perceived as having smaller pelvic dimensions (Ellison, 2001; Möller & Lindmark, 1997; Stulp & Barrett, 2016; Wells, 2015; Wells et al., 2012). However, it is important to mention that pelvic dimensions may not change with body size to be directly proportionate (Betti, 2017; Wells et al., 2012). As previously deliberated, it is unknown whether or not the OD is real phenomenon that restricts reproductive health and success.

Concurrent short stature and obesity have been hypothesized by Wells (2010, 2016; 2012) as possible outcomes of the nutritional transition, which refers to the displacement of traditional diets by refined foods, and a decline in physical activity level (Popkin, 2011). These morbidities may also result from the burden of malnutrition, even as a nutritional transition takes place (Azcorra et al.). Short stature and obesity in turn are associated with fetal macrosomia and cephalopelvic disproportion. Fetal macrosomia is defined as an infant who has a birth weight of more than 4 kg, regardless of their gestational age (Chauhan et al., 2005; Clinic, 2015). Infants who are over 4 kilos can make vaginal birth dangerous for the mother and infant. Cephalopelvic disproportion occurs when a baby's head or body is too large to fit through the mother's pelvis (Association, 2015). When available, birth by cesarean section is necessary to successfully deliver the infant (Rosenberg & Trevathan, 2018; Shibley-Hyde & DeLamater, 2000). Research indicates that women who are short-statured within population averages are at higher risk of obstetric complications due to cephalopelvic disproportion (Azcorra et al., 2018; Möller & Lindmark, 1997; Toh-adam et al., 2012). Maternal obesity is also associated with cephalopelvic disproportion and fetal macrosomia and may increase the potential for CS as evidenced by data from the Netherlands, Tanzania, Israel, Thailand, and Lithuania (Clausen et al., 2005; Kirchengast & Hartmann, 2007; Möller & Lindmark, 1997; Sheiner et al., 2005; Toh-adam et al., 2012). However, Stulp and Barrett (2016) caution researchers to avoid generalizations, because we may see an effect of stature on obstetric complications within but not between communities. Though safe access to CS is limited in many areas of the world, it is conversely overused in others. The implications of the excessive application of CS has called the attention of anthropologists, doctors, and health practitioners concerned with maternal child outcomes (Betrán et al., 2016; Rosenberg & Trevathan, 2018).

1.6 Cesarean Birth

A CS requires surgically extracting the neonate from the womb through an incision in the abdomen (Rosenberg & Trevathan, 2018; Rutherford et al., 2019). The short- and long-term impacts of CS on women and children have mainly been investigated in clinical settings in the United States and Europe (Dominguez-Bello et al., 2016; Hyde, Mostyn, Modi, & Kemp, 2012; Keag et al., 2018; Kearney et al., 1990; Veile & Kramer, 2016). The economic and individual health costs of unnecessary CS are potentially quite high and may be intensified in settings with low resource access, poor infrastructure, and limited care options. While CS can be a necessary emergency procedure, it's over-application in recent decades has prompted researchers to investigate the risks associated with the operation. Before the use of anesthesia in surgery and medicine, doctors were reluctant to make use of CS in emergency situations because of the harm it would cause the mother (Wolf, 2018). Even in advanced medical settings, there is a higher risk of maternal mortality associated with CS than vaginal birth due to complications after surgery. A French study found that CS was significantly associated with maternal death due to infection, blood clotting, and complications of anesthesia (Deneux-Tharaux, Carmona, Bouvier-Colle, & Bréart, 2006). CS is also associated with a range of postpartum morbidities. A systematic review of the risks and benefits of CS found that subsequent pregnancies were more likely to be complicated by miscarriages, placenta previa, placenta accrete, and placental abruption (Keag et al., 2018). CS is also frequently associated with poor breastfeeding outcomes, impaired by post-surgery separation of mother and infant (Kearney et al., 1990; Pérez-Escamilla, Maulén-Radovan, & Dewey, 1996; Rowe-Murray & Fisher, 2002; Zanardo et al., 2010).

While CS rates can range up to and above 50% in some regions, the prescribed justifications for the procedure are not consistent. A common reason for CS is attributed to failure of the birth to progress, indicating that birth is taking too long according to Friedman's curve, which measures "normal" durations of labor up to 14 hours (Dekker, 2013; Friedman, 1955; Rutherford et al., 2019). Friedman's curve has been criticized recently as a measurement of normal birth, since it is not uncommon for labor to exceed 14 hours without negative outcomes for the infant or laboring person (Dekker, 2013; Rutherford et al., 2019). It is likely that CS rates in excess of 15%, which was estimated by the WHO as sufficient to encompass emergency CS, are medically unnecessary and therefore increase the probability of complication and injury.

While the notable increase in CS delivery in the last 35 years has led researches to question it's driving causes and consequences, it is apparent they vary between global region and population (Betrán et al., 2007; Mariani & Vain, 2019; Rosenberg & Trevathan, 2018; Rosenberg & Veile, 2019; Sobhy et al., 2019; Veile, Valeggia, et al., 2019). The increase in CS is not observed in all regions or nations of the world. Many countries fall below 10%, which is the WHO recommended minimum for CS to capture emergency and medically necessary procedures (*WHO Statement on Cesarean Section Rates*, 2015). The majority of these countries are considered "least developed" by the United Nations (Betrán et al., 2007). However, countries at a slightly greater level of economic development have exceedingly high CS rates. In 1990, Latin America and the Caribbean had a regional cesarean rate of 22.8%, which rose to 42.2% in 2014, the most rapid rate of increase compared to other global regions (Mariani & Vain, 2019). Differences in these rates have been broken down by country, region, demographic, as well as public and private hospital setting. For example, in Argentina the average cesarean rate for public hospitals is 30%, ranging from 23% in Chaco province to 49% in La Rioja, but over 50% of births in private hospitals are CS deliveries (Mariani & Vain, 2019).

CS is often performed because of obstetric complications during birth. According to the American Pregnancy Association, medical reasons for a CS might include high maternal blood pressure, breech position of the fetus, uterine rupture, or fetal distress (Association). Specific criteria are globally debated, though many nations, including much of Latin America follow the same standards as the United States. Cephalopelvic disproportion is also a risk factor for CS as well as fetal macrosomia. Both cephalopelvic disproportion and fetal macrosomia are associated with maternal short stature and obesity (Clausen et al., 2005; Möller & Lindmark, 1997; Sheiner et al., 2005; Toh-adam et al., 2012). The impact of diabetes, obesity, and short stature on maternal-child health outcomes has been connected with global changes in nutritional and physical activity (Wells, 2015; Wells et al., 2012). This may be one factor driving increased CS rates in specific regions of the world, and will be further discussed throughout this paper.

Women may also request non-emergency CS for a number of reasons. A recent study in the United States indicated that almost half of women who had CS delivery expressed a fear of vaginal birth (Reyes & Rosenberg, 2019). This procedure is also frequently planned ahead of expected delivery to facilitate the time constraints of either or both patient and doctor. This has become a more commonly observed phenomenon especially in Latin America (Mariani & Vain, 2019; Veile, Valeggia, et al., 2019). Overcrowding in hospitals can contribute to the emerging pattern of scheduling CS in order to free up bed space and the attention of doctors. Ethnographic data collection in Mexico indicates that this is a more frequent occurrence in rural hospitals, especially as women are encouraged to take advantage of biomedical resources locally (Smith-Oka, 2015; Tuller et al., 2019). Recovery from a CS is often contingent on individual access to medical resources, sanitary infrastructure, and healthcare as well as sociopolitical dimensions that define their experience during parturition (Rosenberg & Trevathan, 2018; Rutherford et al., 2019; Wolf, 2018). While early studies found that higher socioeconomic [SES] status was affiliated with a higher risk of CS (Sakala, 1993), CS delivery has become increasingly common in low SES regions (Gibbons et al., 2012; Siqueira Boccolini, Pérez-Escamilla, Justo Giugliani, & de Moraes Mello Boccolini, 2015; Wolf, 2018). CS is an expensive procedure, not just for the patient but for local medical institutions and governments (Gibbons et al., 2012). Despite this fact, many low-income countries spend millions of US dollars on cesarean deliveries per year (Gibbons et al., 2012). It is unclear what is propelling high CS rates in these global regions, though the specific reasons are likely to be contextually distinct to each population.

For neonates, research indicates that passage through the birth canal during a normal, vaginal birth is necessary for respiratory function, immunity, and developing diverse microflora both internally and externally (Dominguez-Bello et al., 2016; Hyde et al., 2012). The stress experienced by the infant during birth catalyzes cortisol secretion, which is necessary for respiratory development and the dissipation of fluid from the lungs. It also contributes to function and maturation of the thyroid, gut, and endocrine systems (Hillman, Kallapur, & Jobe, 2012; Hyde et al., 2012). This response is dampened if the neonate undergoes CS birth with no attempted labor. CS delivery also deters breastfeeding immediately after delivery. While a neonate may begin breastfeeding immediately after a homebirth or vaginal birth, it can be hours before a neonate begins breastfeeding after a CS birth while the patient recovers from surgery. Breastfeeding immediately after birth is necessary not only for mother-infant bonding, but for strengthening immunity and digestive function (Prior et al., 2012; Siqueira Boccolini et al., 2015; Veile & Kramer, 2015, 2018).

1.7 Birth & Obstetrics in Mexico

Because Latin America has the highest rate of increase in CS, it's necessary to contextualize this trend with sociocultural histories of the region. In Latin America, stature and obstetrics are connected to a broader narrative of eugenics and racism against indigenous peoples. In the early 20th century, several Latin American nations adopted eugenic policy and medical practices specifically aimed at women's reproduction. In Mexico during this period of time, positivist and social Darwinian ideals permeated medical science and obstetrics (O'Brien, 2012; Schell & Bashford, 2010). Short, indigenous women were assumed to have inferior reproductive anatomy and therefore doctors regularly performed non-consensual cesarean sections sterility operations. This practice has since been condemned in Mexico, though contemporary examples of forced or non-consensual sterilization occasionally come into public knowledge (Onland-Moret et al., 2005). The legacy of this practice in Yucatec Maya populations has not been well explored in the literature, though the study village was isolated from biomedical intervention until the mid-20th century (Kramer, 2005; Veile & Kramer, 2018). Ethnographic evidence in indicates that Yucatec Maya women participated in voluntary sterilization procedures beginning in the 1990s. While this was initially considered strange, frightening, and improper, tubal ligation is now the most common form of contraception in the study community.

Anthropologists have also published accounts of microaggressive behavior and underlying prejudice displayed by medical practitioners when interacting with indigenous women and mothers (Braff, 2013; Smith-Oka, 2015). This refers to disparaging, insulting behavior directed towards a group of people perceived as unequal to the perpetrator (Smith-Oka, 2015; Solorzano, Ceja, & Yosso, 2000). Observations of maternal medical care in Mexico indicates that doctors, nurses, and staff focus these behaviors on indigenous and impoverished women as a result of deeply engrained race, class, and gender hierarchies in Mexico and in medicine (Braff, 2013; Smith-Oka, 2015; Smith-Oka, 2013). Historically, women were encouraged to have large families, especially if they were white, wealthy, urban, and middle class. This contributed to the idea that indigenous women, who were by virtue inferior to white women, would be unable to reproduce as successfully. But once family sizes shrank and white women began having less children, the stereotype flipped and indigenous women were criticized for having too many children (Braff, 2013). The portrayal of indigenous, poor, rural women as hyperfertile and hypersexual pervades some medical and bureaucratic spaces and often manifests in how pregnant indigenous women are treated (Braff, 2013; Smith-Oka, 2015). Additionally, public hospitals, in both rural and urban settings, are frequently understaffed and overburdened, exacerbating the ability of staff to provide comprehensive and empathetic care (Smith-Oka, 2015).

Biomedical intervention in the study community and others accelerated and became pervasive in the last 30-40 years (Kramer & McMillan, 2000, 2006; Veile & Kramer, 2018). Under Maya traditions, the midwife plays a significant role as she consults with the mother during pregnancy, provides massages, and attends the home birth (Güémez Pineda, 2000; Jordan, 1993). She also serves as a “supernatural specialist” (Jordan, 1989) whose work is sanctioned and who can help the family navigate potential supernatural danger. Ethnomedical practices have been recently supplemented with biomedical ones at the behest of the Mexican government. Brigitte Jordan (1989) described the training provided to indigenous midwives in the late 1980s and early 1990s as culturally inappropriate, despite the desire to do well on the part of Mexican medical practitioners. During one session, it became clear through conversation that many medical personnel felt that as midwives do not conduct CS, doctors do not perform external cephalic inversions, which move the fetus out of breech position while in the womb (Jordan, 1989). The preference for CS on the part of doctors and nurses is described as a need to move patients through the hospitals quickly and free up bed space, but some scholars have described the enforcement of medicalized birth as an exercise of power and control over women’s bodies (Rutherford et al., 2019; Smith-Oka, 2015).

CHAPTER 2. SAMPLE & METHODS

The goal of this project was to determine if maternal stature has a significant impact on reproductive outcomes and obstetric complications in three cohorts of Yucatec Maya mothers with differential access to medical care based on the timing of their births. This project utilized data that has been collected since 1992 in a single Yucatec Maya community. Anthropometric, census, and ethnographic data were made available to the author in order to answer this research question. This data had been collected by Dr. Karen Kramer and Dr. Amanda Veile since 1992 (Kramer, 2005; Veile & Kramer, 2018). The author was given access to demographic, biometric, and interview materials collected over the last 27 years. I was able to participate in interview sessions during the summer field season of 2018 and collected one interview independently with the assistance of a Yucatec Maya translator. Field work was approved by the Purdue University Institutional Review Board (Veile, 2018). Consent was verbally requested before each interview in the participant's preferred language, Spanish or Yucatec Maya.

Utilizing information from interviews and medical records [when available], the number of births, number of stillbirths, number of CS, maternal stature measurements, and rates of infant and maternal mortality were compiled and analyzed. As of 2018, this dataset included complete reproductive histories of each woman to the furthest extent allowed by interview recall and official records. Data tables were constructed in Excel and statistical tests were run using IBM-SPSS. The combination of multiple records collected over 30 years required extensive cleaning to remove irrelevant or duplicate information and to corroborate unified reproductive records. A new codebook that could be interpreted by project newcomers was also created for the completed dataset. Data cleaning, organization, and analysis were undertaken by the author from the summer of 2018 until the spring of 2019. Datasets are maintained in the Microsoft programs, Excel and Access.

2.1 Research Community

The study community comes from a small town located in Mexican state of Campeche on the Yucatán peninsula. It was founded in the early 20th century around the ruins of a 19th century hacienda, which includes a fresh water well (Kramer, 2005; Veile & Kramer, 2018). The community maintains its allotment of village, forest, and farmland granted by the governmental *ejido* system of collective land ownership. A road connecting the village to other townships and cities likely existed as early as 1935, but was not fully paved until 2005 (Kramer, 2005; Veile & Kramer, 2018). In the late 1990s, electrical lines were installed and a clinic was built, though it was not staffed with a health promoter until the early 2000s (Kramer, 2005; Veile & Kramer, 2018). In 2003, the Mexican government expanded their health insurance program, Oportunidades, and created Seguro Popular, which brought freely accessible health insurance to the nation (Salud, 2019). This made it possible for low income families, including all members of the study community, to give birth in the hospital at a very low cost. Small-scale farming on *milpas* remains the main source of food acquisition, complimented by hunted game, and domesticated farm animals like chicken, duck, turkey, and pig. Recently, processed foods high in sugar, salt, and fat have been assimilated into daily diets. Coca-Cola in particular plays a large role, not just as the local preferred beverage, but in ritual offerings and gift-giving (see Leatherman & Goodman, 2005). The introduction of mechanized farming equipment [e.g. tractors, mechanical planters, etc.], labor saving technology [e.g. washing machines, piped water, electricity, etc.], processed foods, and Western biomedicine all occurred in the last half century spanning three generations. This dramatic, almost immediate change has impacted women's labor, nutrition, and birthing experiences.

Anthropological and biological research has been ongoing at this community since the early 1990s. Contributors to this body of work have previously published on breastfeeding practices, energy allocation, childhood growth and development, and changing birthing practices (Kramer, 2005; Kramer & McMillan, 2000; Veile & Kramer, 2015, 2016, 2018). These past publications have established that with the proliferation labor saving technology, women's age at first birth became younger and completed fertility, for women who had finished reproducing, became higher (Kramer & McMillan, 1998, 2000, 2006). The CS rate has increased for Maya women in this community from 4% [1982-1992, n=137] to 25% [2000-2017, n=155] since medical care became more accessible. This frequency increases to 32% when only hospital births are considered [2000-2017, n = 122]. Children in this community born via CS were found to have higher BMI that those born vaginally, but childhood obesity has not yet been observed in this community (Veile, Faria, et al., 2019; Veile & Kramer, 2015). While CS has been associated with negative breastfeeding outcomes compared to vaginal birth, mothers in this community breastfeed for 2.6 years (Veile & Kramer, 2015).

Data for the current project are derived from demographic and anthropometric collection from 1992 to 2018, but include birth records from as early as the 1940s. Participants were selected based on availability and quality of data related to reproductive history, child survivorship, and adult stature before menopause. While reproductive histories and child survivorship data were gathered through individual and group interviews (Bernard, 2011), stature was collected using a Seca 213 portable stadiometer. Stature measurements for children and adults were gathered during visits for interviews at a family household. Following methods from Lohman and colleagues (Lohman, Roche, & Martorell, 1988), participants were asked to stand barefoot on a flat surface, straight against the vertical metric rule with shoulders relaxed. A sliding horizontal headboard was brought to the superior-most point of the participant's crown to obtain an accurate measurement of height in centimeters. Stature measurements for women between ages 20 and 40 were considered accurate maternal height. When maternal height was not available, stature loss over time was calculated to equal 0.02 cm per year. This number was derived by subtracting the mean height in 2012 from the mean height in 1993 to estimate stature loss over 18 years. Height data exists for 135 women during their reproductive years.

Interviews were conducted with mothers and families regarding birth mode, birth complications, breastfeeding practices, number of living and deceased children, and general family history. Yucatec Maya is the first language of most residents, so interviews were conducted in Yucatec Maya and Spanish with a local translator. Mothers were asked to list all of their births, and to provide birthdates and birth locations [home, hospital, or other] for each child. If birthdates were unknown, which was not uncommon for older mothers, ages were estimated in relation to a major local event (Kramer, 2005). Mothers were also asked if they had ever experienced stillbirths and miscarriages. While there is no taboo against speaking about unsuccessful pregnancies, it is unlikely that our reported data on miscarriages or stillbirths is reliable. Mothers were included in this study if a complete reproductive history was available as well as their stature before menopause. For a small number of older women, stature was available but not reproductive history due to a death or migration event. If possible, husbands [if living] and/or older sisters were interviewed to obtain missing information on reproductive histories. The total sample ultimately included 132 mothers, representing 21.6% of the total community and 45.1% of all females according to the 2016 community census gathered by the researchers working in this community.

Before conducting analyses, the database on fertility and motherhood was compiled , cleaned, and coded in Excel. Criteria for inclusion in the study encompassed maternal year of first birth [YFB], maternal age at first birth [MAFB], parity, the number of hospital births, the number of CS, whether or not the mother had experienced menopause [indicated as 1 or 0], and how they became post reproductive if applicable [e.g. tubal ligation, widowed, natural menopause]. Widows were considered post-reproductive as none continued reproducing after their partner passed away. Mothers who fit the criteria were then divided according to the criteria in Table 1. Cohort divisions and definitions are based on methods established by Veile and Kramer (2018). Table 1 describes each mother cohort in terms of biomedical care available, common birth mode, and most common subsistence practices and energetic expenditure. Data on these parameters are only available from the past century. Cohort divisions were determined based on major developments in medical access and modernization. For example, between 1979 and 1999, the village gained a gas-powered corn mill and water pump, which reduced daily labor requirements of women. Meanwhile, mothers in cohort 1 reported hauling water from the well everyday, even while in labor (Veile & Kramer, 2018).

Table 1. Mother cohorts

Cohort	n	Year of First Birth [YFB]	Medical Care	Birth Mode	Subsistence and Energetics
1	23	1950-1977	Limited medical care.	Traditional midwifery, no hospital births.	Small-scale farming, high energy expenditure.
2	42	1978-1999	Some medical care.	Small number of hospital births.	Introduction of labor-saving technology. Beginning of nutritional transition.
3	67	2000-2017	Medical care available and affordable	Most births in hospital.	Low energy expenditure. Highly processed food high in sugar and saturated fat common.

Maternal and infant mortality are very low in each cohort, though it is likely stillbirths and miscarriages are underreported (Veile & Kramer, 2018). Body Mass Index [BMI] for reproductive aged females [20-40] has increased in this population from 24.8 in 1992 to 27.7 in 2015 (Veile & Kramer, 2018). This number is considered overweight by the WHO, but likely has different implications for Yucatec Maya women, who are quite short. Past work has calculated the impact of obesity for Maya communities based on population-specific means and distributions (Smith et al., 2003), however specific weight percentiles have not been produced for this study community. The increase in BMI likely reflects changes in diet and access to foods.

2.2 Statistical Modeling

To determine if stature has a significant impact on the outcome variables of interest [reproductive outcomes or obstetric complications] in each cohort of mothers, descriptive statistics were computed, and several different statistical models constructed, using IBM-SPSS. For the purpose of this project, *reproductive outcomes* are defined as 1) parity, or the number of live births to a particular mother; and the 2) percentage of a mother's children that survived beyond the first year of life. *Obstetric complication* refers to 1) the number of infant deaths within the first year of life, 2) the number of stillbirths, and 3) cesarean deliveries, when available, indicated by the number of CS in a mother's reproductive career as of 2017. Analyses of cesarean deliveries were limited to hospital births as no CS took place in a home or other birthing location. The other proxies for reproductive outcomes and obstetric complications were analyzed for all births and all mothers. Maternal height was examined as the main predictor of these five outcomes outcome variables.

In the first stage of data analysis, descriptive statistics [means, standard deviations, standard errors, 95% confidence intervals, and ranges], were computed for each maternal cohort and for all linear variables. One-way ANOVA and Bonferroni post-hoc tests were used to assess statistical differences between cohorts in the unweighted predictor and outcome variables. A one-way ANOVA test was preferred to compare the means of each cohort. A Bonferroni post-hoc was used to make pairwise comparisons of each cohort against another (Diez, Barr, & Çetinkaya-Rundel, 2015). In the second stage of analysis, univariate general linear models were used to compare the effect of multiple variables on reproductive outcomes (Diez et al., 2015). Specifically, maternal height was modeled as a predictor of reproductive outcomes and obstetric complication proxy variables [parity, infant survivorship, infant mortality, stillbirth, and CS]. Because ANOVA comparisons revealed a number of significant differences in the outcome variables across cohorts, cohort effects were accounted for in general linear models [Table 2]. Maternal cohort was therefore treated as a categorical variable and modeled in conjunction with maternal height, except in Model 6. For this last model, birthweight data was only available for births as recent as 2011.

Table 2: List of univariate general linear models.

Model	Predictor	Covariate	Outcome	Category	Outcome Variable Type
1	Maternal height [cm]	Maternal cohort [categorical]	Parity	Reproductive outcomes	Count
2	Maternal height [cm]	Maternal cohort [categorical]	Infant survivorship	Reproductive outcomes	Proportion
3	Maternal height [cm]	Maternal cohort [categorical]	Infant mortality	Obstetric complication	Count
4	Maternal height [cm]	Maternal cohort [categorical]	Stillbirth	Obstetric complication	Count
5	Maternal height [cm]	Maternal cohort [categorical]	Cesarean	Obstetric complication	Binomial
6	Infant Birthweight [g]	--	Cesarean	Obstetric complication	Binomial

In the third stage of data analysis, the statistical relationships between maternal stature, fetal macrosomia, and CS were also modeled to discern whether interactions of short maternal height and large infant birthweight would contribute the likelihood of having a CS. Mean birthweight for this population is 3.01 kg [6.8 pounds] [n=161 live births from 2011-2017, SD = 0.43, max = 4.0, min = 1.8], we computed a population-specific cutoff for macrosomia, using the 90th percentile of all available birthweights. Macrosomia is typically defined as an infant who has a birth weight of more than 4 kg, regardless of their gestational age (Chauhan et al., 2005). In this population, macrosomic birthweight is equal to or greater than 3.76 kg [8.3 pounds]. Fetal macrosomia as a predictor of CS was calculated for births with available birthweight data, extending as far back as 1993. It is unclear if birthweight has increased significantly over each cohort with modernization and the nutritional and energetic transitions.

In a preliminary analysis, logistic regression models were constructed to predict the probability of CS, where the outcome of a CS birth is indicated by 1 or 0. Predictors for this model are fetal macrosomia, maternal [non-pregnant] BMI, and maternal height. Predictors were modeled individually and they in an interaction [Table 7]. This analysis was conducted for Cohort 3, which has the most robust data on CS.

CHAPTER 3. RESULTS

As stated above, the Yucatec Maya have experienced significant change to livelihoods and health in the last 30 years. Data collected from 1992 to 2018 were utilized to create descriptive statistics [Table 3] for each maternal cohort. Over time, cohorts have seen declined fertility, slightly increased maternal height, and increased hospital and cesarean deliveries. This is due in large part to the modernization of the community and increased access to biomedical services and market goods. A summary of parity, hospital births, and CS by cohort is provided in Table 3. From this, we can infer that 20.2% of all births in Cohort 2 took place in hospital, and that 6.7% of all births were delivered by cesarean. By comparison, 78.7% of all births in Cohort 3 have been hospital births, and 25.2% of births so far have been CS. This percentage is much less than the Mexican national average of 32.8%, (Betrán et al., 2016) but represents a significant increase for this population in 29 years. The specific reasons for why a CS was performed and whether or not it was an emergency CS is not known. Notably, all mothers stated in interviews that they preferred a vaginal birth to a CS, but were willing to defer to doctors.

Table 3: Parity by Cohort

Cohort	n	Year of First Birth [YFB]	Total Parity	Fertility	# Hospital Births	# Cesarean Births
1	23	1950-1977	146	6.4	2	0
2	42	1978-1999	253	6.0	51	17
3	67	2000-2017	155*	2.3	122	39

* This does not represent completed parity.

Mean height has also increased significantly from Cohort 1 to 3, from 139.9 cm to 144.3 cm [Table 4]. This may be due to the improved availability of highly caloric foods and reduced physical stress during development, which would agree with previous work done on environmental conditions, nutrition, and growth and development (Bogin, 2001). More women have also married into the study community from other nearby communities in recent decades, potentially introducing new height variation to the population via exogamy (Veile, 2019). Parity has decreased from 7.2 in Cohort 1 to 2.3 in Cohort 3 [Table 3], due in large part to biomedical family planning options now available to mothers. Infant deaths have been characteristically low throughout all three cohorts, reaching a maximum of 3 in Cohort 2. The proportion of hospital births compared to home births, attended by midwives, also increased from Cohort 1 to 3, as did the proportion of CS births [total and compared to all hospital births]. The instance of infant deaths delivered via CS has not increased between Cohorts 2 and 3. The available high quality, high certainty data from Cohort 1 [YFB = 1950-1977] is unfortunately limited. Many mothers from this generation died before it was possible to interview them or measure their stature. In some cases, it was possible to gather birth and parity information from a woman's husband, sister, or child, but it is likely that some details were lost. This accounts for the small sample size of Cohort 1. Data collection began during the period in which Cohort 2 was in their reproductive years [YFB = 1978-1999] and represents the first generation of mothers to begin to widely give birth in a hospital, largely because of the introduction of Seguro Popular in the community. It is also during this time that the first recorded CS and tubal ligations took place. Cohort 3 [YFB = 2000-2017] offers the largest sample size and the greatest percentage of hospital and cesarean births.

Table 4. Descriptive Statistics

	Cohort Characteristics						**One-way ANOVA [between groups]**	
	Cohort	**n**	**Mean**	**SD**	**Minimum**	**Maximum**	**F**	**P Value**
Maternal Height [cm]	1	23	139.9	5.8	124.7	151.6	7.215	0.001
	2	42	143.0	4.6	133.2	153.5		
	3	67	144.3	4.6	133.8	154.2		
	Total	132	143.1	5.1	124.7	154.2		
Parity	1	23	7.2	2.4	1.0	11.0	67.166	>0.001
	2	42	6.1	2.9	1.0	15.0		
	3	67	2.3	1.2	1.0	5.0		
	Total	132	4.4	3.0	1.0	15.0		
Infant deaths [<1 year]	1	23	0.3	0.6	0.0	2.0	4.370	0.015
	2	42	0.3	0.7	0.0	3.0		
	3	67	0.1	0.2	0.0	1.0		
	Total	132	0.2	0.5	0.0	3.0		
Proportion Hospital Births	1	23	0.0	0.0	0.0	0.2	113.851	>0.001
	2	42	0.3	0.3	0.0	1.0		
	3	67	0.9	0.3	0.0	1.0		
	Total	132	0.5	0.4	0.0	1.0		
Proportion CS Births	1	23	0.0	0.0	0.0	0.0	8.894	>0.001
	2	42	0.1	0.2	0.0	1.0		
	3	67	0.3	0.4	0.0	1.0		
	Total	132	0.2	0.3	0.0	1.0		

Table 4 continued

Proportion CS Hospital Births	1	2	0.0	0.0	0.0	0.0	0.730	0.484
	2	30	0.4	0.5	0.0	1.0		
	3	66	0.3	0.4	0.0	1.0		
	Total	98	0.3	0.4	0.0	1.0		
Proportion CS Infant Deaths	1	0	0.1	0.2	0.0	1.0	2.187	0.116
	2	13	0.0	0.1	0.0	0.4		
	3	27	0.0	0.1	0.0	0.5		
	Total	40	0.0	0.1	0.0	1.0		

The post hoc Bonferroni test indicates that there is a significant difference in height between cohorts of women. Cohort 1 is on average 3.091 cm shorter than Cohort 2 and 4.435 cm shorter than Cohort 3; these differences are statistically significant. Women in Cohort 2 are on average 1.344 cm shorter than their peers in Cohort 3, however this difference is not significant. In terms of parity, women in Cohort 1 had about 4 more children than those in Cohort 3. Women in Cohort 2 had around 3 more children than women in Cohort 3. This indicates that women in Cohort 1 were shorter but were having more children than their counterparts in Cohort 3, who were taller. Infant death does not differ significantly between these three groups. Here attempts were made to correct for height loss with age. Though height at reproductive age [roughly 20-40 years old] was available for all women, 17 were measured past age 40 [n Cohort 1 = 16, n Cohort 2 = 1, n Cohort 3 = 0]. By back-calculating how many centimeters on average were lost from reproductive to post-reproductive periods [-0.02 cm per year], it was possible to estimate reproductive height for women older than 40 at the time of measurement. However, this may have affected the apparent difference in height between cohorts.

Table 5: Bonferroni Post- Hoc Test

Dependent Variable	Cohort	n	Between Cohort	Mean	SD	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Maternal Height [cm]	1	23	2	-3.091*	1.256	0.045	-6.137	-0.05
			3	-4.435*	1.170	0.001	-7.273	-1.60
	2	42	1	3.091*	1.256	0.045	0.045	6.14
			3	-1.344	0.953	0.482	-3.655	0.97
	3	67	1	4.435*	1.170	0.001	1.598	7.27
			2	1.344	0.953	0.482	-0.967	3.66
Parity	1	23	2	1.102	0.542	0.132	-0.21	2.42
			3	4.860*	0.505	<0.001	3.64	6.08
	2	42	1	-1.102	0.542	0.132	-2.42	0.21
			3	3.758*	0.411	<0.001	2.76	4.75
	3	67	1	-4.860*	0.505	<0.001	-6.08	-3.64
			2	-3.758*	0.411	<0.001	-4.75	-2.76

Table 5 continued

Infant deaths [<1 year]	1	23	2	-0.029	0.133	1.000	-0.35	0.29
			3	0.245	0.124	0.152	-0.06	0.55
	2	42	1	0.029	0.133	1.000	-0.29	0.35
			3	0.274*	0.101	0.023	0.03	0.52
	3	67	1	-0.245	0.124	0.152	-0.55	0.06
			2	-0.274*	0.101	0.023	-0.52	-0.03
Hospital Births	1	23	2	-1.127*	0.249	<0.001	-1.73	-0.52
			3	-1.734*	0.232	<0.001	-2.30	-1.17
	2	42	1	1.127*	0.249	<0.001	0.52	1.73
			3	-0.607*	0.189	0.005	-1.06	-0.15
	3	67	1	1.734*	0.232	<0.001	1.17	2.30
			2	0.607*	0.189	0.005	0.15	1.06
Cesarean Sections	1	23	2	-0.405	0.183	0.087	-0.85	0.04
			3	-0.582*	0.171	0.003	-1.00	-0.17
	2	42	1	0.405	0.183	0.087	-0.04	0.85
			3	-0.177	0.139	0.614	-0.51	0.16
	3	67	1	0.582*	0.171	0.003	0.17	1.00
			2	0.177	0.139	0.614	-0.16	0.51
Proportion Hospital Births	1	23	2	-0.250*	0.070	0.001	-0.419	-0.081
			3	-0.847*	0.065	<0.001	-1.004	-0.689
	2	42	1	0.250*	0.070	0.001	0.081	0.419
			3	-0.597*	0.053	<0.001	-0.725	-0.468
	3	67	1	0.847*	0.065	<0.001	0.689	1.004
			2	0.597*	0.053	<0.001	0.468	0.725
Proportion CS Birth	1	23	2	-0.111	0.080	0.512	-0.306	0.084
			3	-0.287*	0.075	0.001	-0.468	-0.105
	2	42	1	0.111	0.080	0.512	-0.084	0.306
			3	-0.176*	0.061	0.014	-0.324	-0.028
	3	67	1	0.287*	0.075	0.001	0.105	0.468
			2	0.176*	0.061	0.014	0.028	0.324
Proportion CS Hospital Births	1	2	2	-0.369	0.316	0.735	-1.139	0.400
			3	-0.318	0.310	0.923	-1.075	0.438
	2	30	1	0.369	0.316	0.735	-0.400	1.139
			3	0.051	0.095	1.000	-0.181	0.283
	3	66	1	0.318	0.310	0.923	-0.438	1.075
			2	-0.051	0.095	1.000	-0.283	0.181
Proportion CS Infant Death [>1 yr]	1	0	2	0.034	0.032	0.846	-0.042	0.111
			3	0.060	0.029	0.130	-0.011	0.131
	2	13	1	-0.034	0.032	0.846	-0.111	0.042
			3	0.026	0.024	0.846	-0.032	0.084
	3	27	1	-0.060	0.029	0.130	-0.131	0.011
			2	-0.026	0.024	0.846	-0.084	0.032

All univariate general linear models are presented in Table 6. In Models 1 and 2, there is no evidence that maternal height predicts reproductive outcomes, operationalized as parity and infant survivorship, neither before nor after accounting for mother cohort. In Model 1, cohort does predict parity and the trend of parity and maternal height is positive, but quite weak and non-significant. There were no cohort level differences in infant survivorship. In model 2, cohort does not predict infant survivorship and the trend with maternal height is also positive, but weak and non-significant. Models 2 and 3 indicate that maternal height was also not a significant predictor of obstetric complication, operationalized as having a stillbirth or infant death, before or after accounting for cohort and parity. Maternal height is positively associated with stillbirths in Model 4, but non-significant. The lack of available data, and potentially limited quality of data on stillbirths, especially for Cohort 1, may have impacted results in this model. In Model 5, cohort does not predict CS, despite the negative trend with maternal height that approaches statistical significance. Stillbirths for each cohort are presented in Model 4. Cohort 2 women reported the most stillbirths [OR=23.012, CI=2.263-233.984]. This odds ratio was significantly greater than Cohort 3, the default, but not significantly greater than Cohort 1. Cohort 1 reported an intermediate number of stillbirths [OR=9.731, CI=0.593-159.621] but this odds ratio did not differ significantly from Cohorts 2 or 3. There were no cohort level differences in infant mortality after accounting for parity.

Table 6: Cohort Models

Model 1: Height Predicts Parity				
Parameter	B	Std. Error	t	Sig.
Cohort 1	4.878	0.534	9.134	<0.001
Cohort 2	3.763	0.416	9.052	<0.001
Cohort 3	ref	na	na	na
Maternal height [cm]	0.004	0.038	0.105	0.916
Model 2: Height Predicts Infant survivorship				
Parameter	B	Std. Error	t	Sig.
Cohort 1	-0.056	0.031	-1.811	0.072
Cohort 2	-0.025	0.024	-1.023	0.308
Cohort 3	ref	na	na	na
Maternal height [cm]	<0.001	0.002	0.369	0.712

Table 6 continued

Model 3: Height Predicts Infant Mortality				
Parameter	B	Std. Error	t	Sig.
Cohort 1	-0.060	0.164	-0.368	0.714
Cohort 2	0.060	0.128	0.475	0.635
Cohort 3	ref	na	na	na
Maternal Height [cm]	-0.011	0.009	-1.204	0.231
Model 4: Height Predicts Stillbirths				
Parameter	B	Std. Error	t	Sig.
Cohort 1	0.209	0.103	2.034	0.044
Cohort 2	0.262	0.080	3.294	0.001
Cohort 3	ref	na	na	na
Maternal Height [cm]	0.004	0.006	0.772	0.442
Model 5: Height Predicts Cesarean Birth				
Parameter	B	Std. Error	t	Sig.
Cohort 1	-0.463	0.112	-4.148	<0.001
Cohort 2	-0.112	0.087	-1.285	0.201
Cohort 3	ref	na	na	na
Maternal Height [cm]	-0.013	0.008	-1.693	0.093

Birthweight was also not found to be a significant predictor of CS as shown by Table 7, though 36 of the 122 births, for which there is infant weight data, were cesarean deliveries. Again, this model is almost entirely represented by births in Cohort 3.

Table 7: CS Cohort Model

Model 6: Birthweight Predicts CS Birth				
Parameter	B	Std. Error	t	Sig.
Intercept	.318	.296	1.074	.286
Birthweight	.000	.000	-.271	.787

Preliminary analysis of the probability of a CS based on maternal height, macrosomia, and maternal [non-pregnant] body mass index found that only maternal height was a significant predictor of CS according to an odds ratio estimate [Table 8]. It is estimated that in this sample, which only represents Cohort 3, a one-centimeter decrease in height is associated with a 22% increase in the likelihood of a CS.

Table 8: Maternal height and fetal macrosomia as predictors of CS.

Parameters	**Odds Ratio**	**Confidence Intervals**	
		Lower	**Upper**
Maternal Height	0.88	0.78	0.99
Macrosomia	1.11	0.20	5.79

The implications of this finding and the circumstances surrounding it are intriguingly complex. Whether stature is associated with CS birth as the result of physiological forces of maternal biology remains unclear due to the low power of this study and the lack of complete biometric data. However, because the above models do not indicate that stature is associated with reproductive outcomes or obstetric complication, it may be that CS rates are increasing due to external sociocultural influences on birth mode and maternal biology. Based on past research, it is plausible that globalization and the medicalization of birth combined with medical perceptions of indigenous bodies are contributing the dramatic increase in CS rates in this community over the last 30 years. Information on the local medicalization of birth and Yucatec Maya women's interactions with medical institutions in the region come from ethnographic interview data.

3.1 Ethnographic Accounts of Birth

In interviews, all women stated a preference for vaginal births but were willing to comply with doctors who prescribe CS. For Yucatec Maya women, the medicalization of birth can have dramatic consequences. Recently, there have been increased accounts from mothers in the study sample who were forced to travel between hospitals while in labor in search of bed space or specialists. The stories of two women, Jocelyn and Maria Rosa [pseudonyms] from Cohorts 3 and 2, respectively, synthesize how institutions like medicine and poverty impact this community at the level of the individual. Each account will be described as they were by the mother during her interview. Jocelyn was interviewed by Dr. Amanda Veile in 2013 and Maria Rosa was interviewed by the author in 2018.

Jocelyn was between her 33rd and 34th week of her first pregnancy when she went for a regular check up with a gynecologist in Hopelchén, located about an hour driving from the study community [Figure 1]. There, she was told the baby was coming that very day, but it was Sunday. The local public hospital had no doctors and no incubator. She was sent to Campeche, another 2.5 hours driving. There Jocelyn and her husband waited for 4 days, but the baby didn't come. They decided to go stay with an aunt near Hecelchakán, a larger town which also had a public hospital. Jocelyn went into labor over the weekend, but once again there were no doctors and no incubator. When her blood pressure reached 150/100, the baby dropped into delivery position, and Jocelyn decided it was better to have a CS. The doctors in Hecelchakán called a public hospital in Campeche, but they were already full to capacity and there were no specialists available. Jocelyn was rushed via ambulance back to Campeche to a private hospital where doctors are legally obligated to accept women in labor. After delivery, the attending doctor said Jocelyn's daughter was fine, just 3 weeks early. Because her baby was premature and a CS, it was 5 hours before Jocelyn could breastfeed. The staff also mixed up her daughter's tags with another infant. The family returned home after 3 days in hospital.

Jocelyn's experience traveling through rural Campeche while pregnant and in labor is heard with increasing frequency during interviews. It's possible that if Jocelyn had received better care earlier, she might not have gotten to the point where a CS was necessary. Fortunately, this was Jocelyn's first birth and she and her husband own a car, something many families in this community do not have.

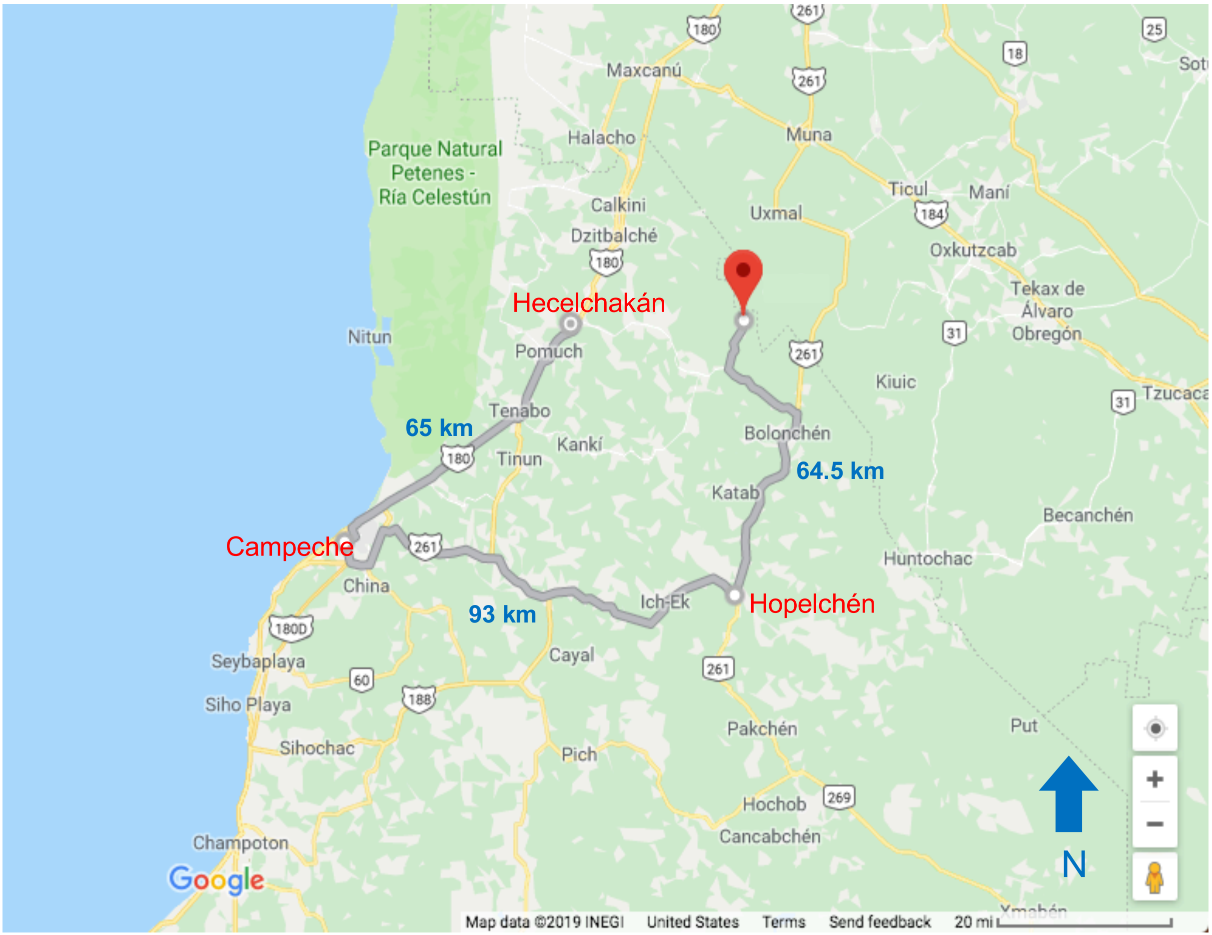

Figure 1: Map of Jocelyn's Route

By comparison, Maria Rosa was at the end of her reproductive career when she gave birth to her daughter in 2005 during Hurricane Wilma. Early one morning, 8 months into her pregnancy, Maria Rosa began to feel labor pains as a torrential rain flooded her house. With the progression of her contractions and the worsening condition of her home, she determined it would be better to give birth in a hospital even though she had initially wanted to give birth at home. She was also unwilling to leave until a family member was able to watch over her other children. Accompanied by her in-laws, they drove to the hospital in Hopelchén, but had to stop when the flooding on the highway became too difficult to traverse. Maria Rosa gave birth to her daughter in the back of the car. When they eventually arrived at the hospital at 6 o'clock at night, it was empty because everyone had evacuated for the hurricane. A doctor didn't arrive at the hospital until 10 o'clock.

Maria Rosa's daughter was healthy at birth and had just turned 13 when Maria Rosa relayed this story to me in 2018.

While Maria Rosa's story is unique in that her birth was compounded by a hurricane, it shares similarities with the experiences of other Yucatec Maya women. In interviews, many have expressed anxiety at having to leave their children at home or with another family while they travel to the hospital. Though some mothers do plan to give birth in the hospital and express a preference for hospital birth, many others prefer to give birth at home. Previous work has indicated that while all mothers in each cohort express a preference for vaginal birth, mothers in Cohort 3 prefer to give birth in a hospital, which they perceive to be a safer environment (Veile & Kramer, 2018). The locally made observation that birth is more difficult for younger women may contribute to this preference, though data analysis presented here does not indicate significant changes in obstetric complications between the cohorts. It is possible that the presence of a clinic in town encourages women to seek biomedical care during pregnancy and birth, and promotes the idea that a medical setting is necessary for a safe, healthy birth.

CHAPTER 4. DISCUSSION

While multiple measurements of individual and reproductive health were tested in this project, it was found that only maternal adult stature was associated with an increased likelihood of birth via CS. Stature was not associated with proxies for reproductive outcomes [parity, infant survivorship beyond year one] or obstetric complications [number of infant deaths within year one, number of stillbirths, and number of cesarean deliveries]. The original prediction that birthweight greater than 3.79 kg, indicating fetal macrosomia, would be associated with increased likelihood of CS was not supported. However, birthweight data for this sample are only available from as recent as 1993. Information on other proxies is also lacking due to absence of records or other commonly encountered issues in longitudinal data collection. Despite limitations derived from a relatively low-powered sample, it was possible to trace specific indicators of reproductive outcomes and obstetric complication through maternal cohorts.

The changes in stature, parity, and birth mode between maternal cohorts from 1950 to 2017 [Table 1] reflect changes in energetic pressures and resources due to modernization and the energetic and nutritional transitions. With increased caloric availability and decreased energetic demands in the 1990s, women began having more children earlier as indicated by the growth in mean parity between Cohorts 1 and 2 [Table 5] (Kramer & McMillan, 1998, 2000, 2006). This fits within the flexible response model of human reproductive ecology [HRE] and basic applications of energetic investment (Hill & Kaplan, 1999; Vitzthum, 2011). Stature also increased during this time, indicating that energetic conditions improved between Cohorts 1 and 3 [Table 5]. Past studies within life history theory [LHT] indicate that stature and growth rates improve with increased nutritional access and reduced environmental stress (Azcorra et al., 2015; Bogin & Loucky, 1997; Veile, Valeggia, et al., 2019). Cohort 3 also has a relatively high average BMI of 27.7, which is considered overweight by the WHO, but which may indicate obesity within this population (Organization, 2018; Smith et al., 2003; Veile & Kramer, 2016). Additionally, shorter women were not more likely to be obese than taller women in this sample. It is important to track the health and energetic conditions of this population to increase our understanding of how a natural fertility population adapts under rapid, dramatic change. As of this moment, the long-term effects of modernization and the nutritional and energetic transitions might not be entirely apparent in the

Yucatec Maya. These changes may be especially relevant to birth outcomes and the increased rate of CS in this population.

Investigations of stature and birth mode indicate that concurrent short stature and obesity are risk factors for obstetric complications, and frequently require CS intervention for successful birth outcomes (Ferreira et al., 2009; Sheiner et al., 2005; Siega-Riz & Laraia, 2006; Wells, 2017). This may manifest as cephalopelvic disproportion or fetal macrosomia, which are generally categorized as types of obstructed labor. It is possible that the obstetric dilemma [OD] is operating for people who are considerably shorter for their population, however its broad application across human populations is not well understood (Betti, 2017; Rosenberg & Trevathan, 1995; Wells, 2015; Wells et al., 2012). In this study it is unclear if the OD is contributing to the rising rate of CS since the results, though under-powered, indicate that obstetric complications are not associated with stature in this Yucatec Maya sample. However, the impact of stature on CS rates may be operating at the socio-cultural level within historical constructions of medicine and race in Mexico.

4.1 Contribution of Clinical Medicine

In rural Mexico, it is likely that overburdened public hospitals and discrimination against indigenous women have exacerbated increasing CS rates (Fernández García, Zarate Grajales, & Lartigue Becerra, 2010; Smith-Oka, 2015; Veile & Kramer, 2018). This conclusion is based on accounts from Yucatec Maya women, like Jocelyn, who have given birth in via CS as well as investigations of hospital conditions in Mexico. Work at a maternity hospital in Puebla indicates that the microagressive behavior doctors and other medical staff direct towards impoverished, indigenous patients is partly a result of poor hospital funding and workplace stress (Smith-Oka, 2015). Others have called attention to the high incidence of burnout observed in nurses and medical staff in Mexican hospitals (Fernández García et al., 2010; Trejo-Lucero, Torres-Pérez, & Valdivia-Chávez, 2011). This dilemma is beyond the scope of this project but has dramatic implications for how medicine is practiced and ultimately maternal-child health outcomes. Overburdening and burnout are likely partially responsible for increased rates of CS in this community.

Often, medical practitioners identify CS as the most time efficient and low-risk delivery mode (Lyerly et al., 2009; Rutherford et al., 2019; Wolf, 2018). In the United States and other countries, obstetricians are more likely than other medical specialists to be accused and charged in medical legal disputes of malpractice (Rutherford et al., 2019; Wolf, 2018). CS is seen by many doctors as a way to forgo litigation and demonstrate that they did all that was possible to achieve a successful outcome for mother and infant in a worse-case scenario. It is also more expensive for the patient to have a CS, while physicians and hospitals benefit financially and therefore have incentive to continue performing cesarean births (Wolf, 2018). Rutherford and colleagues (2019) also call attention to the fact that although consent is necessary to perform a CS, people in labor are often forced to give consent under conditions of "personal emotional stress, or external stress by family members or physicians" (Paterick, Carson, Allen, & Paterick, 2008; Rutherford et al., 2019). This undermines patient agency of consent and introduces situations where doctors could persuade patients to have a CS even if it is not medically necessary. The question of agency also presents the possibility that Yucatec Maya patients who are disempowered within the medical system by being indigenous and impoverished have even less authority over their own bodies (Crenshaw, 1990; Smith-Oka, 2015).

To understand how medical perceptions of Yucatec Maya women are affecting CS rates in this region, it would be useful to interview doctors and medical staff that work with the study community. While ethnographic accounts of Mexican maternity hospitals exist (Braff, 2013; Fernández García et al., 2010; Smith-Oka, 2015; Smith-Oka, 2013), no medical staff were interviewed specifically for this project. The inclusion of their insight would be invaluable to future work on this topic. Within the community, hospital births and CS are becoming more socially acceptable and CS is frequently viewed as inevitable for some women. This has contributed to the local view that birth has become more difficult in recent years. Augmented interview materials as well as longitudinal studies of health, demography, and birth in the Yucatec Maya are needed to strengthen the results and conclusions of this study.

4.2 Study Limitations & Reflection

While thorough, the conclusions of this project are hindered by the fact that it is statistically underpowered and lacking complete information. Cohort 1 in particular suffered from gaps in recall during interviews, and the fact that some women passed away before their stories could be recorded. This limited the number of mothers who could be included in the final sample. Cohort 3 has not yet finished reproducing, so present trends of CS, obstetric complications, and reproductive outcomes could change. It is also probable that the available data for stillbirths, a proxy for obstetric complication, are incomplete since it is likely some mothers were unwilling to share the experience of losing a pregnancy with outsiders.

To improve the power and quality of these results, more demographic and health data in a longitudinal format is needed. For example, longitudinal data on diabetes or obesity prevalence does not currently exist in this community and our understanding of the increased incidence of both morbidities comes exclusively from interview material. This makes it difficult to quantify the frequency of diabetes and obesity, despite being commonly referred to in interviews. There is also not an organized dataset of prescribed reasons for CS and whether they were planned or a medical emergency. Though as stated before, every mother in this sample expressed a preference for vaginal births. This would further illuminate the influence that clinical medicine has on rising CS rates in this region.

It would have been valuable to visit a hospital near the study community and speak with doctors, nurses, and health workers that serve Yucatec Maya families in this area. Once gathered, an interview with medical practitioners in rural Campeche could indicate motives and reasoning on the part of doctors for high CS rates. Additionally, no local midwives were interviewed specifically for this project and all information on traditional birth and medicine were taken from previously published accounts (Jordan, 1989, 1992; Veile & Kramer, 2018). This would have been useful in understanding traditional perceptions of birth and what may have changed in the last 30 years according to another set of professionals. For example, many older women expressed the belief that birth is more difficult for the current generation. Would a Yucatec Maya midwife agree? Reportedly, the elderly midwife who resides in the study community is grateful for the recent increase in hospital births as it lightens her workload (Veile, 2019). Alternatively, Güémez Pineda (2000) describes divergent perceptions of birth and the body between Yucatec Maya traditions and biomedical science introduced by the Spanish. He argues that it is beneficial for pregnant Yucatec Maya mothers to have support from midwives or others that can conceptualize her experience within the reproductive cycle and its social dimensions (Güémez Pineda, 2000). How do perceptions of labor and the need for medical intervention correspond to traditional conceptualizations of reproductive physiology?

With additional demographic, biometric, and ethnographic data it would be possible to draw clearer associations between the causes of rising CS in the Yucatec Maya. It is also crucial to follow up with mothers and infants that have undergone CS in this community. Morbidities associated with CS have not been consistently identified in rural, impoverished populations, though they likely manifest differently. Some of the morbidities associated with CS could also be mitigated by intensive breastfeeding practices, as has been observed in the Yucatec Maya (Veile, Faria, et al., 2019; Veile & Kramer, 2015). It is also possible that the consequences of increased CS birth are not yet discernable to anthropologists and health workers. For this reason, continued collection of longitudinal health data and local ethnographic accounts is vital to understanding how CS impacts maternal-child health across the life course. This became obvious as the project, and my own understanding of the epistemology of biocultural anthropology, developed.

Over the course of my research, it became apparent that the available biometric and demographic data were insufficient to answer the initial research questions and that more ethnographic information was required. This posed an unusual challenge as the majority of work conducted at this study community by Karen Kramer and Amanda Veile has focused on questions regarding biology, ecology, and health, while being contextualized within a biocultural framework. Additionally, I was only able to spend a week in the study village with Yucatec Maya families and did not conduct a full ethnography of the community. Many questions that arose regarding local practices and history were easily answered by past work conducted with this community and other Yucatec Maya populations, however I feel a deeper cultural analysis of this population is needed.

Since Karen Kramer began working with this community in 1993, the concerns of the Yucatec Maya have been considered by lead researchers in the community. Results are shared back to the public in locally held town hall style meetings and many gifts have been granted to the village over the years, including computers for the local school. Both Karen Kramer and Amanda Veile have commented on and written about how uniquely hospitable and welcoming the Yucatec May are toward themselves and others. This was my experience as well. But I recall a conversation with our Yucatec Maya hosts in the summer of 2018 on the numerous outsiders who have come to the village and never returned. Regrettably, I too may fit that category. This conversation brought to mind questions of how the community has interacted with outsiders in the past before the 1990s and what expectations, explicit or implicit, people may have of visitors whether they come from the Mexican government or a university in the United States. As a biocultural anthropologist, I am also aware that biological anthropology has historically endorsed eugenic, deterministic principles through supposedly scientific research, frequently causing injury to indigenous peoples (Blakey, 1987, 2001; Tuhiwai Smith, 2013). Just as knowledge of colonial medical practices in Mexico are important to the conclusions of this study, a profound understanding of the history of biological research in indigenous populations is vital to continuing work with the Yucatec Maya. I believe current research is already mindful of this history and has made efforts to distinguish itself from harmful practices of the past.

Building future biocultural investigations around the concerns and expectations of the community are, and should continue to be, a priority to researchers on this project. For example, the frequent mention of diabetes in interviews indicates that community members are concerned about the disease and how to prevent and/or manage it for themselves and their families. Tracking the decision-making process of CS in the community would also fit these criteria and help address the concern that birth has become more difficult for young women. Ultimately, this research provides a partial explanation to this observation, since CS rates are not associated with obstetric complication or reproductive outcomes. This project also provides a patient perspective on cesarean birth not typically found in the literature.

CHAPTER 5. CONCLUSIONS

In this study, no evidence was found to indicate that stature is related to reproductive outcomes or obstetric complication in any cohort. However, the analyses are limited in power and the dataset is likely incomplete. Women in Cohort 1 were shorter but had more children on average than their counterparts in Cohort 3, who were taller by more than 4 cm. As previously established (Kramer & McMillan, 2006; Veile & Kramer, 2018), the introduction of labor-saving technology in this village reduced the workload for women and freed up time, which was subsequently diverted to leisure and reproduction. This energetic transition occurred during the time Cohort 2 was reproducing. The reduction in environmental stress and workload may have improved conditions of early growth and development for Cohorts 2 and 3 resulting in increased stature. This is also when the nutritional transition begins, which means more calories became readily available with little energetic cost. According to life history theory [LHT], time and energy place high constraints on the body (Hill & Kaplan, 1999; Kramer & McMillan, 1998, 2000). The energetic and nutritional transition starting in the later 1990s appears to have resulted in an excess of both, which was redirected to childrearing in some cases and leisure activities or personal development in others. As contraception became available in the early 2000s, concurrent with cohort 3, age at first birth increased and family size shrank. Women in Cohort 3 also have more formal education than their mothers or grandmothers, and some have successfully taken on business enterprises.

From a health perspective, adult diabetes and obesity have also reportedly become more common during this period of time. Many elderly individuals have contracted diabetes, though only one woman in Cohort 3 has yet to experience gestational diabetes (Veile & Kramer, 2018). BMI for adult women between ages 20 and 40 has increased in just 20 years from 24.8 to 27.7, which the World Health Organization classifies as overweight but not necessarily obese (Organization, 2018; Veile & Kramer, 2018). The maximum BMI recorded in 2013 for women in this age range is 38.14, while the minimum is 16.51. While not tested here, CS is associated with infant and child morbidity conditions like obesity, allergies, diabetes, and immunological sensitivity. Previous work has indicated that in this community morbidity conditions associated with CS might be mitigated by prolonged breastfeeding (Kearney et al., 1990; Veile, Faria, et al., 2019; Veile &

Kramer, 2015). Childhood obesity is rare in this community and no case of childhood diabetes has yet been found here (Veile & Kramer, 2016).

The introduction of a clinic in the late 1990s provided more resources and education for community members in terms of general health and family planning. Contraception in the form of tubal ligation is relatively common, despite historic practices in Mexican obstetrics. Interview data indicates that many women will plan to give birth in a hospital so that they can undergo tubal ligation during their stay. Currently, mothers and families are frequently referred to obstetric/gynecologists in larger towns and cities. Local midwives are also consulted throughout pregnancy, but today most births take place in hospitals [Table 3]. Infant death does not differ significantly between Cohorts 1 and 3, however infant mortality has been historically low in this population (Kramer, 2005). The higher incident of stillbirths in Cohort 2 compared with 1 and 3 might be more indicative of underreporting.

Importantly, while Cohort 3 has the most CS, they have not completed fertility, which means they could potentially continue reproducing. Previous research has found that women who give birth via CS are more likely to continue to have cesarean deliveries (Menacker, 2005; Rosenberg & Trevathan, 2018; Wolf, 2018). Whether the increased prevalence of CS in this community is driven by changing maternal biology or clinical practices remains to be seen. However, it is quite likely that the recent introduction of clinical medicine in rural Mexico is part of what is driving this trend.

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