FROM ECOLOGY TO IDEOLOGY: ENVIRONMENTAL AND CULTURAL DRIVERS OF MENSTRUAL TABOOS

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DEDICATION

“Each time a woman stands up for herself, without knowing it possibly, without claiming it, she stands up for all women.”

— Maya Angelou

This work is dedicated to my younger self—the girl who feared math, data, coding, and anything to do with numbers. Guess what? You conquered your fear.

ABSTRACT

This thesis explores the environmental and cultural influences on the prevalence and expression of menstrual taboos. Using cross-cultural ethnographic data, two hypotheses were tested: (i) menstrual taboos are more common in high-investment ecological conditions, such as harsh environments and pastoral subsistence strategies, and (ii) stricter menstrual taboos are more prevalent in these conditions, as they may serve as more effective mate-guarding mechanisms. The findings suggest that environmental factors have a weak effect on the likelihood and level of restriction of menstrual taboos. The thesis also investigates why these taboos persist despite increased education and globalization. Three main factors were explored: (i) costly signalling of mate quality, (ii) religion and supernatural punishment, and (iii) group signalling and social cohesion. This research contributes to a broader understanding of the persistence of menstrual taboos and offers insights into how cultural norms evolve and endure across diverse environments.

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LIST OF ABBREVIATIONS

FGM	Female Genital Mutilation
eHRAF	Electronic Human Relations Area Files
OCM	Outline of Cultural Materials
D-PLACE	Database of Places, Languages, Cultures, and Environment
pPCA	Phylogenetically Controlled Principal Components Analysis
MICE	Multivariate Imputation by Chained Equations
MCMC	Markov Chain Monte Carlo
CI	Credible Interval
ESS	Effective Sample Size
WEIRD	Western, Educated, Industrialized, Rich, and Democratic

CHAPTER 1: GENERAL INTRODUCTION

Menstruation occurs cyclically as a natural biological process in the female reproductive system of some mammal species. This process involves hormone production and structured changes in the uteruses and ovaries of the species that menstruate. The menstrual cycle remains a relatively rare biological trait because most mammals reabsorb the endometrium instead of expelling it. Scientists have identified four mammalian taxon groups that menstruate: spiny mice (Bellofiore et al., 2017; Bellofiore et al., 2018; Bellofiore & Evans, 2019), elephant shrews (Van der Horst, 1941), some – but not all – bat species (Krishna & Bhatnagar, 2011), and Haplorhine primates (Strassmann, 1996a; Martin, 2007).

In humans, menstrual bleeding marks the first day of the menstrual cycle and signals that pregnancy did not occur in the previous cycle. This occurs because implantation did not take place and the thickened endometrium breaks down and is expelled. Falling progesterone and estrogen levels trigger menstrual bleeding, while prostaglandins help constrict the spiral arteries in the thickened endometrium (Edlund et al., 2004; Critchley & Maybin, 2011). As a result, the blood supply to the endometrium is cut off, causing the tissue to break down, leading to this expulsion, which we know as menstrual bleeding.

The menstrual cycle includes two sub-cycles: the ovarian and uterine. The ovarian sub-cycle regulates the production, development, and release of eggs, estrogen, and progesterone through three phases: follicular, ovulatory, and luteal. During the follicular phase, the follicles in the ovaries mature until they rupture and release an egg into the ovarian ducts. Ovulation marks the end of this phase as the egg exits the ovary. In the luteal phase, the corpus luteum – a temporary cluster of cells formed after the follicle releases an egg – emerges and produces progesterone while decreasing estrogen levels. The uterine sub-cycle functions alongside the ovarian sub-cycle. The uterine sub-cycle prepares and maintains the uterine lining for the next potential implantation of a fertilized egg through three phases: menstrual, proliferative, and secretory. During the menstrual phase, the endometrium breaks down, causing menstrual bleeding. In the proliferative phase, the uterus rebuilds its lining by generating new tissue. The secretory phase follows, marked by rising progesterone levels and glycogen secretion (Milwidsky et al., 1980). During this phase, decidualization occurs, transforming endometrial cells into decidua – a specialized endometrium that is the basis of the placenta if implantation occurs (Rytkönen et al., 2018; Okada et al., 2019).

1.1 What is Decidualization?

During decidualization, stromal cells in the endometrium transform into decidual cells, which help establish the maternal-fetal connection, restrict fetal invasion, maintain homeostasis, and create an immune-tolerant environment (Haig, 1993). In placental mammals, decidualization occurs either spontaneously or in response to pregnancy. Induced decidualization happens only during pregnancy, while spontaneous decidualization occurs at regular intervals, such as during the luteal/secretory phase of the menstrual cycle, regardless of fertilization. Some menstruating animals, including humans and spiny mice, exhibit spontaneous decidualization, but researchers have not yet identified this process in non-menstruating mammals (Catalini & Fedder, 2020). This suggests a likely relationship between ovulation, spontaneous decidualization of the endometrium, and endometrial shedding.

1.2 Why Menstruate?

Researchers have proposed four main hypotheses to explain why some animals evolved to menstruate. The first, by Profet (1993), suggests that menstruation evolved to remove pathogens introduced by sperm. However, this hypothesis fails to consider copulation at different points in the cycle (Emera et al., 2012), the incubation times of various pathogens, or the rates of sexually transmitted infections in different species.

Secondly, Strassmann (1996b) proposed that menstruation conserves energy because maintaining a decidualized endometrium requires more energy than shedding it. However, this argument does not account for species that reabsorb their uterine lining instead of menstruating (Emera et al., 2012). While menstruation may relate to energy efficiency, this hypothesis needs further development if it is to explain why reabsorbing the uterine lining would become inefficient, leading to a menstruating species.

The third hypothesis, by Finn (1998), suggests that menstrual bleeding evolved as a by-product of spontaneous decidualization. Emera et al. (2012) challenged this idea, arguing that it explains only the evolutionary origin of spontaneous decidualization, not menstruation itself. This hypothesis applies only to humans, some primates, spiny mice, and certain bat species, all of which exhibit spontaneous decidualization (Catalini & Fedder, 2020). However, it fails to explain menstruation across all species. This limitation may stem from examining the wrong part of the reproductive cycle. Instead, exploring spontaneous ovulation—the release of an egg without mating—or the presence of a hemochorial placenta, which creates a direct connection between maternal and fetal bloodstreams, could help explain why all menstruating species evolved to shed their endometrial lining (Catalini & Fedder, 2020). Even so, this idea does not directly address Emera et al. (2012) criticism involving the evolution of menstruation. Essentially, assuming menstruation evolved separately from other reproductive traits implies that it serves an independent evolutionary function. However, this assumption may not be accurate. Instead, spontaneous ovulation and/or a hemochorial placenta may have shaped the menstrual cycle, making menstrual bleeding an inevitable consequence of these reproductive traits rather than an adaptation.

The final hypothesis, proposed by Brosens et al. (2009), suggests that menstruation prepares the uterus for pregnancy by protecting against hyperinflammation and oxidative stress caused by a hemochorial placenta. Since hemochorial placentas modify maternal arteries to provide unrestricted access to nutrients and oxygen, menstruation may have evolved as a protective mechanism for successful pregnancies (Emera et al., 2012). Alvergne & Tabor (2018) further argue that menstruation allows mothers to exert control over embryo selection before implantation occurs. These hypotheses support the idea that menstruation evolved alongside other reproductive adaptations. Specifically, hemochorial placentation may have driven the need for maternal control and fetal restriction, reinforcing the link between menstruation and other reproductive traits.

1.3 Ovulatory Cues and Ovulation

In addition to menstruation, spontaneous decidualization and hemochorial placentas, human females are said to have concealed ovulation because no reliable, conspicuous physiological cues correlate with ovulation. However, studies challenge this view, showing that female vocal production (Pipitone & Gallup, 2008; Banai, 2017), walking gait (Provost et al., 2008), and ratings of female attractiveness (Roberts et al., 2004) fluctuate throughout the menstrual cycle. Researchers such as Gangestad & Haselton (2015), Gangestad & Thornhill (2008), and Gangestad et al. (2022) argue that these fluctuations suggest human females must have an oestrus cycle. The oestrus cycle consists of recurring physiological changes induced by reproductive hormones, including a period of sexual receptivity known as "heat." Many mammals, such as dogs, cats, elephants, and kangaroos, have oestrus cycles. However, differences in reproductive systems indicate that animals cannot simultaneously undergo both an oestrus cycle and a menstrual cycle (see Table 1.1). Despite this, the presence of ovulatory cues seems distinct from having an oestrus cycle. This means an animal can have a menstrual cycle while displaying ovulatory cues, much like how baboons exhibit sexual swellings. Although human females do not show obvious ovulatory cues, it makes sense for males to be attracted to certain features of fertile females. This attraction, however, may result from evolutionary history rather than a signal of fertility status (Havliček et al., 2015). Rather than being an adaptation selected to signal ovulation, it could instead be a by-product of how hormones influence the body, shaping both long-term traits and subtle cyclical changes. Alternatively, human females might produce weak or "leaky" ovulatory signals (Haselton & Gildersleeve, 2011), which would be hard to detect without consistent interaction between sexual partners. Partners who spend a lot of time together, interact often, and communicate regularly might be better at picking up subtle hormonal shifts throughout the cycle, unlike a partner who divides their attention due to food acquisition or multiple wives. Nevertheless, this raises the possibility of mating conflict between the sexes. Given these dynamics, the challenge of detecting ovulatory cues in humans can intensify these potential mating conflicts, particularly as issues like mate guarding and paternal investment come into play.

Table 1.1 Reproductive System Differences Between the Oestrus and Menstrual Cycles

	Oestrus Cycle	**Menstrual Cycle**
Decidualization	Induced	Spontaneous (not all species)
Placenta	Hemochorial, Endotheliochorial, Syndesmochorial, or Epitheliochorial	Hemochorial
Ovulation	Induced or Spontaneous	Spontaneous
Endometrium	Reabsorbed	Expelled
Sexual Receptivity	Seasonal	Continual

Note. Hemochorial means that three cellular layers separate the maternal and fetal bloodstream. Endotheliochorial means that there are around four cellular layers that separate the maternal and fetal bloodstreams. Syndesmochorial means that around five cellular layers separate the maternal and fetal bloodstreams. Epitheliochorial means that around six cellular layers separate the maternal and fetal bloodstreams.

1.4 Conflicts in Mating

Humans lack obvious ovulation cues, and menstruation is the only conspicuous phase of the reproductive cycle. This complicates paternity assurance and, if so, affects the extent of male investment in offspring (Platek & Shackelford, 2006). This issue is particularly problematic because human children require long, intensive care to overcome high mortality rates (Mace, 2000), and their developmental growth patterns depend on available resources (Winking & Koster, 2015). As a result, males and females must cooperate economically and reproductively to enhance survival by maximizing direct childcare and nutrition (Kaplan et al., 2003; Kaplan & Lancaster, 2003). However, parental care comes at a high energetic cost, limits future mating opportunities, reduces resources for other offspring, and hinders a parent's ability to maintain health (Shenk, 2011). Therefore, we would expect males to provide less care when paternity certainty decreases due to the risks involved in misdirecting resources, time, and energy (Trivers, 1972; Gray & Anderson, 2010). Genetic paternity assurance can differ from paternity confidence, which refers to the confidence a male has that he fathered the offspring in question. Males estimate paternity confidence using cues such as child resemblance (e.g., Apicella & Marlowe, 2004; Alvergne et al., 2010; Chang et al., 2010; Prokop et al., 2010; Tracey & Polachek, 2018; Yu et al., 2019). Paternity confidence plays a significant role in determining paternal investment (Queller, 1997; Marlowe, 1999) and the investment from paternal relatives (Gaulin et al., 1997; McBurney et al., 2002; Geary, 2006; Huber & Breedlove, 2007). This, in turn, suggests that females should be sensitive to a male's need for paternity assurance, given their need to secure sufficient care for their offspring, while males should be sensitive to a female's need for additional care, given his need for paternity assurance.

Males also need to balance their investments based on paternity confidence, the costs of raising another male's offspring, and the social and cultural benefits of paternal investment regardless of biological paternity (Kempenaers & Sheldon, 1997; Geary, 2000; Scelza, 2010). Paternity confidence seems to correlate with actual paternity as males with low paternity confidence, which they challenge through paternity testing, are less likely than males with high paternity confidence to be the biological father of contested offspring (Anderson, 2006). In Albuquerque, New Mexico, males were, on average, more likely to divorce women after the birth of an offspring in which they had low paternity confidence (Anderson et al., 2007). This is likely to happen because of the potential risk involved as males structure the quality (resources, time spent, frequency of abuse, and/or amount of sexual jealousy) of the relationship with their offspring and their partner based on paternity confidence (Burch & Gallup, 2004; Daly & Wilson, 1998; Scelza et al., 2020a). Culture further complicates this picture as there is variation across cultures in paternity beliefs as some culture's kinship systems do not directly map onto biological relatedness, nor does every culture believe in the idea of a singular or biological father (e.g., Beckerman et al., 1998; Hrdy, 2000, Prall & Scelza, 2020). This cultural variation suggests that different societies may develop distinctive solutions to address the biological conflicts surrounding paternity and parental investment, influencing how males navigate these challenges.

1.5 Cultural Solutions to Biological Conflicts

Humans have developed cultural solutions to address the biological conflicts outlined in the previous section. For example, one major reason some cultures practice female genital mutilation (FGM) is to restrict female sexuality (Skaine, 2005; Onyishi et al., 2016; Howard & Gibson, 2019). Another example is mate guarding through the patrilocal post-marital residence, which influences paternity confidence and enables a male's family to police the behaviour of female sexual partners (Burgess & Draper, 1989; Guha, 2012). Religion also plays a significant role in alleviating paternity uncertainty, as most major religious traditions condemn extra-pair partnerships and promote restricted sexual behaviours and ideals, especially for females (Burdette et al., 2007; Atkins & Kessel, 2008; Weeden et al., 2008).

Menstrual taboos are rules and restrictions (Table 1.2 provides examples of the types of restrictions cultures impose on menstruating females) that limit a female's movements, activities, or behaviour due to cultural beliefs about menstruation. These taboos vary widely and produce different consequences for those who observe them. For example, personal hygiene restrictions and ritualistic cleansing at the end of menstruation reinforce cultural stigma by associating menstruation with notions of uncleanliness and impurity. Similarly, sex avoidance or prohibitions often restrict sexual intercourse to periods when conception is more likely (Montgomery, 1974). Furthermore, menstrual taboos, such as menstrual seclusion, signal female reproductive status, allowing others to estimate ovulation, provided the behaviour is reliably practiced.

In cultures that practice menstrual seclusion, such as the Dogon people of Mali, females typically follow these rules, entering and exiting seclusion as expected, even when they may have incentives to hide their reproductive status (Strassmann, 1996c). This signalling helps males more accurately assess female reproductive status and increase paternity certainty, especially through highly restrictive menstrual taboos like menstrual seclusion, which makes a female's position in the menstrual cycle more apparent. Strassmann et al. (2012) found that males practicing the Dogon religion had higher father-son paternity match rates than Muslim males, who had an intermediate match rate, and Catholic males, who had the lowest match rate. Researchers attributed the differences in paternity matching to the variations in the restrictiveness of menstrual taboos, which make reproductive status more or less conspicuous. This means that practices such as menstrual taboos, which signal female reproductive status, likely affect the extra-pair paternity rate and influence not only the stigmatization of women but also the likelihood of paternal investment, which is sensitive to resource availability. In places with fewer resources, males are more likely to be sensitive to paternity concerns and their ability to invest than in places with abundance.

Table 1.2 Examples of Different Types of Menstrual Restrictions, Descriptions, and Example Societies.

Type of Restriction	Description	Example Societies
Menstrual Seclusion	Menstruating females are required to stay in a separate space (e.g., menstrual huts).	Alutiiq (Holmberg, 1985); Dogon (Dieterlen et al. 1960);
Food Taboos	Restrictions on eating or preparing certain foods	Amish (Huntington, 1987); Zulu (Reader, 1966);
Religious Exclusion	Prohibition from entering temples, participating in rituals, or touching sacred objects.	Wayuu (Bolinder, 1957); Greeks (Dubisch, 1986);
Sexual Restrictions	Prohibition on sexual intercourse during menstruation.	Shipibo (Behrens et al. 1988); Kuna (Marshall, 1999);
Work & Social Life Restrictions	Prohibition on things such as subsistence acquisition activities, cooking, or engaging in daily labor.	Seminole (Garbarino, 1989); Katab (Meek, 1931);
Ritual Purification	Cleansing rituals required post-menstruation before resuming normal activities.	Aleut (Lantis, 1984); Hadza (Marlowe, 2010);
General Stigmatization	Negative attitudes, secrecy, and shame surrounding menstruation.	Rural Irish (Humphreys, 2010); Iban (Davison & Sutlive, 1991);

1.6 Environmental Influences on Culture

Ecological conditions such as pathogen stress, resource availability, climate variability, and geographical limitations influence human strategies for overcoming biological conflicts (e.g., the need for paternal investment and the need to assure paternity) and affect the expression of various cultural traits. On average, ecological conditions account for 1-20% of the variance we see in cultural variables such as egalitarianism, mate acquisition norms, and individualism (Wormley et al., 2023). For example, clothing, which expresses cultural identity, also reflects environmental conditions. Cultures like the Yanomami wear minimal clothing due to high temperatures and humidity, while the Sámi rely on heavy layers and fur to withstand the extreme cold. Similarly, subsistence strategies vary based on ecological constraints, with pastoralism being more common in harsh environments. These examples show that while many factors influence culture, ecological conditions play a crucial role in shaping cultural behaviours and norms, sometimes in ways that may not be immediately apparent.

Among the many ways the environment shapes culture, its influence on social structures surrounding reproduction and kinship stands out. In many societies, environmental pressures heighten concerns over paternity and inheritance in resource-scarce environments, leading to stricter cultural controls on female reproductive behaviour. Essentially, the environment modulates the available resources, which impacts sensitivity to paternity, willingness to invest, and the amount of investment parents can provide (Sear, 2016). It also affects how likely a female is to acquire alloparental care (Martin et al., 2020), which can increase or decrease her need for paternal investment. The environment influences mate-guarding behaviour, with stricter practices arising in response to environmental pressures. For example, religious veiling (Pazhoohi et al., 2017) and restrictions on female premarital sex (Šaffa et al., 2022a) are more common in harsher environments, likely due to the increased costs of paternity uncertainty for males in those environments. In pastoralist societies, adherence to restrictive norms on female sexuality and mobility is common, not only because of resource availability and harsh environmental conditions but also because of the extended periods of spousal separation that heighten paternity uncertainty (Becker, 2019). These examples illustrate the possibility that as environmental pressures increase, paternity uncertainty drives stricter mate-guarding practices, compelling males to invest more effort in controlling female sexuality to mitigate the increased costs associated with investing in non-biological children.

Menstrual taboos, as described in the previous section, can serve as a mate-guarding strategy by regulating female sexuality (Strassmann et al., 2012) and advertising reproductive status through signals of non-pregnancy (Strassmann, 1992). Other cultural traits, such as polygyny, affect menstrual taboos. For example, Stephens (1962) found a moderate positive correlation between menstrual taboos and polygyny. In polygynous societies, men may struggle to monitor the reproductive cycles of multiple wives, especially when co-wives live at a large distance from one another. In such cases, menstrual taboos provide a clear and culturally defined signal of a female's reproductive status, making her menstrual cycle easily identifiable even if a male cannot directly track it. Beyond social structures like polygyny, menstrual taboos are also influenced by a society's subsistence strategy, which is also shaped by ecology. Kitahara (1982) found that menstrual taboos correlate with the importance of hunting. In hunting and gathering societies, where the sexual division of labour is pronounced, menstrual taboos may function not only as reproductive signals but also to reinforce gender roles and social organization. Given that both subsistence strategies and social structures are influenced by environmental conditions, along with other mate-guarding strategies such as religious veiling (Pazhoohi et al., 2017) and restrictions on female premarital sex (Šaffa et al., 2022a), we must examine whether factors like environmental harshness—known to affect paternal investment and paternity uncertainty—play a role in shaping the prevalence and restrictiveness of menstrual taboos. Furthermore, exploring the reasons menstrual taboos persist and the historical shifts in these practices may reveal broader patterns in how cultural norms evolve in response to ecological and social pressures.

1.7 Thesis Outline

In this thesis, I investigate how environmental factors influence the presence and restriction level of menstrual taboos using cross-cultural ethnographic data. I also explore potential causes for the persistence of menstrual taboos beyond the paternity certainty hypothesis proposed by Strassmann et al. (2012) and examine historical shifts in how menstrual taboos are practiced. To better understand the environmental conditions that affect menstrual taboo prevalence and restriction levels, I test two hypotheses. First, because ecological conditions influence resource availability and are related to paternal investment, I hypothesize that the presence of menstrual taboos should be more common in ecological conditions with higher investment costs (e.g., harsh ecological conditions and pastoralism subsistence strategies). Second, I hypothesize that stricter menstrual taboos will be more prevalent in these high-investment conditions, as they may offer more effective mate-guarding compared to less restrictive taboos. Given the potential impact of menstrual taboos on paternity and the influence of environmental conditions on other forms of mate-guarding, such as religious veiling, I predict that cultures in harsher environments and those practicing pastoralism will have more restrictive menstrual taboos.

Following this introduction, Chapter 2 provides an overview of the sample used, the data collection process, the coding schemes, and the statistical analyses I conducted. In Chapter 3, I present findings from six Bayesian multilevel models that test whether environmental harshness and subsistence patterns are related to the prevalence and restrictiveness of menstrual taboos. In Chapter 4, I explore other potential factors that could explain the persistence of menstrual taboos. Lastly, in Chapter 5, I discuss my findings, explain how they contribute to research on human mate-guarding strategies, and consider the limitations and directions for future research.

CHAPTER 2: METHODOLOGY

I collected menstrual taboo data from ethnographies in the electronic Human Relations Area Files (eHRAF; http://ehrafworldcultures.yale.edu). This data came from different cultures worldwide (see Table 2.1 for the distribution of cultures across eHRAF world area categories and Appendix A for the visualizations of the distribution of the presence and level of restriction of menstrual taboos worldwide). I obtained data on the presence and restrictive levels of menstrual taboos using the Outline of Cultural Materials (OCM) label 841: 'Menstruation' search feature available on eHRAF. I read all entries in OCM 841 (n = 270 cultures) and recorded information on the presence of menstrual taboos, the number of taboos present, and the details of their restrictiveness (n = 254). More information on the coding and definition are provided in the subsequent section. The ethnographic data with citations are available here: https://arianna-quinn.github.io/eHRAF%20ethnographic%20data.html.

Table 2.1 The Number of Cultures in the Sample Across Human Relation Area File World Area Categories

HRAF world area category	**Number of cultures (Percentage of sample)**
North America	25 (17%)
South America	19 (13%)
Oceania	17 (12%)
Middle America & Caribbean	8 (5%)
Africa	36 (24%)
Asia	34 (23%)
Europe	4 (3%)
Middle East	4 (3%)

I extracted historical environmental data and the percentage of polygynously married males for each cultural group from the Database of Places, Languages, Cultures, and Environment (D-PLACE; https://d-place.org/), if available (n =200). The subsequent sections provide further details on coding and definitions. I then cross-referenced the eHRAF data with available cultural phylogenetic tree data from the supertree provided by Minocher et al. (2019) to account for phylogenetic autocorrelation—the idea that closely related cultures tend to share similar cultural traits, also known as Galton’s problem (Bromham, 2022). This process resulted in a final sample of 144 cultures (see Figure 2.1 for the exclusion flowchart). The final dataset is available here: https://arianna-quinn.github.io/Mastersdataset.htm.

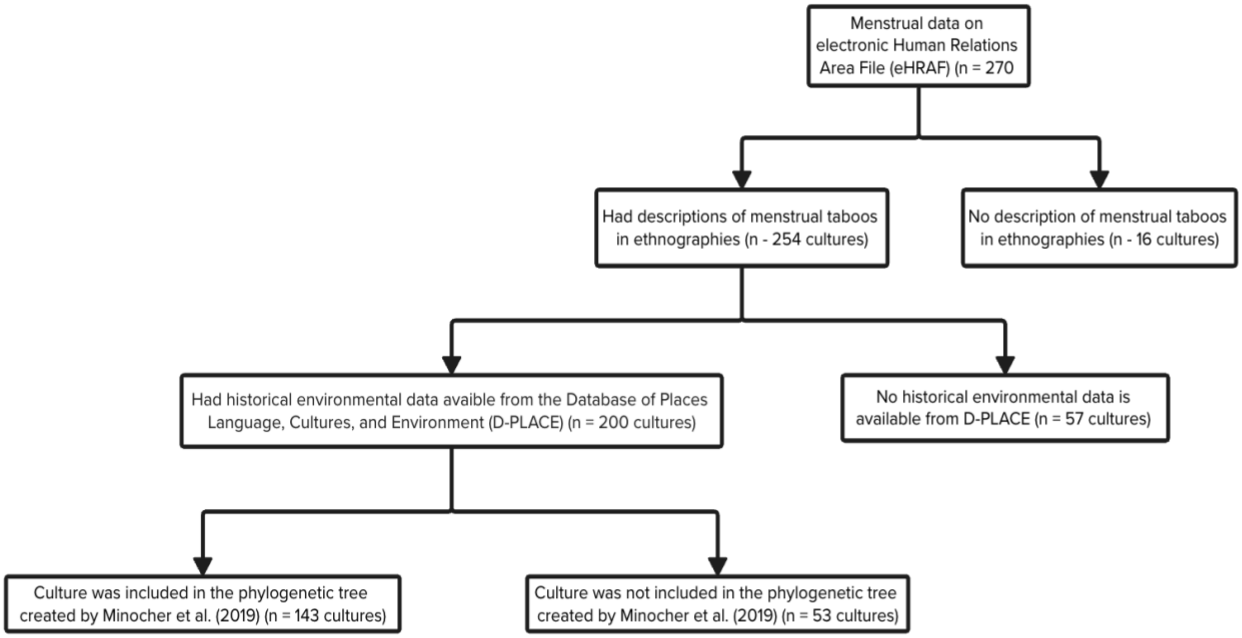

Figure 2.1 Flow chart provides the reason and number of cultures excluded at each step of the data collection process.

2.1 Presence and Level of Restriction of Menstrual Taboos

I categorized menstrual taboo data in two ways. First, I coded the presence of menstrual taboos as 0 if the ethnography explicitly noted their absence and 1 if it reported their presence or described them. Second, I coded the level of restriction on a scale from 0 to 3. A score of 0 indicated that ethnographers explicitly stated menstrual taboos were absent. A score of 1 indicated the presence of minimally restrictive taboos (e.g., general superstitions, concealment of menstruation and menstrual products, innuendoes about menstruation, or beliefs that menstruation is disgusting, magical, or polluting). A score of 2 indicated moderately restrictive taboos (e.g., some alterations to daily life, dress, eating, and/or daily activities). A score of 3 indicated severely restrictive taboos (e.g., significant disruptions to daily routines, such as restrictions on food acquisition, personal hygiene, clothing, locations, or food consumption, or at the most extreme, complete isolation or seclusion). To assess coding reliability, a second rater independently coded a randomized subset of the data (n = 102 cultures). The raters agreed on 92.2% of the codes for this subset.

2.2 Other Cultural Data Collected

I obtained data on primary subsistence strategies from the culture summaries in eHRAF. Seven distinct subsistence categories emerged: i. pastoralist, ii. intensive agriculturalist, iii. other combinations (e.g., hunting and horticulture or pastoralism and foraging), iv. hunter-gatherers, v. horticulturalist, vi. agro-pastoralist, and vii. commercial economy. To reduce data complexity and noise, I excluded cultures with a commercial economy (n = 3) and reclassified cultures in the agro-pastoralism and ‘other subsistence combinations’ categories using the D-PLACE variable ‘Subsistence Economy: Dominant Mode (SCCS833).’ Since agriculture and horticulture differ in scale and focus—agriculture involves large-scale mechanized staple crop production, whereas horticulture involves small-scale cultivation with minimal machinery—I treated them as separate strategies. This process yielded four subsistence categories for analysis (Table 2.2): i. hunter-gatherers (n = 49), ii. horticulturalists (n = 39), iii. agriculturalists (n = 44), and iv. pastoralists (n = 12). I obtained data on the percentage of polygynously married males from D-PLACE’s variable ‘SCCS871: Percentage of Married Men with More than One Wife.

Table 2.2 Descriptions of the Condensed Primary Subsistence Strategy Categories

Primary Subsistence Strategy	Description
Agriculturalists	Depends mostly on agriculture. A type of agriculture that uses both crops and animal husbandry. It has higher levels of input and output per unit of agricultural land area. With more or less permanent field cultivation and/or irrigation.
Pastoralists	Depends mostly on herding or pastoralism for subsistence.
Horticulturalists	Depends mostly on simple agriculture for subsistence.
Hunter-Gatherers	Depends mostly on hunting, fishing, and gathering for subsistence.

To explore the persistence of menstrual taboos (Chapter 4), I analyzed the eHRAF data for evidence of changes in menstrual taboos over time. In cultures where practices shifted, I documented the specific changes and their underlying reasons. While most cultures showed no documented changes, 38 cultures reported shifts, and 11 ethnographies provided reasons for these changes. Chapter 4 also examines the relationship between paternity beliefs and menstrual taboos. I categorized paternity into three types: i. biological father (n = 19 cultures), where paternity is based on genetic contribution; ii. social father (n = 29 cultures), where paternity is determined by a social event or role such as marriage, and iii. multiple fathers (n = 5 cultures), where multiple men share paternal duties. I identified data on paternity beliefs using a keyword search for "paternity" in eHRAF (n = 195 cultures), and cross-referencing revealed an overlap of 53 cultures.

2.3 Historical Environmental Data

Based on the work of Cornwallis et al. (2017) and Martin et al. (2020), I operationalized the definition of harsh environments as those characterized by less predictable climates and more extreme temperature and rainfall measurements, which result in harsher environmental conditions and reduced resource availability, compared to stable environments with more consistent climate and weather patterns. I collected means and variances of monthly temperature and precipitation from the EcoClimate database (Lima-Ribeiro et al., 2015) and Colwell's (1974) standardized annual temperature and precipitation predictability indices made available through D-PLACE.

To create these latent variables that reflect how cultures experience environmental harshness, I used a phylogenetically controlled principal components analysis (pPCA) (Revell, 2024) to reduce multicollinearity and phylogenetic autocorrelation in the environmental data. I then applied a parallel analysis procedure to identify components that explained more variance in my sample than expected by chance. After selecting two principal components, I used an orthogonal Quartimax rotation (Jackson, 2005) to enhance their biological interpretability. These components explained 74% of the total variance: the first component captured temperature patterns (average monthly temperature, predictability, and variability), accounting for 41% of the variance, while the second component captured precipitation patterns (average monthly precipitation, predictability, and variability), explaining 33% of the variance. Appendix C provides the component loadings.

To account for ecological clustering beyond the continuous environmental variables, I incorporated biome classifications from Olson et al. (2001). These classifications covered 14 biome types: i. tropical and subtropical moist broadleaf forests, ii. tropical and subtropical dry broadleaf forests, iii. tropical and subtropical coniferous forests, iv. temperate broadleaf and mixed forests, v. temperate conifer forests, vi. boreal forests/taiga, vii. tropical and subtropical grasslands, savannas, and shrublands, viii. temperate grasslands, savannas, and shrublands, ix. flooded grasslands and savannas, x. montane grasslands and shrublands, xi. tundra, xii. Mediterranean forests, woodlands, and scrub, xiii. deserts and xeric shrublands, and xiv. ice. To simplify the data and reduce noise, I consolidated these into four broader categories based on the predominant type of landscape (Table 2.4): forests (n = 89), grasslands (n = 38), polar (n = 5), and desert (n = 12).

Table 2.4 Descriptions of Biome Categories Used

Landscape	Biome	Description
Forests	Tropical & Subtropical Moist Broadleaf Forests	Found near the equator, with stable temperatures, high rainfall, and the highest species diversity.
	Tropical & Subtropical Dry Broadleaf Forests	Warm climates with high rainfall and long dry seasons; species adapted to seasonal droughts.
	Tropical & Subtropical Coniferous Forests	Found in North and Central America, with low precipitation, moderate temperature variability, and high conifer diversity.
	Temperate Broadleaf & Mixed Forests	Significant temperature and precipitation variability, with high forest floor species diversity.
	Temperate Conifer Forests	Coastal or mountainous areas with mild winters and varying plant species.
	Boreal Forests/Taiga	Cold winters, warm, humid summers; low species diversity and few endemics.
	Mediterranean Forests, Woodlands, & Scrub	Hot, dry summers and cool, moist winters; plants fire-adapted and sensitive to disturbance.
Grasslands	Tropical & Subtropical Grasslands, Savannas, & Shrublands	Dominated by grasses with few trees; receives insufficient rainfall for widespread tree growth.
	Temperate Grasslands, Savannas, & Shrublands	Similar to tropical grasslands but commonly converted to agriculture; grasses dominate.
	Flooded Grasslands & Savannas	Diverse plants and animals, crucial for migratory species; reliant on intact hydrological systems.
	Montane Grasslands & Shrublands	High-elevation grasslands with biodiversity adapted to cool, wet conditions.
Polar	Tundra	Found in high latitudes in the polar regions, characterized by dry extremely cold winters, minimal vegetation.
	Ice	Permanent ice with minimal precipitation, dominated by microorganisms, and low biodiversity.
Deserts	Deserts & Xeric Shrublands	Evaporation exceeds rainfall; temperature variability with adapted species to survive low water availability.

2.4 Ancestral Relatedness

To control for autocorrelation due to shared population history, I used a supertree of human cultures based on genetic and linguistic data (Duda & Zrzavý, 2016; Duda & Zrzavý, 2019; Minocher et al., 2019). This supertree (Figure 2.2) integrates 388 source trees from 250 studies and a topological constraint based on linguistic classification.

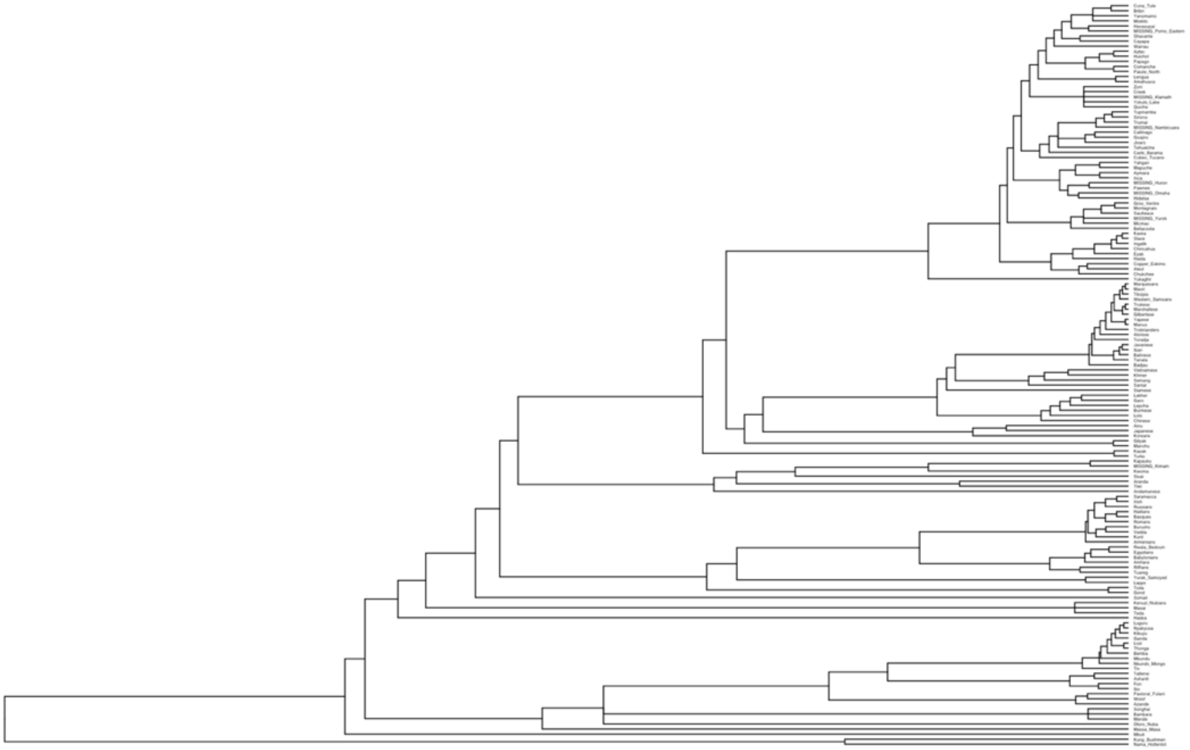

Figure 2.2 The potential phylogenetic relationship between cultures in sample. For an interactive version, please visit https://arianna-quinn.github.io/P.PHYLO.pdf for a phylogenetic tree depicting the presence and https://arianna-quinn.github.io/R.PHYLO.pdf for a phylogenetic tree depicting the restriction level of menstrual taboos.

2.5 Data Analysis

I conducted a statistical analysis to explore how environmental conditions, including temperature patterns, precipitation patterns, biome type, and subsistence patterns, influence both the presence and restriction level of menstrual taboos. I tested the following hypotheses: environmental conditions predict (i) the probability of menstrual taboo practices and (ii) the restriction level of menstrual taboos. I chose a Bayesian framework for this analysis because it effectively handles complex data structures and incorporates prior information. I selected the ‘brms’ package (Bürkner, 2017) in R (v4.1.2; R Core Team, 2021) due to its suitability for modelling hierarchical structures, making it ideal for multi-level data. The R code for this analysis is available here: https://arianna-quinn.github.io/Masters-Thesis-Analysis.html.

Before performing the analysis, I prepared the data through several steps. First, I coded categorical variables using dummy variables. I standardized continuous variables to have a mean of zero and a standard deviation of one. Lastly, I used the multivariate imputation by chained equations (MICE) technique from the ‘mice’ package in R (van Buuren & Groothuis-Oudshoorn, 2011) to impute missing values (n = 25) in the polygyny estimate.

I created three models for each outcome variable (Table 2.5). The first outcome variable was a binary variable indicating menstrual taboo presence. The second outcome variable was an ordinal variable representing the restriction level of menstrual taboos. For each statistical model, I included a random intercept for phylogeny to account for the non-independence of cultures due to their shared ancestral relationships. This approach mitigates the influence of Galton’s Problem (Bromham, 2022) since cultures with closer phylogenetic relationships tend to share similar cultural traits. To achieve this, I used a covariance matrix that reflects the phylogenetic structure of the data, adjusting the random intercepts for the groups (Bürkner, 2024). The covariance matrix models the correlations between cultures based on their position in the phylogenetic tree, allowing each culture to have its own baseline outcome while enabling cultures within the same phylogenetic cluster to share similar outcomes. This method prevents results from being overinflated due to ancestral relatedness, ensuring that shared cultural traits from common ancestry do not unduly influence the model’s estimates. For each outcome variable, I first created an intercept-only model as a baseline to compare with models that included predictors. The second model for each outcome variable incorporated fixed effects for subsistence patterns, polygyny, temperature patterns, and precipitation patterns to assess their influence on menstrual taboo presence and restriction levels. In the third model for each outcome variable, I added biome as a fixed effect to capture broader ecological contexts (e.g., soil type, vegetation, ecosystem productivity) that temperature and precipitation patterns alone might not fully explain. This allowed me to test whether biome data provided additional explanatory power beyond other climatic variables.

Table 2.5 Model Formulas

	Model Formula
Model 1	Outcome Variable ~ (1|Ancestral Relatedness)
Model 2	Outcome Variable ~ Subsistence + Temperature Patterns + Precipitation Patterns + Polygyny + (1|Ancestral Relatedness)
Model 3	Outcome Variable ~ Subsistence + Biome + Temperature Patterns + Precipitation Patterns + Polygyny + (1|Ancestral Relatedness)

For the presence outcome, I used a Bernoulli family to model the probability of presence (coded as 1) versus absence (coded as 0). I applied a logit link function in the Bernoulli models to connect the predictors to the probability of the outcome. The logit function transformed the probability, enabling the model to estimate the log odds of success as a linear function of the predictors. This ensured that the predicted values corresponded to valid probabilities between zero and one. For the restriction outcome, I used a Cumulative family to model categorical data with a meaningful order where category distances were not necessarily equal. I employed a logit link function in the cumulative models to model the cumulative probabilities of the outcome variable falling into each category or lower, transforming these cumulative probabilities into a linear relationship with the predictor variables. I selected weakly informative priors for all models, setting normal priors with a mean of zero and a standard deviation of one. I used the Markov Chain Monte Carlo (MCMC) method for model estimation via the 'brms' package. For the presence models, I ran four chains with 3000 iterations, including 1500 warm-up iterations. For the restriction models, I ran four chains with 6000 iterations, including 3000 warm-up iterations, to improve the goodness of fit. Table 2.6 provides full specifications for all six models.

Table 2.6 Specifications for all Models

Formula	**Family**	**Priors**	**Chains**	**Warm-Up Iterations**	**Iterations**
Presence ~ (1|Ancestral Relatedness)	Bernoulli (link = logit)	Weakly informative	4	1500	3000
Presence ~ Subsistence + Temperature Pattern + Precipitation Patterns + Polygyny + (1|Ancestral Relatedness)	Bernoulli (link = logit)	Weakly informative	4	1500	3000
Presence ~ Subsistence + Biome + Temperature Pattern + Precipitation Patterns + Polygyny + (1|Ancestral Relatedness)	Bernoulli (link = logit)	Weakly informative	4	1500	3000
Restriction ~ (1|Ancestral Relatedness)	Cumulative (link = logit)	Weakly informative	4	3000	6000
Restriction ~ Subsistence + Temperature Pattern + Precipitation Patterns + Polygyny + (1|Ancestral Relatedness)	Cumulative (link = logit)	Weakly informative	4	3000	6000
Restriction ~ Subsistence + Biome + Temperature Pattern + Precipitation Pattern + Polygyny + (1|Ancestral Relatedness)	Cumulative (link = logit)	Weakly informative	4	3000	6000

I assessed chain convergence using $\widehat{R}$ values, which measure the potential scale reduction factor. All $\widehat{R}$ values were below 1.05, indicating good convergence. I examined trace plots for all parameters and confirmed adequate mixing. Chapter 3 provides more information on model outputs. I performed posterior predictive checks to evaluate model fit by comparing simulated data from the posterior predictive distribution with observed data using the ‘bayesplot’ package (Gabry et al., 2019) in R. All models demonstrated a good fit to the data for both the presence and restriction models, though the restriction model exhibited some uncertainty. I checked the effective sample size for each parameter and found it sufficient (> 500), indicating that the MCMC chains adequately explored the posterior distribution. To test model robustness, I conducted a sensitivity analysis by testing alternative priors for each model, which confirmed that the primary results remained consistent across different prior specifications.

CHAPTER 3: IT'S ALRIGHT, MA (I'M ONLY BLEEDING) – A STATISTICAL LOOK AT HOW THE ENVIRONMENT SHAPES MENSTRUAL TABOOS

Of the 144 cultures I identified and extracted, 14 displayed no menstrual taboos, while 130 exhibited a menstrual taboo. The sample disproportionately represents cultures with menstrual taboos: 35 cultures had minimal restrictions, 46 cultures had moderate restrictions, and 49 cultures had severe restrictions. This bias likely results from the availability of ethnographic data, as ethnographers rarely noted the absence of evidence for a particular trait. For polygyny, the average percentage of men married to more than one wife was 16% (SD = 20%). Figure 3.1 illustrates the distribution of men married polygynously across restriction levels.

Figure 3.1 Violin plot with boxplot overlayed to show the distribution of percentage of men married with more than one wife across restriction levels. Menstrual taboo restriction level is on the x-axis while percentage of men married with more than one wife is on the y-axis. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

Regarding subsistence strategies, 44 cultures practiced agriculture, 49 cultures practiced hunting and gathering, 39 cultures practiced horticulture, and 12 cultures practiced pastoralism. Figure 3.2 illustrates the distribution of subsistence strategies by restriction level. Across biome categories, 89 cultures inhabited forests, 38 cultures inhabited grasslands, 12 cultures inhabited deserts, and 5 cultures inhabited polar environments. Figure 3.3 illustrates the distribution of biomes by restriction level.

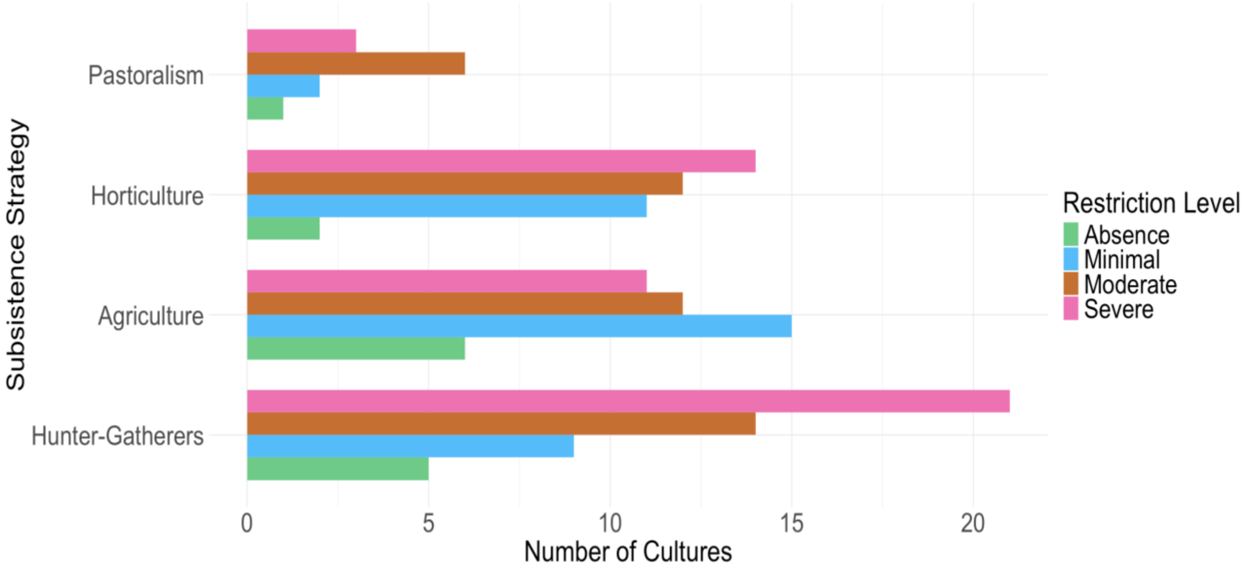

Figure 3.2 Bar plot depicting the frequency distribution of cultures across subsistence strategies compared to restriction levels. The number of cultures is on the x-axis while the subsistence strategy is on the y-axis. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

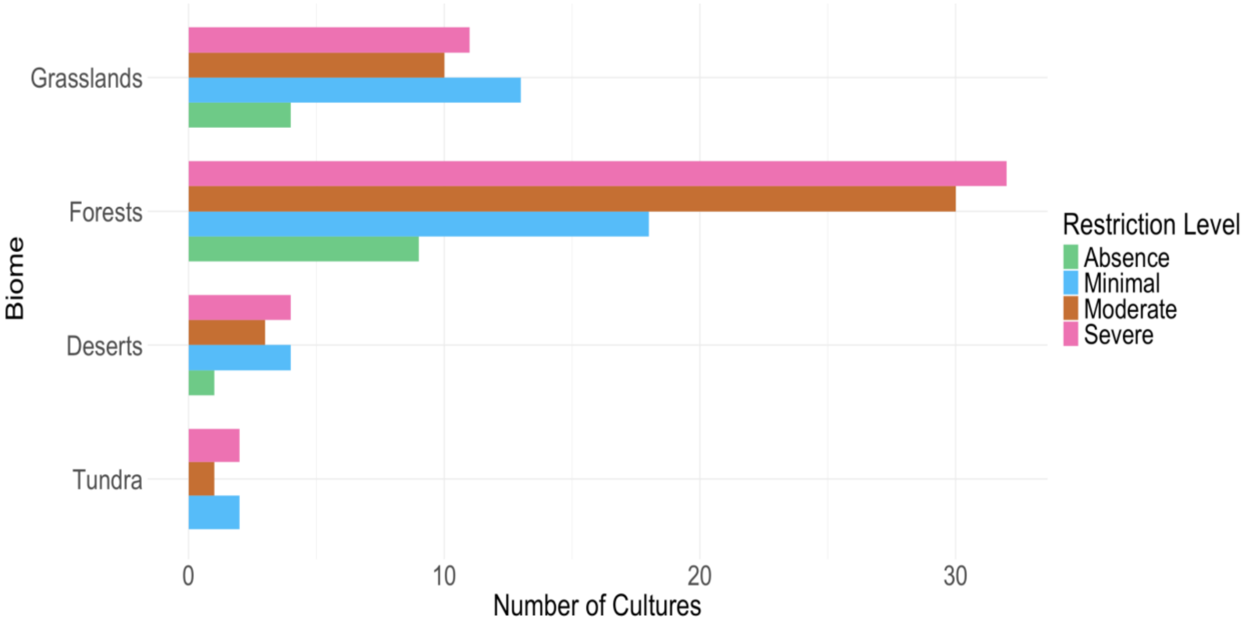

Figure 3.3 Bar plot depicting the frequency distribution of cultures across biomes compared to restriction levels. The number of cultures is on the x-axis while biomes are on the y-axis. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

3.1 Climate

As outlined in Chapter 2 (Methodology), I created two latent variables to capture different aspects of climate. The first principal component captured temperature patterns, while the second captured precipitation patterns. To describe the potential climatic variation among cultures, the sample's mean monthly temperature was 17°C (SD = 10°C), and the mean monthly precipitation was 115695 ml/m^2/month (SD = 77241 ml/m^2/month). Figure 3.4 illustrates the distribution of mean monthly temperature by restriction level. Figure 3.5 illustrates the distribution of mean monthly precipitation by restriction level. Mean monthly temperature and mean monthly precipitation serve a descriptive purpose and were not included in the models.

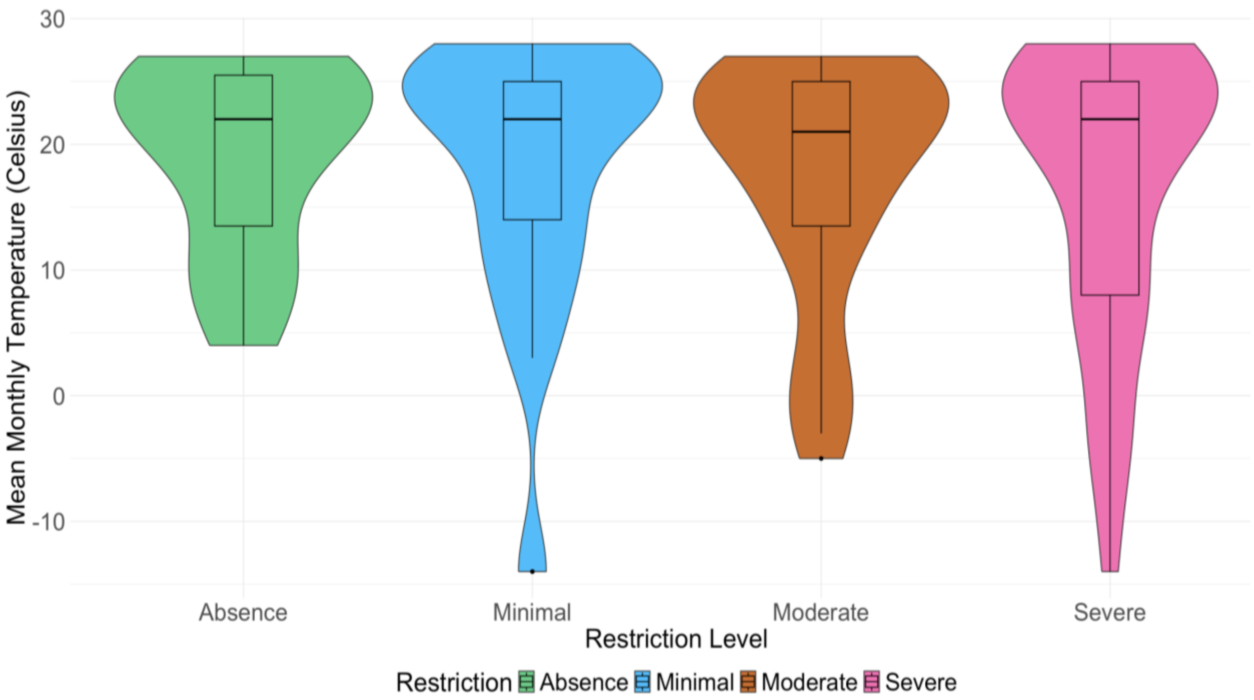

Figure 3.4 Violin plot with boxplot overlayed to show the distribution of mean monthly temperature across restriction levels. The menstrual taboo restriction level is on the x-axis while the mean monthly temperature is on the y-axis. The mean monthly temperature was measured in Celsius. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

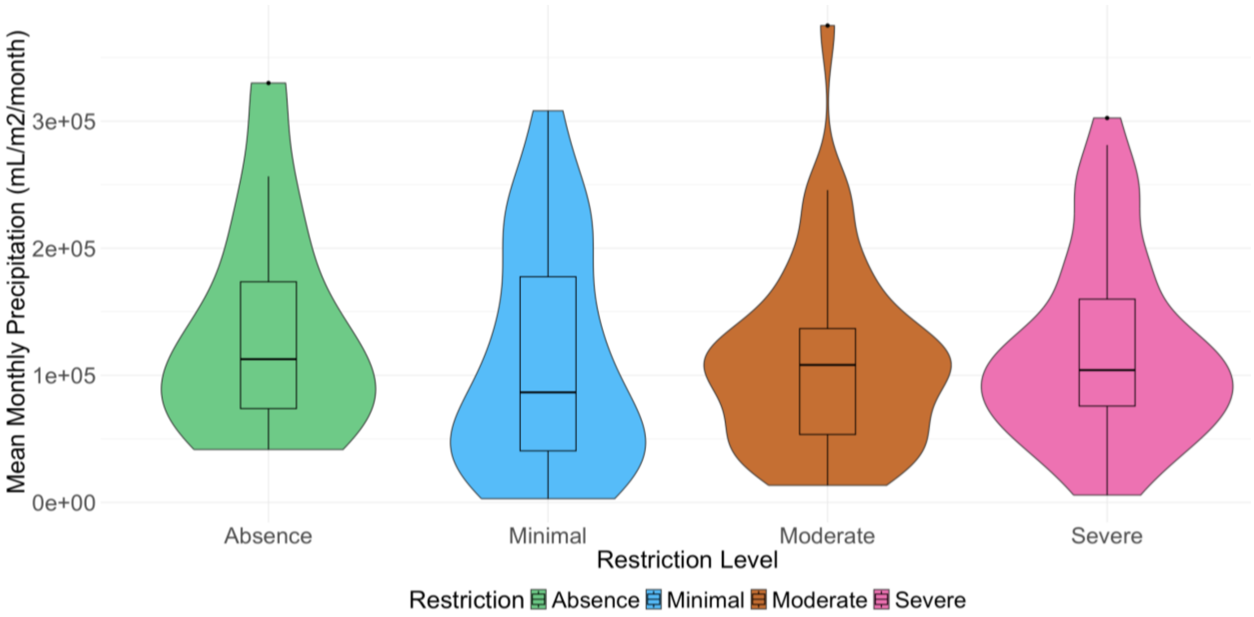

Figure 3.5 Violin plot with boxplot overlayed to show the distribution of mean monthly temperature across restriction levels. The menstrual taboo restriction level is on the x-axis, while

the mean monthly precipitation is on the y-axis. Mean monthly precipitation was measured in ml/m^2/month. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

3.2 Presence of Menstrual Taboos

I modelled the effect of environmental conditions on the probability of menstrual taboo practices. To prevent overfitting and ensure additional predictors contributed meaningfully to explaining the variance, I fitted an intercept-only model (See section 3.1.4 Model Comparison for the Leave-One-Out comparison results). Next, I built a model that included menstrual taboo presence as the outcome, with temperature pattern, precipitation pattern, subsistence pattern, and polygyny as fixed effects and ancestral relatedness as a random effect. Finally, I tested whether adding the biome improved the explanatory power.

3.2.1 Intercept-Only Model

This model provided a baseline to prevent overfitting in more complex models. All $\widehat{R}$ values were 1.00, confirming good chain convergence (Table 3.1; Appendix D for the trace plots). Appendix E includes the posterior predictive check. The posterior mean for ancestral relatedness was 0.60 (95% CI [0.04, 1.61]), indicating a small positive effect with moderate precision, which remained consistent across all three models (Figure 3.6 illustrates the posterior distributions). The marginal R^2 for the model was 0.017, explaining approximately 2% of the variance in menstrual taboos. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4). Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix F).

Table 3.1 Posterior Estimates of Intercept-Only Model

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept	2.34	0.60	1.48	3.34	1.00	3336
Group-Level Effects	sd(Ancestral Relatedness)	0.60	0.54	0.04	1.61	1.00	2267

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R^2 marginal = 0.00; R^2 conditional = 0.017.

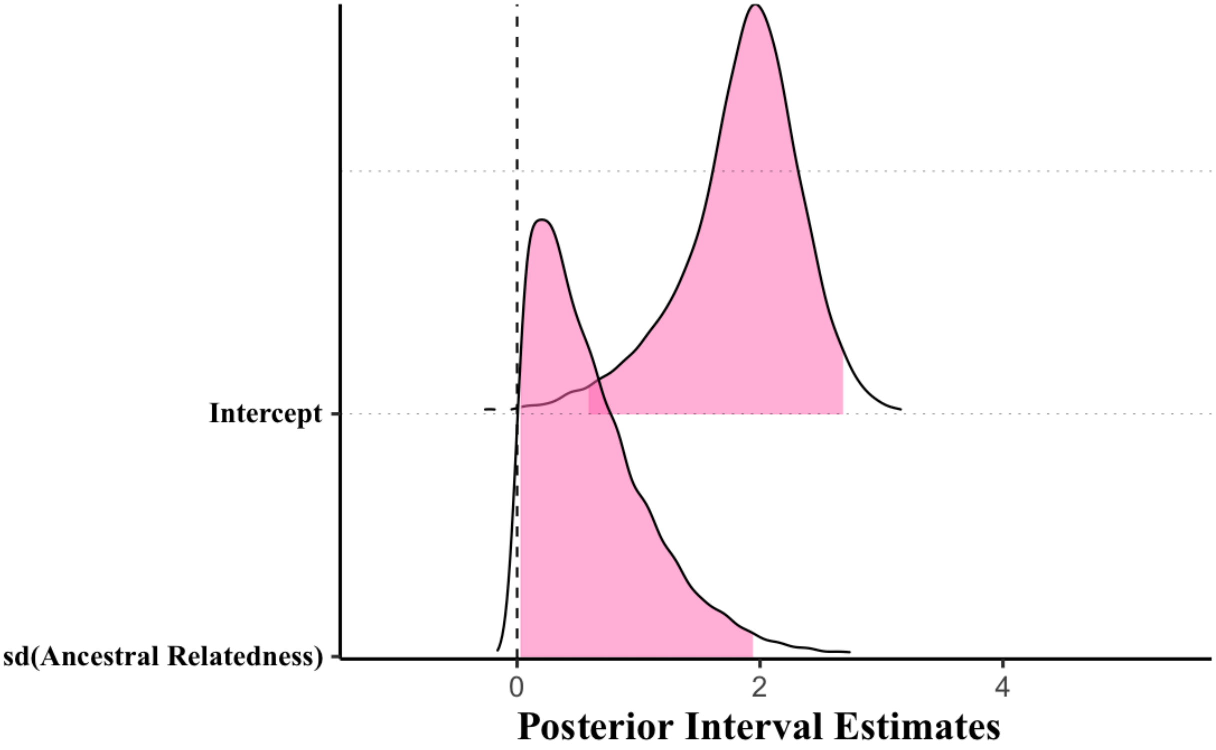

Figure 3.6 Posterior density estimates for the probability of menstrual taboos in relation to ancestral relatedness. Pink fill is truncated to indicate the 95% credible intervals.

3.2.2 Presence Model Excluding Biome

I used the model excluding biome to examine how environmental conditions affected the probability of menstrual taboos. All $\hat{R}$ values were 1.00, confirming good chain convergence (Table 3.2; Appendix G for the trace plots). Appendix H includes the posterior predictive check.

The posterior mean for temperature pattern was 0.60 (95% CI [0.00, 1.29]), suggesting a weak, moderately precise, positive effect, where higher values in temperature pattern are associated with a higher likelihood of menstrual taboos. The posterior mean for the precipitation pattern was 0.29 (95% CI [-0.19, 0.76]), suggesting a very weak but moderately precise positive effect between the precipitation pattern and the presence of menstrual taboos. Regarding subsistence strategy, horticulturalism showed a weak positive effect on the likelihood of menstrual taboos ($\beta = 0.83$, 95% CI [-0.25, 1.96]), suggesting that horticultural societies may be slightly more likely than hunter-gatherer societies to have menstrual taboos. Pastoralism ($\beta = -0.03$, 95% CI [-1.22, 1.38]) and agriculture ($\beta = -0.34$, 95% CI [-1.26, 0.59]) showed negligible effects compared to hunting and gathering. The posterior mean for polygyny was -0.03 (95% CI [-0.50, 0.47]), indicating no meaningful relationship between polygyny and menstrual taboos. However, because this model primarily explored ecological influences on menstrual taboos rather than the relationship with polygyny, caution is warranted when interpreting this effect. Figure 3.7 illustrates the posterior distributions and Table 3.2 contains the posterior estimates of each parameter in the model. The marginal R^2 for the model was 0.076, explaining approximately 8% of the variance in menstrual taboos, while the conditional R^2 was 0.067, suggesting that the fixed effects explained around 7% of the variance. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4). Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix I).

Table 3.2 Posterior Estimates of Menstrual Taboo Presence (y/n)

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\widehat{R}$	ESS
Population - Level Effects	Intercept	2.33	0.73	1.21	3.50	1.00	3428
	Temperature Pattern	0.60	0.39	0.00	1.29	1.00	7065
	Precipitation Pattern	0.29	0.29	-0.19	0.76	1.00	7965
	Agriculture	-0.34	0.57	-1.26	0.59	1.00	7027
	Horticulture	0.83	0.66	-0.25	1.96	1.00	7324
	Pastoralism	0.05	0.78	-1.22	1.38	1.00	7985
	Polygyny	-0.03	0.29	-0.50	0.47	1.00	7492
Group - Level Effects	sd(Ancestral Relatedness)	0.70	0.62	0.04	1.95	1.00	1937

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R^2 marginal = 0.076; R^2 conditional = 0.067.

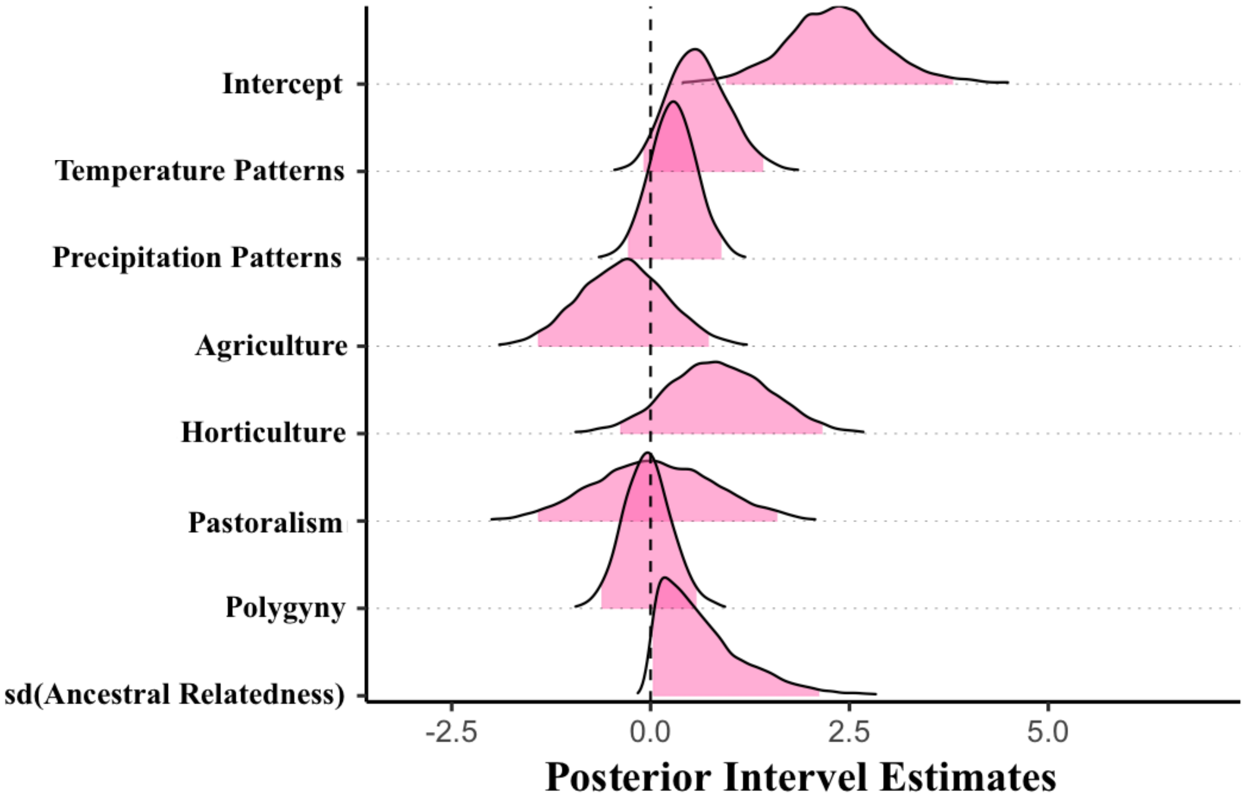

Figure 3.7 Posterior density estimates for the probability of menstrual taboos (Y/N) in relation to temperature pattern, precipitation pattern, subsistence strategy, polygyny, and ancestral relatedness. The subsistence strategy is relative to hunter-gatherers. Pink fill is truncated to indicate the 95% credible intervals.

3.2.3 Presence Model Including Biome

I next assessed whether including the biome increased the explanatory power. All $\widehat{R}$ values for this model were 1.00 (Table 3.3; Appendix J for the trace plots). Appendix K includes the posterior predictive check. Results for temperature pattern, precipitation pattern, subsistence strategy, and polygyny were consistent across the two models. For biomes, deserts ($\beta = 0.00$, 95% CI [-1.34, 1.37]), forests ($\beta = -0.14$, 95% CI [-1.32, 1.07]), and grasslands ($\beta = -0.01$, 95% CI [-1.18, 1.16]) showed no effect on menstrual taboos compared to polar biomes. Figure 3.8 illustrates the posterior distributions and Table 3.3 provides the posterior estimates for each parameter. The marginal R^2 was 0.084, indicating that the model explained approximately 8% of the variance in menstrual taboos, while the conditional R^2 was 0.076, indicating that the fixed effects explained around 8% of the variance. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4). Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix L).

Table 3.3 Posterior Estimates of Menstrual Taboo Presence (y/n)

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.45	0.94	0.98	4.01	1.00	4118
	Temperature Pattern	0.61	0.38	0.02	1.28	1.00	7200
	Precipitation Pattern	0.29	0.31	-0.22	0.78	1.00	7442
	Agriculture	-0.35	0.57	-1.28	0.60	1.00	8894
	Horticulture	0.87	0.65	-0.17	1.94	1.00	8879
	Pastoralism	0.06	0.79	-1.20	1.38	1.00	9763
	Forests	-0.04	0.31	-0.52	0.48	1.00	8936
	Grasslands	0.00	0.83	-1.34	1.37	1.00	8909
	Deserts	-0.14	0.72	-1.32	1.07	1.00	6536
	Polygyny	-0.01	0.71	-1.18	1.16	1.00	7372
Group - Level Effects	sd(Ancestral Relatedness)	0.74	0.65	0.05	1.95	1.00	2189

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R^2 marginal = 0.084; R^2 conditional = 0.076.

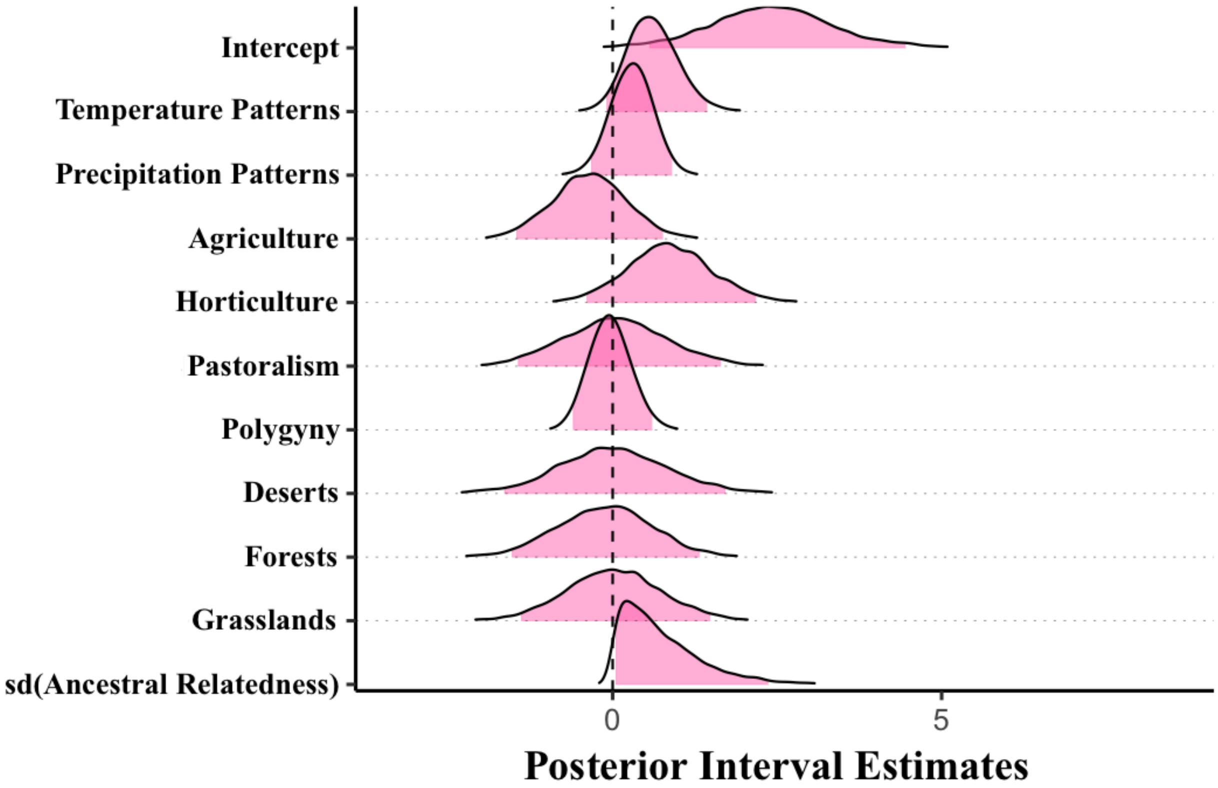

Figure 3.8 Posterior density estimates for the probability of menstrual taboos (Y/N) in relation to temperature pattern, precipitation pattern, subsistence strategy, polygyny, biome, and ancestral relatedness. The *s*ubsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Pink fill is truncated to indicate the 95% credible intervals.

3.2.4 Model Comparison

I used the Leave-One-Out Cross-Validation (LOO) criterion to compare the performance of the models. For the three presence models, the more complex models performed worse than the intercept-only model. However, the differences in expected log pointwise predictive density (elpd) had large standard errors, making it uncertain whether these differences are meaningful or attributable to random variation (Table 3.4 presents the LOO criterion results).

Table 3.4 Leave-One-Out Comparison Results for Presence Models

	Expected Log Pointwise Predictive Density Difference	**Standard Error Difference**

Presence ~ (1|Ancestral Relatedness)	0.0	0.0
Presence ~ Subsistence + Temperature Pattern + Precipitation Pattern + Polygyny + (1|Ancestral Relatedness)	-1.2	2.0
Presence ~ Subsistence + Biome + Temperature Pattern + Precipitation Pattern + Polygyny + (1|Ancestral Relatedness)	-2.6	2.3

3.3 Restriction Level of Menstrual Taboos

I then modelled the effect of environmental conditions on the restriction level of menstrual taboo practices. I first fitted an intercept-only model to prevent overfitting and ensure that additional predictors contributed meaningfully (Section 3.2.4 Model Comparison presents the Leave-One-Out comparison results). I then constructed a model including the restriction level as the outcome variable, with temperature pattern, precipitation pattern, subsistence pattern, and polygyny as fixed effects and ancestral relatedness as a random effect. Finally, I tested whether including the biome variable improved explanatory power.

3.3.1 Intercept-Only Model

This model served as a baseline to prevent overfitting the more complex models. All $\widehat{R}$ values for the model were 1.00, indicating good convergence of the chains (Table 3.5; Appendix M for the trace plots). Appendix N includes the posterior predictive check. The posterior mean for ancestral relatedness was 0.60 (95% CI [0.04, 1.61]), indicating a weak positive effect with moderate precision, which remained consistent across all three models (Figure 3.9 illustrates the posterior distributions). The marginal R^2 for the model was 0.019, explaining approximately 2% of the variance in menstrual taboos. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4). Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix O).

Table 3.5 Posterior Estimates of Intercept-Only Model

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.23	0.41	-2.88	-1.58	1.00	8488
	Intercept [Minimal to Moderate]	-0.55	0.35	-1.06	0.02	1.00	9049
	Intercept [Moderate to Severe]	0.74	0.35	0.24	1.33	1.00	9298
Group-Level Effects	sd(Ancestral Relatedness)	0.60	0.54	0.04	1.61	1.00	4703

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R^2 marginal = 0.00; R^2 conditional = 0.019.

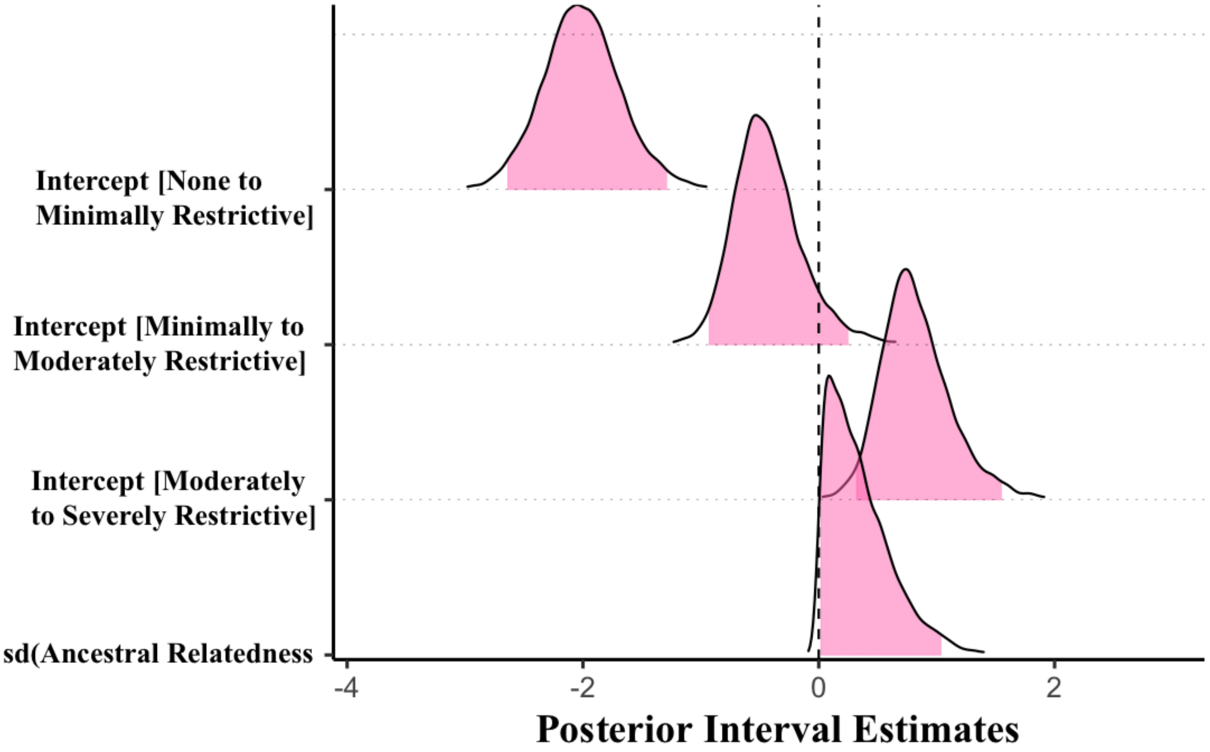

Figure 3.9 Posterior density estimates for the probability of higher restriction level of menstrual taboos in relation to ancestral relatedness. Pink fill is truncated to indicate the 95% credible intervals.

3.3.2 Restriction Model Excluding Biome

The first statistical model examined how environmental conditions excluding biome affected the probability of menstrual taboos. All $\hat{R}$ values for the model were 1.00, indicating good convergence of the chains (Table 3.6; Appendix P for the trace plots). Appendix Q includes the posterior predictive check.

The posterior mean for temperature pattern was 0.23 (95% CI [-0.06, 0.52]), suggesting a very weak, moderately precise, positive effect, where higher values in temperature pattern are associated with a slightly increased probability of being in a higher restriction level. There was no observed effect of the precipitation pattern on restriction levels ($\beta = 0.00$, 95% CI [-0.29, 0.30]).]). Regarding subsistence strategies, the model suggested that practicing agriculture was associated with a higher likelihood of having a lower restriction level compared to hunting and gathering ($\beta = -0.69$, 95% CI [-1.38, 0.00]). In contrast, there was a negligible difference between horticulture ($\beta = -0.01$, 95% CI [-0.78, 0.76]) and pastoralism ($\beta = -0.23$, 95% CI [-1.24, 0.78]) compared to hunting and gathering. The posterior mean for polygyny was 0.12 (95% CI [-0.50, 0.47]), indicating a negligible relationship between polygyny and menstrual taboos. However, because this model primarily explored ecological influences on the restriction level of menstrual taboos rather than the relationship with polygyny, so caution is warranted when interpreting this effect. Figure 3.10 illustrates the posterior distributions and Table 3.6 contains the posterior estimates of each parameter in the model. The marginal R^2 for the model was 0.089, explaining approximately 9% of the variance in menstrual taboos, while the conditional R^2 was 0.077, suggesting that the fixed effects explained around 8% of the variance. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4).

Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix R).

Table 3.6 Posterior Estimates of No Biome Restriction Model

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\widehat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.46	0.49	-3.25	-1.67	1.00	10244
	Intercept [Minimal to Moderate]	-0.74	0.44	-1.43	-0.02	1.00	10757
	Intercept [Moderate to Severe]	0.61	0.44	-0.07	1.34	1.00	10594
	Temperature Pattern	0.23	0.18	-0.06	0.52	1.00	16372
	Precipitation Pattern	0.00	0.18	-0.29	0.30	1.00	16263
	Agriculture	-0.69	0.42	-1.38	-0.00	1.00	14628
	Horticulture	-0.01	0.47	-0.78	0.76	1.00	13594
	Pastoralism	-0.23	0.61	-1.24	0.78	1.00	16065
	Polygyny	0.12	0.18	-0.16	0.41	1.00	19804
Group-Level Effects	sd(Ancestral Relatedness)	0.38	0.33	0.03	1.04	1.00	4157

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R^2 marginal = 0.105; R^2 conditional = 0.117.

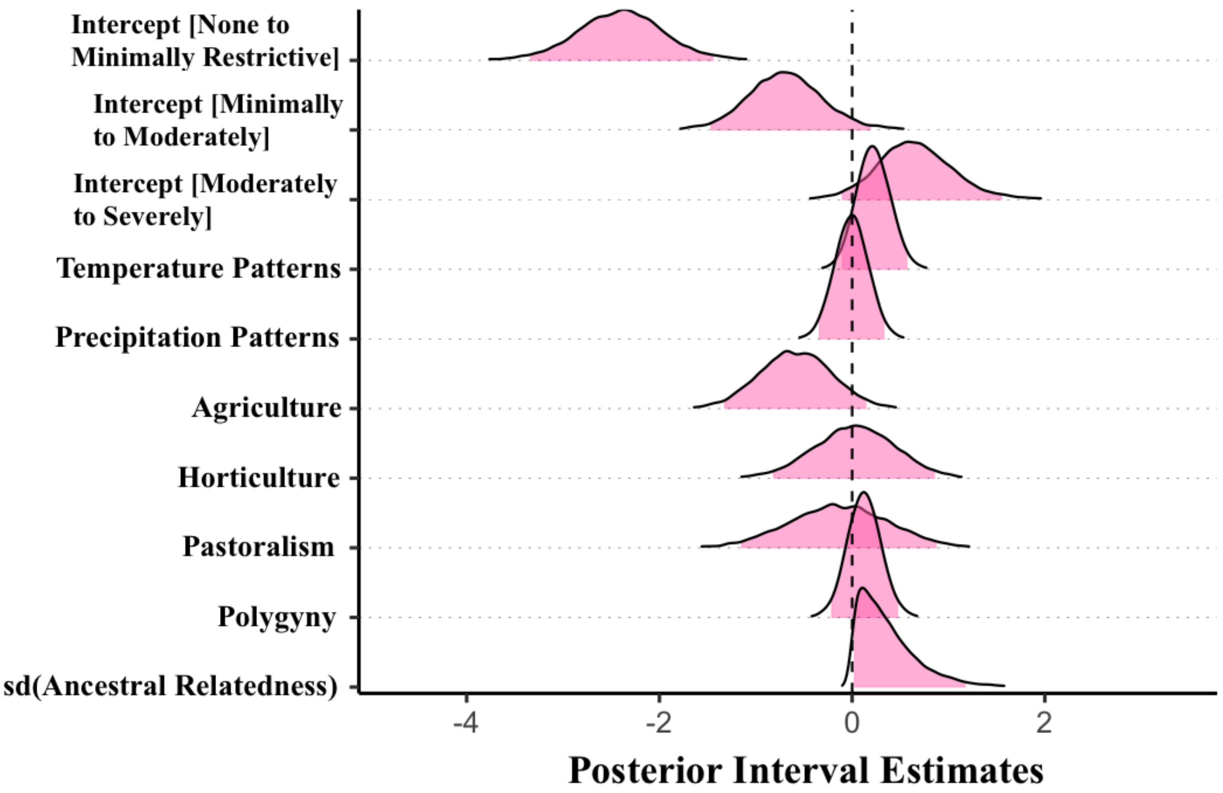

Figure 3.10 Posterior density estimates for the probability of a higher restriction level of menstrual taboos in relation to temperature pattern, precipitation pattern, subsistence strategy, polygyny, and ancestral relatedness. The subsistence strategy is relative to hunter-gatherers. Pink fill is truncated to indicate the 95% credible intervals.

3.3.3 Restriction Model Including Biome

I next assessed whether including the biome increased the explanatory power. All $\widehat{R}$ values for this model were 1.00 (Table 3.7; Appendix S for the trace plots). Appendix T includes the posterior predictive check. Results for temperature patterns, precipitation patterns, subsistence strategies, and polygyny were consistent across models. Regarding biome, the model suggested that forest biomes were associated with a higher likelihood of having a higher restriction level compared to polar biomes ($\beta = 0.83$, 95% CI [-0.98, 2.63]). However, deserts ($\beta = 0.43$, 95% CI [-1.66, 2.58]), and grasslands ($\beta = 0.28$, 95% CI [-1.58, 2.16]) had a negligible effect compared to polar biomes. Figure 3.11 illustrates the posterior distributions, and Table 3.7 provides the posterior estimates for each parameter. The marginal R^2 for the model was 0.116, explaining approximately 12% of the variance in menstrual taboos, while the conditional R² was 0.105, suggesting that the fixed effects explained around 11% of the variance. To assess the robustness of these results, I conducted a sensitivity analysis by varying the priors – normal(0,1), normal(0,5), and normal(0,4). Since the posterior estimates remained stable across priors, the results appear reliable and unaffected by prior selection (Appendix U).

Table 3.7 Posterior Estimates of Biome Included Restriction Model

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept [No to Minimal]	-1.94	1.21	-3.94	0.03	1.00	5024
	Intercept [Minimal to Moderate]	-0.19	1.19	-2.15	1.76	1.00	5002
	Intercept [Moderate to Severe]	1.19	1.19	-0.76	3.15	1.00	5002
	Temperature Pattern	0.28	0.20	-0.26	0.61	1.00	8332
	Precipitation Pattern	0.07	0.20	-1.42	0.40	1.00	16096
	Agriculture	-0.72	0.42	-0.88	-0.02	1.00	11473
	Horticulture	-0.09	0.47	-1.21	0.68	1.00	10984
	Pastoralism	-0.17	0.64	-0.11	0.87	1.00	14395
	Forests	0.83	1.10	-0.98	2.63	1.00	5384
	Grasslands	0.28	1.15	-1.58	2.16	1.00	5408
	Deserts	0.43	1.30	-1.66	2.58	1.00	5819
	Polygyny	0.19	0.18	-0.11	0.48	1.00	16895
Group - Level Effects	sd(Ancestral Relatedness)	0.42	0.34	0.03	1.08	1.00	4205

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size. N = 144. R² marginal = 0.077; R² conditional = 0.090.

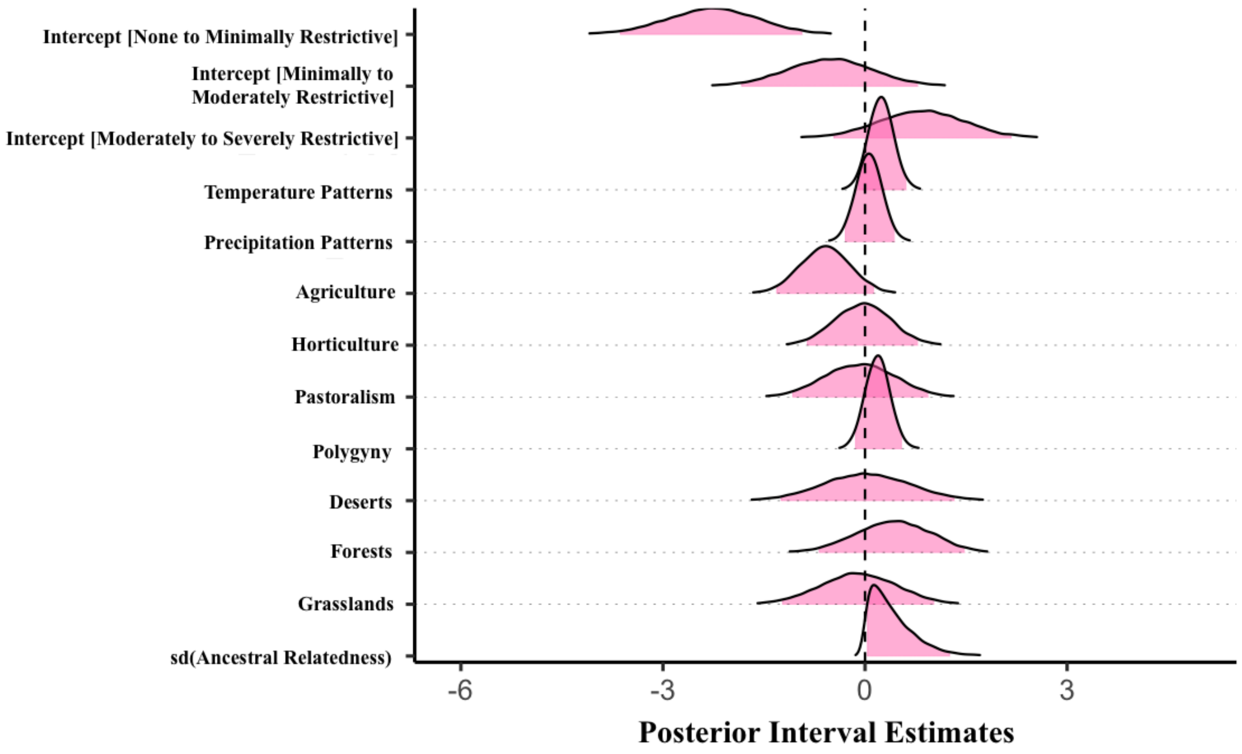

Figure 3.11 Posterior density estimates for the probability of higher restriction level of menstrual taboos in relation to temperature pattern, precipitation pattern, subsistence strategy, polygyny, biome, and ancestral relatedness. The subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Pink fill is truncated to indicate the 95% credible intervals.

3.3.4 Model Comparison

I used the LOO criterion to compare the performance of the models. For the three restriction models, the more complex models performed worse than the intercept-only model. However, the elpd difference values had large standard errors, making it unclear whether these differences are reliable or attributable to random variation. See Table 3.8 for the LOO criterion results for the restriction models.

Table 3.8 Leave-One-Out Comparison Results for Restriction Models

	Expected Log Pointwise Predictive Density Difference	Standard Error Difference

Restriction ~ (1|Ancestral Relatedness)	0.0	0.0
Restriction ~ Subsistence + Temperature Pattern + Precipitation Pattern + Polygyny + (1|Ancestral Relatedness)	-3.2	2.8
Restriction ~ Subsistence + Biome + Temperature Pattern + Precipitation Pattern + Polygyny + (1|Ancestral Relatedness)	-6.0	3.5

3.4 Discussion

The current study examines the relationship between ecology and menstrual taboos. The results suggest that environmental factors weakly influence both the probability of menstrual taboos and their restriction level. Specifically, I found a weak effect between temperature pattern and both the presence and restriction level of menstrual taboos. Additionally, precipitation pattern showed a very weak effect on the probability of menstrual taboos. Regarding subsistence strategies, horticultural societies exhibited a higher likelihood of menstrual taboos than hunter-gatherers, while agricultural societies were more likely to have a lower restriction level than hunter-gatherers. Lastly, forested landscapes showed a weak association with higher restriction levels compared to polar landscapes. These findings also indicated that while ecological factors play a role in shaping menstrual taboos, cultural influences likely exert a stronger effect on their persistence and variation. These findings align with my hypotheses that the environment influences the persistence and restriction level of menstrual taboos and meets expectations, as strong ecological effects were not anticipated. These results also provide weak support for the paternity certainty hypothesis proposed by Strassmann et al. (2012) and add evidence that environmental conditions shape cultural restrictions on females' sexuality similarly to religious veiling (Pazhoohi et al., 2017), restrictions on female premarital sex (Šaffa et al., 2002a) and FGM (Šaffa et al., 2022b).

However, two unexpected results emerged. First, the study found no significant evidence linking pastoralism to menstrual taboos, despite the association between pastoralism and harsh environments. The mobility of pastoralist societies may disrupt the enforcement of menstrual taboos due to prolonged spousal separation, which increases the cost of mate guarding. Additionally, pastoralists may regulate female sexuality through alternative mechanisms such as female infibulation (Šaffa et al., 2022b) or social norms that promote female sexual autonomy (Scelza et al., 2021), reducing the need for menstrual restrictions. Second, the study did not find evidence supporting a link between polygyny and menstrual taboos, despite Stephens (1962) reporting a moderate positive association between them. Given the age of that study, it is likely that subsequent data updates and methodological differences account for the discrepancy. Additionally, Stephens (1962) used a categorical measure of polygyny, this study employed a continuous variable estimating the percentage of men married polygynously. Future research should reassess this relationship using updated data to determine the extent to which polygyny influences menstrual taboos.

Several factors may explain the weak environmental effects observed in this study. One possibility is that menstrual taboos originated in ancestral environments where they provided a greater benefit to male fitness, particularly by enhancing paternity certainty at a time when tracking paternity was more difficult and resources were scarcer. If menstrual taboos historically benefited male fitness, their persistence today may stem from cultural inertia rather than ongoing adaptive significance. Alternatively, socioecological changes may have rendered menstrual taboos as neutral or low-cost fitness-wise, meaning the associated costs are not high enough to drive their eradication. More stable environments may also promote cultural conservatism, leading societies to uphold traditions, including menstrual taboos, across generations (Giuliano & Nunn, 2017).

Additionally, cultural trait dispersal patterns depend on environmental barriers, which may prevent cultural exchange and contribute to the persistence of menstrual taboos in certain regions. If these taboos spread in environment-dependent ways, their continued existence in specific ecological settings may result from historical transmission patterns rather than active selection pressures.

This study has several limitations. First, potential ethnographer bias arises from the lack of standardized data reporting in ethnographies, leading to uneven data availability across cultures. Since menstruation and menstrual practices were likely not the primary focus of all ethnographies, some cultures in the eHRAF database lack relevant information. Additionally, the study's small sample size results from cross-referencing ethnographic data with the phylogenetic tree reducing the number of applicable cultures. More ethnographic and phylogenetic data could expand the sample size and improve the robustness of the findings. Furthermore, the phylogenetic tree represents a hypothesized model of ancestral relationships, meaning additional data could refine or alter results. Missing polygyny data from 25 cultures also posed a challenge as potential biases could have distorted the relationship between menstrual taboos and polygyny. Finally, the results only reflect the historical data ranging from 1665 to 2014 and capture group-level patterns rather than individual behaviours.

Future research should explore several key areas. First, researchers should examine how female contributions to subsistence influence menstrual taboos. In cultures where females play a major role in subsistence, male investment may be less necessary. For instance, as female contributions decline, restrictions on female sexual expression like restrictions on premarital sex may increase (Schlegel & Barry, 1986; Price et al., 2014; Šaffa et al., 2022a). Investigating this relationship could clarify the link between paternity certainty, paternal investment, and menstrual taboos. Second, future researchers should assess the role of spousal separation, which increases paternity uncertainty and complicates mate guarding. Research should examine whether cultures with high rates of spousal separation implement alternative forms of female sexual control, such as infibulation (Šaffa et al., 2022b) or relaxed sexual restrictions for females (Scelza et al., 2021). Third, given that globalization has likely weakened the environmental influences on menstrual taboos, a time-delineated analysis of well-documented cultures over multiple periods could provide insights into how these taboos evolved and how a culture's social and ecological environment plays a role over time. Another key area would be to investigate how menstrual taboos are being transmitted – looking at if they are being transmitted vertically, obliquely, or horizontally and through what mechanisms such as local enhancement, observation, emulation, or imitation – as this could help clarify who enforces these taboos, particularly since parental influence appears to play a key role in female sexual suppression (Kellie et al., 2020), with enforcement primarily by males except when mothers have sons (Blake et al., 2018). Future research could also examine whether restrictive menstrual taboos and other forms of mate guarding are more prevalent in patrilocal societies, where extended male kin may facilitate mate guarding. Additionally, investigating how population density affects menstrual taboos is valuable, as smaller communities may enforce them more strictly due to the high value placed on reputation, or they might show a parabolic relationship similar to religious veiling practices (Pazhoohi, 2024a).

The results of this study contribute to our understanding of how environmental factors shape menstrual taboos, offering an insight into cultural practices that restrict female sexuality. This research can also inform policymakers by highlighting the factors that influence the persistence and restrictiveness of menstrual taboos, helping to combat menstrual stigmatization and improve reproductive health and education. These findings emphasize the complexity of cultural traits, demonstrating that they emerge from the interplay of multiple, interacting influences rather than any single factor. In the next chapter, I will examine how cultural factors contribute to the persistence of menstrual taboos and explore how historical shifts have shaped these practices.

CHAPTER 4: THE RED THREAD OF CULTURE – WEAVING THROUGH MENSTRUAL TABOOS

With increasing globalization and education, we might expect menstrual taboos to weaken or disappear, as these factors have driven shifts in other forms of mate-guarding. For example, education was negatively correlated with the importance of religious veiling (Pazhoohi, 2024a) and FGM (Ameyaw et al., 2020; Tamire & Molla, 2013). Additionally, urbanization, a consequence of globalization, contributes to lower rates of FGM (Karmaker et al., 2011; Tamire & Molla, 2013). The anonymity in urban settings makes it harder to track nonparticipation and reduces reputational costs, lessening the pressures to conform (Danielson et al., 2023; Suzuki & Akiyama, 2005). Regarding menstrual taboos, increased education and professional opportunities have weakened their influence among the Havik Brahmin (Ullrich, 1992). Among cultures with menstrual taboos from the eHRAF, 10 cultures identified two primary reasons for shifts in menstrual taboo practices: (i) external group influence and (ii) urbanization (Figure 4.1). Despite expectations that globalization, education, and urbanization would erode menstrual taboos, these taboos remain widespread. In Nepal, menstrual huts persist despite legal prohibitions (Adhikari, 2020), and menstruation continues to carry stigma even in Western, Educated, Industrialized, Rich, and Democratic (WEIRD) societies (Olson et al., 2022; Ramaiyer et al., 2023). This persistence raises the question: why do menstrual taboos continue to endure?

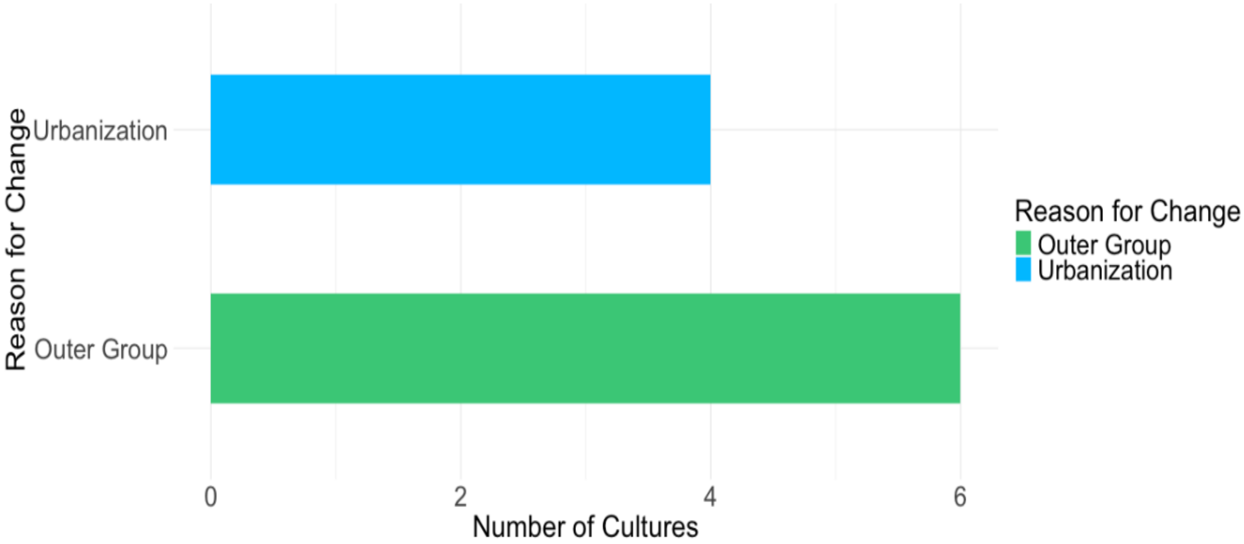

Figure 4.1 The distribution of reasons given for a shift in menstrual taboo practices. The number of cultures is on the x-axis, while the reasons given for change are on the y-axis. The colours represent the 2 reasons (green = outer-group influence and blue = urbanization).

Menstrual taboos may persist partly due to their role in paternity assurance by restricting female mobility and sexuality, thereby increasing male confidence in offspring. However, many cultures that practice menstrual taboos, such as the Dogon, determine paternity socially rather than biologically (Figure 4.2). Among the Dogon, a man assumes paternity when he is the first to have sex with a female after her menstrual seclusion (Palau Martí & Schütze, 1957; van Beek, 1992). This suggests that paternity assurance alone cannot fully explain the persistence of menstrual taboos. Instead, multiple factors work together, making these taboos difficult to eradicate. Policies prohibiting them may prove ineffective if they fail to address the root causes. This chapter explores three potential influences on the persistence of menstrual taboos: (i) costly signals of mate quality, (ii) religion and supernatural punishment, and (iii) group identity signalling and social cohesion.

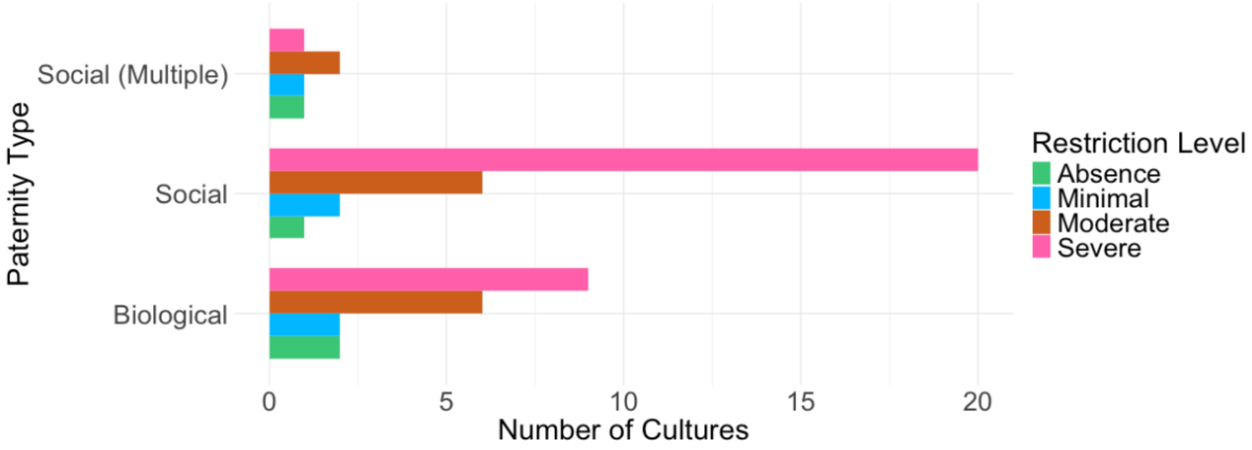

Figure 4.2 The distribution of menstrual taboo restriction levels across different cultural conceptions of paternity. The number of cultures is on the x-axis while paternity type is on the y-axis. The colours represent the 4 restriction levels (green = absence of menstrual taboos, blue = minimally restrictive menstrual taboos, orange = moderately restrictive menstrual taboos, and pink = severely restrictive menstrual taboos).

4.1 Costly Signal of Mate Quality

Social paternity appears most common in cultures with the most restrictive menstrual taboos (Figure 4.2), suggesting another possible explanation for their persistence. Since social paternity often assigns fatherhood to husbands, restrictive menstrual taboos may function as a costly signal of mate quality. This would happen through parents enforcing participation before marriage as an investment strategy. This makes sense, however, as parents have a lot to gain from influencing and exerting control over their children’s marriage and reproductive decisions (Apostalou, 2007). For example, that appears to be part of the explanation for the persistence of FGM as females who have undergone FGM are married younger (Howard & Gibson, 2019) and have lower dowries (Gibson et al., 2023). In terms of religious veiling, Muslim males rated females wearing religious veiling and conservative dress as more trustworthy and committed than Christian males (Pazhoohi et al. 2025). This costly signal framework applies to males as well. Females rate males who engage in cultural practices as better potential mates, and parents rank those who participate in more costly practices the highest (Xygalatas et al., 2022). Cultural participation provides social, material, and protective benefits. For instance, FGM facilitates social capital accumulation (Shell-Duncan et al., 2014), polygynous unions offer material capital accumulation (Hames, 1996; Lawson et al., 2015; Winking et al., 2013), and religious veiling provides male protection (Pazhoohi, 2024b). Thus, severely restrictive menstrual taboos may offer similar benefits by signalling mate quality, but this influence likely applies only to highly restrictive taboos such as menstrual seclusion.

4.2 The Influence of Religion and Supernatural Punishment

Religious traditions frequently include menstrual taboos. For example, Judaism, Hinduism, and some Christian denominations classify menstruating women as ritually unclean. Religious norms often regulate extra-pair partnerships (e.g., Trinitapoli & Regerus, 2006; Hone et al., 2021; Schmitt & Fuller, 2015; Weeden & Kurzban, 2013), and menstrual stigma may reflect this concern. However, religion also relies heavily on conjectural knowledge—assumptions, inferences, and speculations rather than empirical evidence (Ginzberg, 1980). This type of knowledge reinforces religious beliefs by explaining unexplained events, invoking supernatural punishment, and signalling group loyalty (Fitouchi & Singh, 2022; Johnson & Krüger, 2004; Purzycki et al., 2022). Supernatural punishment functions as a potent deterrent, reducing the need for direct enforcement (Laurin et al., 2012). Cultures frequently use supernatural threats to enforce menstrual taboos, such as claiming crops will fail if a menstruating woman enters a field (Tan et al., 2017). The part that makes supernatural punishment help beliefs persist is that individuals may avoid testing supernatural claims to prevent cognitive dissonance, which reinforces social norms (Atkinson & Bourrat, 2011). This means that individuals within a culture may refrain from testing claims such as the crops will die if I enter them when menstruating just in case it does lead to the crops dying (thus leading to a hypothetical consequence such as famine).

4.3 Group Identity Signal and Social Cohesion

Menstrual taboos may also persist because they reinforce group identity and social cohesion. These taboos can signal social identity and shape cultural conceptions of femininity. Markers of social identity encourage norm compliance and influence the persistence of cultural practices (Rathbone et al., 2023). This is partly because people are more likely to adopt behaviours perceived as common within their group. For instance, individuals in Namibia adopted new medical recommendations when they believed them to be widespread in their social group (Hagen & Scelza, 2020). In terms of other mate-guarding traits, religious veiling holds greater importance for women in larger settlements, possibly because it serves as a social identity signal (Pazhoohi, 2024a). Menstrual taboos may reinforce group or gender identity by demonstrating commitment and shared values, promoting cooperation within groups (Macanovic et al., 2024; Przrpiorka & Diekmann, 2021) which could be why they continue to persist.

4.4 Conclusions

This chapter explored the persistence of menstrual taboos. Since cultural practices are not stagnant but dynamic and change over time and place, we can assume menstrual taboos would weaken in response to similar factors that cause shifts in other forms of mate-guarding, such as religious veiling or FGM. However, menstrual taboos continue to persist today, even with globalization and increased female education. While hierarchical cultural traits tend to change incrementally (Walker, 2015), menstrual taboos remain prevalent even as globalization and female education increase. Gradual shifts may occur over time, transitioning through less restrictive forms before disappearing. Researching the persistence of practices such as menstrual taboos is important because it is crucial for gender equality. Menstrual taboos negatively impact female health, social participation, and economic opportunities (Garrido Martín et al., 2025). They affect a female's access to education (Sommer & Sahin, 2013) and healthcare (Babbar et al., 2022). This impact on females makes it crucial for goals toward global gender equality to aim for the eradication of menstrual taboos and stigmatization. A key strategy for reducing menstrual taboos is promoting a neutral perspective on menstruation—neither glorifying nor stigmatizing it. This means accepting it as a normal part of female life (Tomlinson, 2024). We shouldn't treat menstruation as making females powerful or mystical, as well as not treating it like it is dirty or impure. Additionally, by also educating people on how menstruation features in everyday experiences and routines could help us promote the normalcy and neutrality of menstruation (Bowen-Viner et al., 2024).

There are several limitations to this review. The first limitation is that although it probes the basis for future research, it cannot establish causality. It is aimed at exploring potential causes behind the persistence of menstrual taboos but does not provide any quantitative analysis to confirm the patterns and claims. Additionally, it potentially overgeneralizes cultural patterns as individual cultures may vary significantly in how they function and the causes of their persistence. Essentially, it risks oversimplifying a complex picture as all these factors likely interact in complex and potentially non-linear ways. This is important because the evolution of cultural traits is influenced by numerous potentially overlapping factors that can be challenging for researchers to isolate. Lastly, this review also overlooks individual agency and may not adequately capture how individuals within societies negotiate, challenge, and reinterpret menstrual taboos.

There are several future research directions one could undertake. The first potential research direction would explore how cultural constructions of paternity, such as partible paternity, influence the restrictions on female sexuality, given that the idea of multiple fathers may require fewer or no restrictions. This is important because it could help provide further clarity on how cultural traits that restrict female sexuality, like menstrual taboos, are related to cultural conceptions of paternity. Additionally, it could provide valuable insights into cultural conceptions of paternity, which appears to be an understudied area of research. Another line of research would be into mate quality signals, as one could investigate dowries in cultures with restrictive menstrual taboos and whether these cultures also have a younger age at first marriage. Another approach would be to use a similar population like Strassmann et al. (2012), that has three or more common religions, each with its varying menstrual taboos, and collect data on individual age at first marriage, dowry price, male resources, and some measure of social capital to explore how menstrual taboos may signal mate quality and what females may gain from participating. Another line of research would be to explore how threats of supernatural punishment vary across cultures that practice menstrual taboos. One could also look within a small sub-set of cultures with taboos and see if belief in supernatural punishment and compliance to menstrual taboos vary. This could help get at the potential relationship that the threat of supernatural punishment could have on menstrual taboos. The last line of research would be to examine how settlement size influences menstrual taboos. This way allows us to look at whether menstrual taboos follow similar patterns where larger settlements make it harder to police these taboos and offer greater anonymity, potentially reducing restrictive practices, or do menstrual taboos show a similar parabolic relationship like Pazhoohi (2024a) found where females rate religious veiling of higher importance in larger settlements indicating a potential group signalling and social cohesion effect.

This research is crucial for developing effective interventions that promote menstrual equity, support gender equality, and challenge harmful cultural norms. Understanding the persistence of menstrual taboos is critical for developing effective interventions that eradicate menstrual stigmatization and menstrual taboos. Additionally, the dismantling of a harmful social norm is important as it will help us achieve further global gender equality. By understanding these factors, we can work toward dismantling menstrual taboos and advancing gender equality.

CHAPTER 5: GENERAL DISCUSSION

In this thesis, I examined the ecological and cultural factors that shape menstrual taboos. In Chapter 1, I proposed two hypotheses to explain how ecological conditions influence menstrual taboos. I expected the presence and restriction level of menstrual taboos to increase in ecological conditions with higher investment costs (e.g., harsh environments and pastoralist subsistence strategies). Additionally, since menstrual taboos appeared to be more common in cultures with social forms of paternity, I identified two key areas for further investigation: the persistence of menstrual taboos over time and the historical shifts that have influenced their evolution. Here, I summarize the results and explore the limitations and future research directions of my thesis.

5.1 Ecological Influence

I found a weak effect of ecological factors, specifically temperature patterns and subsistence strategy, on the presence and restriction level of menstrual taboos. This ecological influence aligns with findings from research on mate-guarding practices, such as religious veiling (Pazhoohi et al., 2017) and restrictions on premarital sex (Šaffa et al., 2022a). Similarly, Wormsley et al. (2023) reported that ecology accounts for 1% to 20% of the variance in cultural traits. This range suggests that a strong ecological effect would imply environmental determinism. The weak ecological influence I observed contributes to our understanding of human behavioural ecology primarily by suggesting that at some point in the historical emergence of socio-cultural diversity, environmental pressures shaped menstrual taboos.

I also identified two surprising outcomes. First, I found no effect of pastoralism, which contradicted my hypothesis that pastoralist cultures, often associated with harsh environments, would exhibit more restrictive menstrual taboos. This discrepancy may result from the limited number of cultures classified as pastoralists, which reduced the ability to detect meaningful patterns. However, I also found that hunter-gatherer societies displayed more restrictive taboos than agriculturalist societies, partially aligning with Kithara's (1982) research, which linked menstrual taboos to the importance of hunting. The pronounced division of labour in hunter-gatherer societies (Bird & Codding, 2015; Marlowe, 2007) may explain this pattern. Males may restrict female sexuality to monopolize resources, while females may have an incentive to comply due to limited subsistence acquisition opportunities or alloparents. Since the division of labour varies across hunter-gatherer populations (Haas et al., 2020; Anderson et al., 2023), future research should examine how menstrual taboos differ within these societies to clarify the role of labour division in shaping restrictive practices. These findings highlight how subsistence strategies can shape gender norms, potentially influencing gender inequalities in certain societies. However, the relatively small effect of ecological conditions on menstrual taboos suggests that cultural and social factors now play a more dominant role in shaping these restrictions.

5.2 Persistence and Shifts in Menstrual Taboos

Since menstrual taboos seemed to be more common in cultures with social forms of paternity, I explored several factors that contribute to the persistence of menstrual taboos beyond biological paternity assurance. Religious elements, such as conjectural knowledge and fears of supernatural punishment, potentially play a role in maintaining these taboos. Additionally, some cultures may use menstrual taboos to signal cultural and female identity, reinforcing the incentive to uphold them. The persistence of menstrual taboos appears to follow similar patterns observed in other female sexuality-restricting practices, such as religious veiling (Pazhoohi, 2024a; Pazhoohi, 2024b), restrictions on premarital sex (Šaffa et al., 2022a), and female genital mutilation (Gibson et al., 2023; Howard & Gibson, 2019). Understanding these mechanisms can inform efforts to challenge menstrual taboos, as it is likely that interventions must address deeply held religious and social beliefs rather than solely focusing on education or resource access.

Even in WEIRD societies (Heinrich et al., 2010), menstruation remains stigmatized, though restrictions take different forms. In WEIRD societies like the United States, menstrual product advertisements potentially perpetrate and reinforce false and negative narratives surrounding menstruation (Mucedola & Smith, 2022). Additionally, menstruation in these places is often shrouded in silence in workplaces and schools, leading to absenteeism and lower self-esteem (Johnston-Robledo & Chrisler, 2013). While these societies lack explicit menstrual taboos, cultural discomfort persists, reinforcing harmful gender norms. Similarly, in many non-WEIRD societies, menstrual taboos such as menstrual seclusion can increase the risk of infections and school dropout rates (Sommer et al., 2015; Sommer et al., 2021). These consequences illustrate that menstrual taboos are not merely relics of tradition but actively harmful practices that hinder female well-being. Given these negative effects, menstrual taboos warrant further research and targeted intervention efforts.

To understand the historical shifts in menstrual taboos, I explored the two reasons expressed by cultures for these shifts: i) increased female education/economic opportunities and ii) the influence of an out-group (which is more common now due to globalization). Since globalization and female education contribute to gender equality (Richards & Gelleny, 2007), this may be why they partly drive shifts in menstrual taboo practices. This means that efforts to reduce menstrual stigma should prioritize increasing educational opportunities for women and fostering cross-cultural interactions that challenge restrictive traditions. However, since researchers have conducted limited studies on the long-term persistence and transformation of menstrual taboos, future studies should examine how shifts occur across generations and whether external influences, such as policy changes, migration, and media representation, accelerate or slow this process. Globalization might also be a double-edged sword, as some cultures may resist changing menstrual taboo practices due to concerns about Western influence, which would end up reinforcing menstrual taboos as a way to preserve cultural identity. From a policy perspective, recognizing that menstrual taboos remain deeply embedded in religious and cultural identities suggests that change must occur incrementally (Walker, 2013). Rather than attempting to eliminate menstrual taboos immediately, interventions should focus on gradually reducing their restrictiveness. Engaging with religious and community leaders to reshape menstruation narratives could serve as a critical step in this process. Understanding these dynamics is essential for designing culturally sensitive policies that promote menstrual equity while avoiding backlash or reinforcing resistance to change.

5.3 Limitations & Future Research Directions

This thesis has several limitations. First, biases exist within the ethnographic data. The perspectives of researchers who document menstrual taboos can introduce observer bias, as their interpretations and reporting may not fully capture local nuances. Additionally, ethnographic data primarily comes from community informants, who may exaggerate or downplay certain aspects of their culture due to personal, social, or political pressures. These factors may have influenced data collection and the coding of menstrual taboos. Furthermore, the data spans multiple historical periods (1800s–2000s), which do not align across cultures, complicating cross-temporal comparisons and potentially obscuring ecological effects. This thesis may also overemphasize ecological determinants while underestimating cultural and social influences. Some cultures follow hybrid practices or experience influences beyond environmental conditions and subsistence patterns, limiting the generalizability of these findings. This thesis also does not account for internal variation in menstrual taboo practices within cultures. Different groups within the same society may hold divergent views, with urban and rural populations or various ethnic groups practicing menstrual taboos at different restriction levels. This internal variation complicates the analysis of a single "cultural norm."

Future research should explore menstrual seclusion as a distinct level of restriction within menstrual taboos, investigating whether unique cultural or environmental pressures shape its practice and persistence. Additionally, researchers should examine how religious doctrine, social enforcement, and fear shape menstrual taboos and how these elements interact with environmental conditions. Conducting interviews, surveys, or case studies in diverse communities could provide insights into male and female perspectives on menstruation and menstrual taboos. That line of research is particularly important to look at from the female perspective, as menstrual taboos may be accepted by females as what it means to be a woman in that culture (Maharaj & Winkler, 2021). To gain a better understanding of how menstrual taboos affect physical health, education, and economic opportunities, we could use a comparative method to look between societies with strong menstrual taboos and those with minimal stigma could quantify the educational, health, and economic costs of these restrictions. Another promising research direction involves analyzing how migration and diaspora communities negotiate menstrual taboos, shedding light on how globalization shifts these practices. Studying how individuals adapt their menstrual traditions after migrating—from rural to urban areas or across countries—could reveal the factors driving cultural change. Researchers could also examine multi-generational family dynamics to determine how menstrual taboos evolve.

5.4 Conclusion

This research enhances our understanding of menstrual taboo persistence by analyzing the ecological and cultural factors that shape their expression. Although environmental pressures may have historically influenced menstrual taboos, cultural mechanisms such as religious beliefs, social identity signalling, and supernatural fears now play a more significant role in maintaining them. Additionally, increased female education, economic opportunities, and globalization appear to drive shifts in menstrual taboos by introducing new perspectives and challenging traditional restrictions.

These findings contribute to broader discussions on gendered restrictions, cultural adaptation, and policy applications. By investigating how ecological and cultural factors shape menstrual taboos, this research offers insights into the mechanisms sustaining mate-guarding strategies in general. While menstrual taboos are often examined in non-WEIRD societies, they remain a global issue, so a more holistic approach to eradicating menstrual stigma should consider both explicit restrictions and implicit biases. The implications extend to public health interventions and policymaking, suggesting that gender equality initiatives and culturally sensitive educational programs could help weaken menstrual taboos. While cultural sensitivity is necessary when addressing menstrual taboos, their persistence highlights broader structural inequalities that restrict female autonomy. A more holistic approach to menstrual stigma should target both explicit taboos and implicit biases, particularly in societies that claim gender equality yet maintain hidden forms of discrimination. Future research must continue investigating the intersection of cultural tradition, social enforcement, and economic shifts to better inform policies aimed at dismantling menstrual restrictions and other restrictive female practices worldwide.

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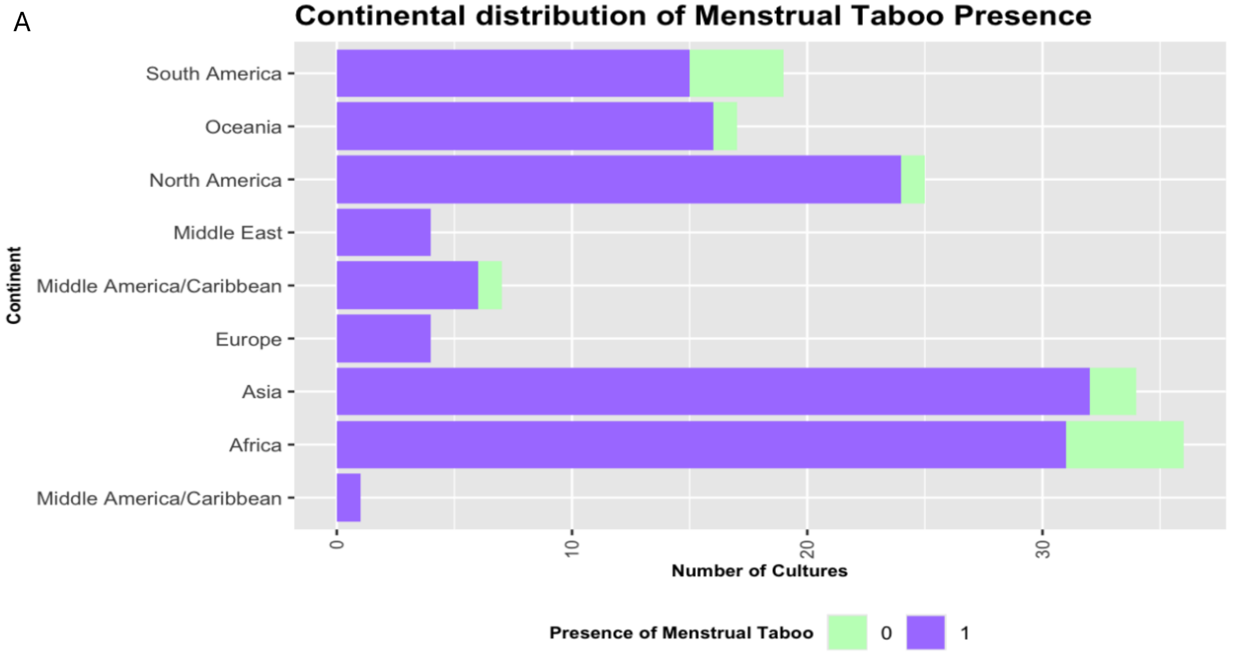
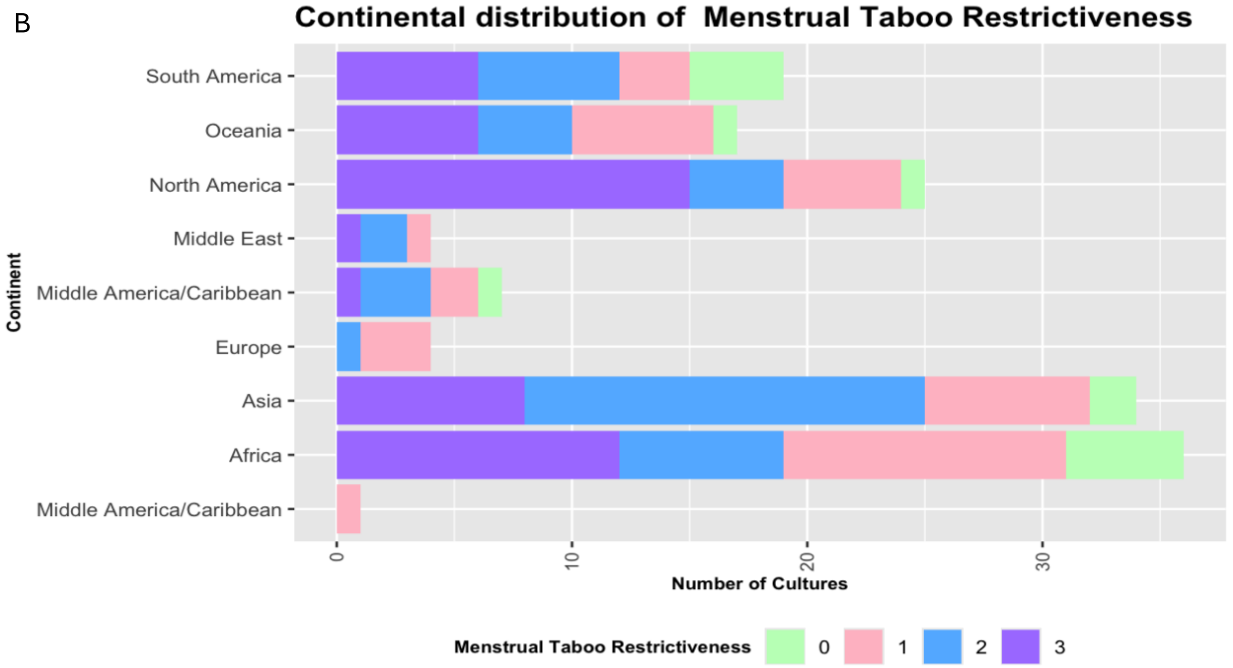
APPENDICES

Appendix A

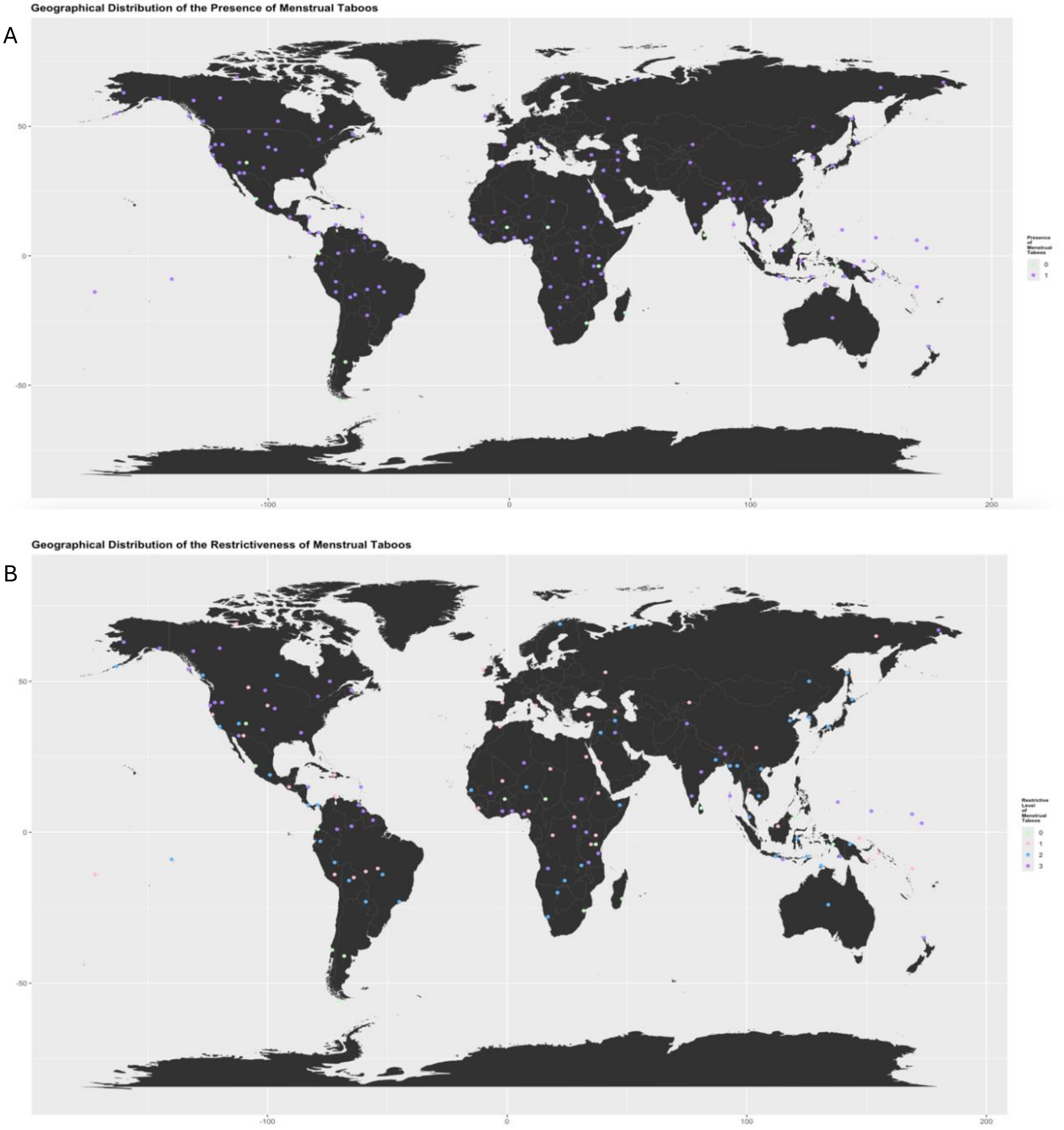
The number of cultures across different continents and the presence (A) and the level of restrictiveness (B) of menstrual taboos.





Appendix B

World map of the presence of menstrual taboos (A) and the level of restriction (B). See https://arianna-quinn.github.io/InteractiveMap.html to view a combined and interactive version of these visualizations.



Appendix C

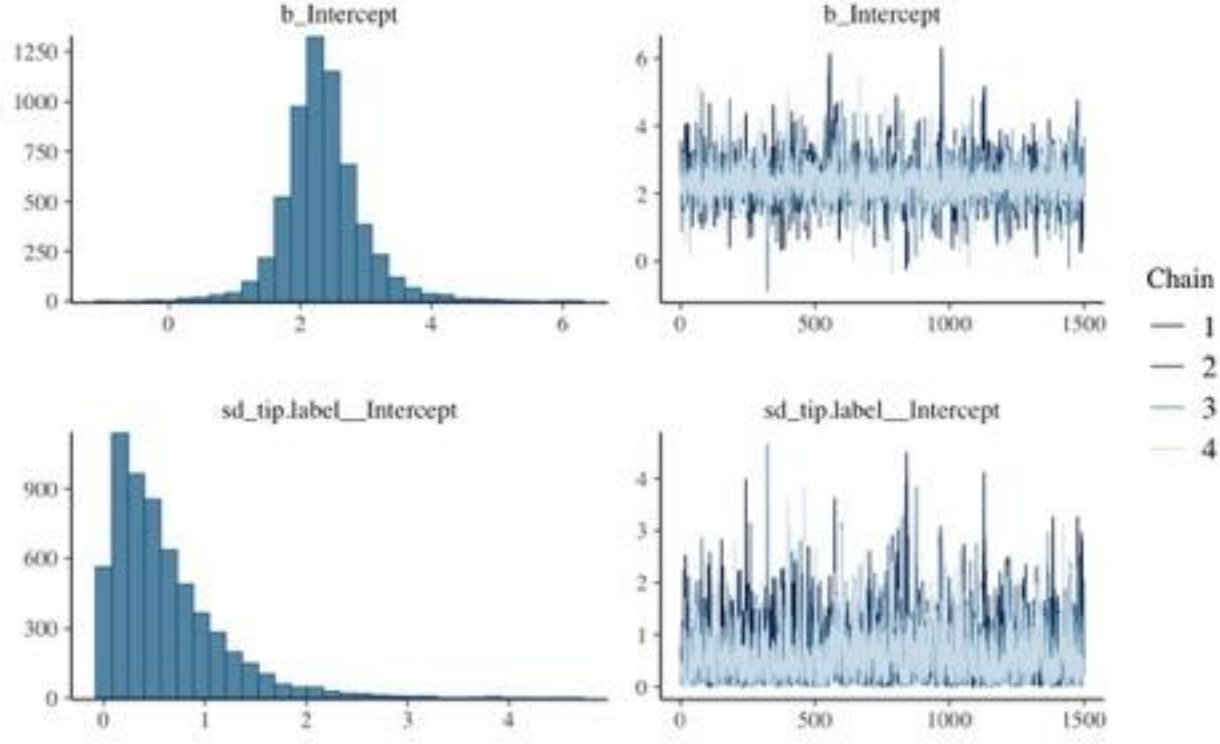
Phylogenetically Controlled Principal Components of Ecological Measures

Variable	**Temperature Pattern (pPC1)**	**Precipitation Pattern (pPC2)**
Mean monthly temperature	**0.9169**	-0.107
Monthly variance in temperature	**0.8511**	0.351
Annual predictability in temperature	**-0.8876**	-0.225
Mean monthly precipitation	0.1458	**0.774**
Monthly variance in precipitation	0.2903	**0.863**
Annual predictability in precipitation	0.0532	**0.656**

Note. Loadings greater than 0.50 (i.e., components describes + 25% original measure variance) are bolded. Components were rotated using the Quartimax Criterion to enhance interpretability.

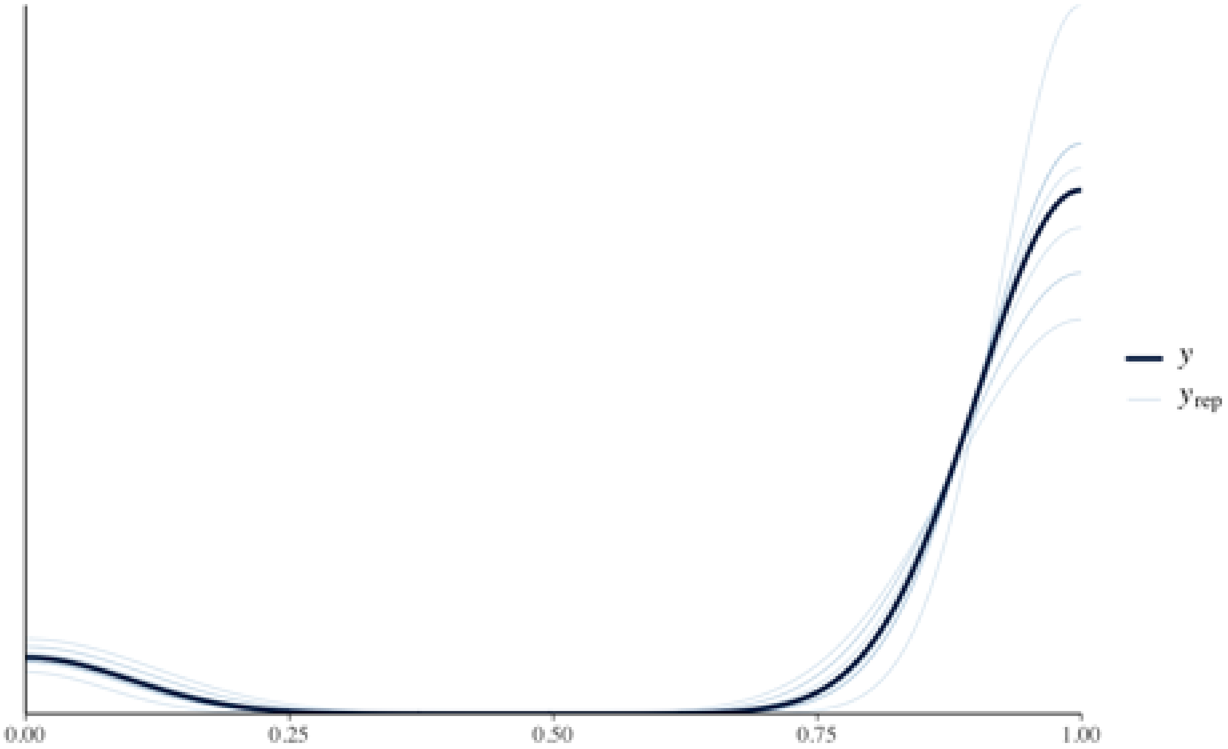
Appendix D

Trace plots for intercept-only presence model which depicts the convergence of the chains.



Appendix E

Posterior Predictive Check for Intercept-Only Presence Model



Appendix F

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the intercept-only presence model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept	2.25	0.56	1.14	3.43	1.00	5511
Group-Level Effects	sd(Ancestral Relatedness)	0.58	0.50	0.02	1.85	1.00	2981

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept	2.34	0.60	1.48	3.34	1.00	3336
Group-Level Effects	sd(Ancestral Relatedness)	0.60	0.54	0.04	1.61	1.00	2267

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

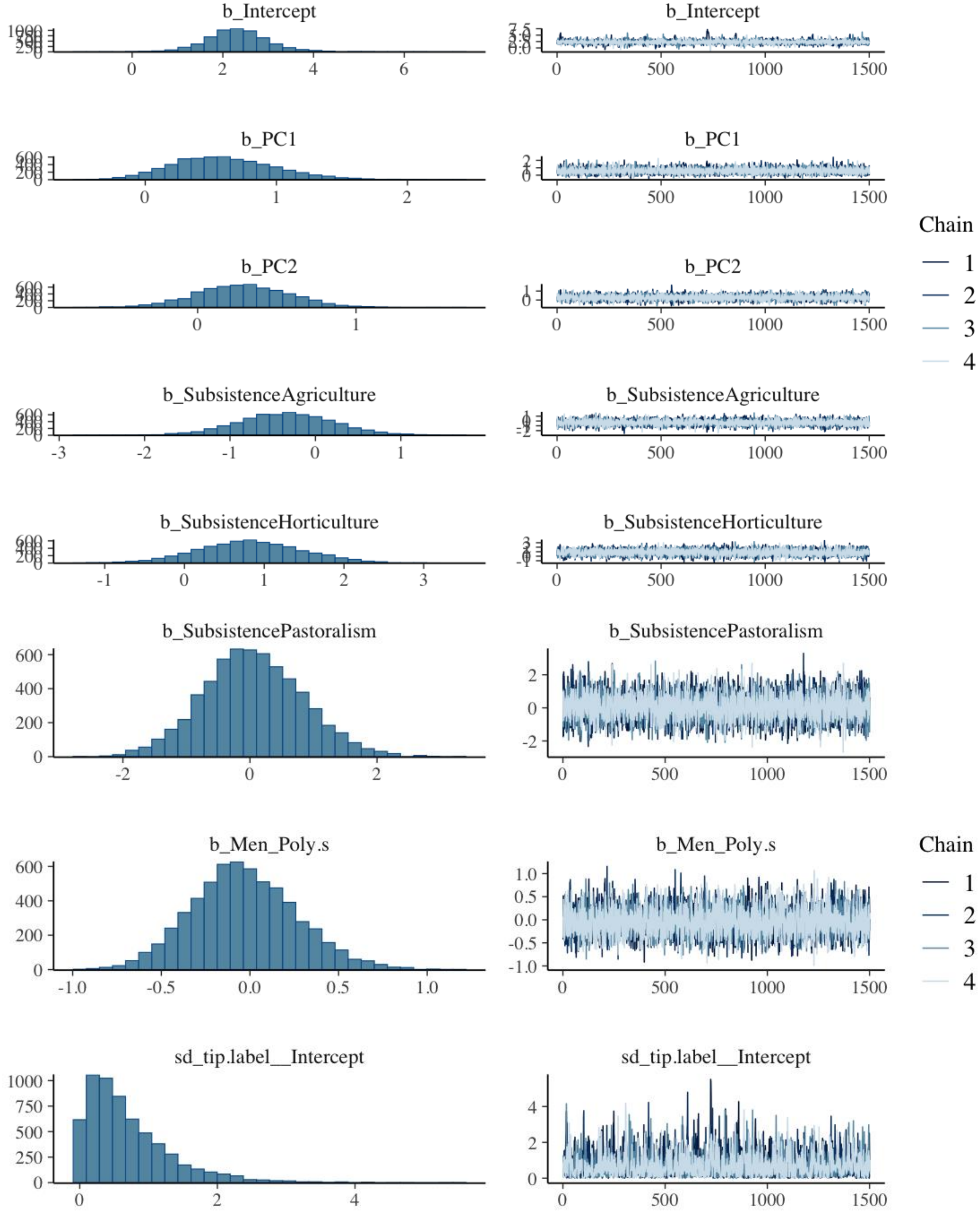
Table C. *Posterior Estimates of Normal (0,4) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept	2.36	0.67	1.28	3.91	1.00	2835
Group-Level Effects	sd(Ancestral Relatedness)	0.59	0.53	0.02	1.97	1.00	2086

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

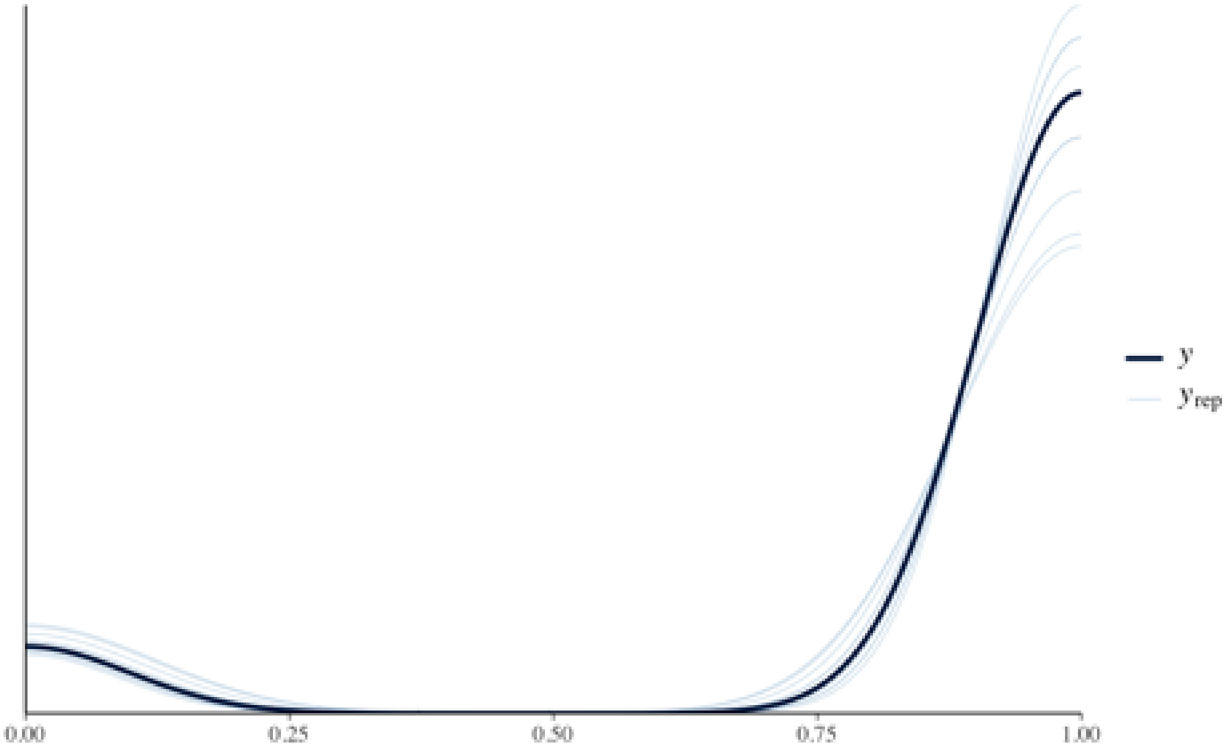
Appendix G

Trace plots for no biome included presence model which depicts the convergence of the chains.



Appendix H

Posterior Predictive Check for No Biome Included Presence Model



Appendix I

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the no biome included presence model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.34	0.70	1.07	3.87	1.00	4724
	Temperature Pattern	0.61	0.37	-0.06	1.40	1.00	9616
	Precipitation Pattern	0.29	0.30	-0.31	0.87	1.00	8603
	Agriculture	-0.34	0.57	-1.46	0.79	1.00	8998
	Horticulture	0.86	0.64	-0.39	2.19	1.00	10086
	Pastoralism	0.06	0.77	-1.38	1.61	1.00	11083
	Polygyny	-0.04	0.30	-0.60	0.60	1.00	9516
Group - Level Effects	sd(Ancestral Relatedness)	0.68	0.60	0.02	2.17	1.00	2531

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.33	0.73	1.21	3.50	1.00	3428
	Temperature Pattern	0.60	0.39	0.00	1.29	1.00	7065
	Precipitation Pattern	0.29	0.29	-0.19	0.76	1.00	7965
	Agriculture	-0.34	0.57	-1.26	0.59	1.00	7027
	Horticulture	0.83	0.66	-0.25	1.96	1.00	7324
	Pastoralism	0.05	0.78	-1.22	1.38	1.00	7985
	Polygyny	-0.03	0.29	-0.50	0.47	1.00	7492
Group - Level Effects	sd(Ancestral Relatedness)	0.70	0.62	0.04	1.95	1.00	1937

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

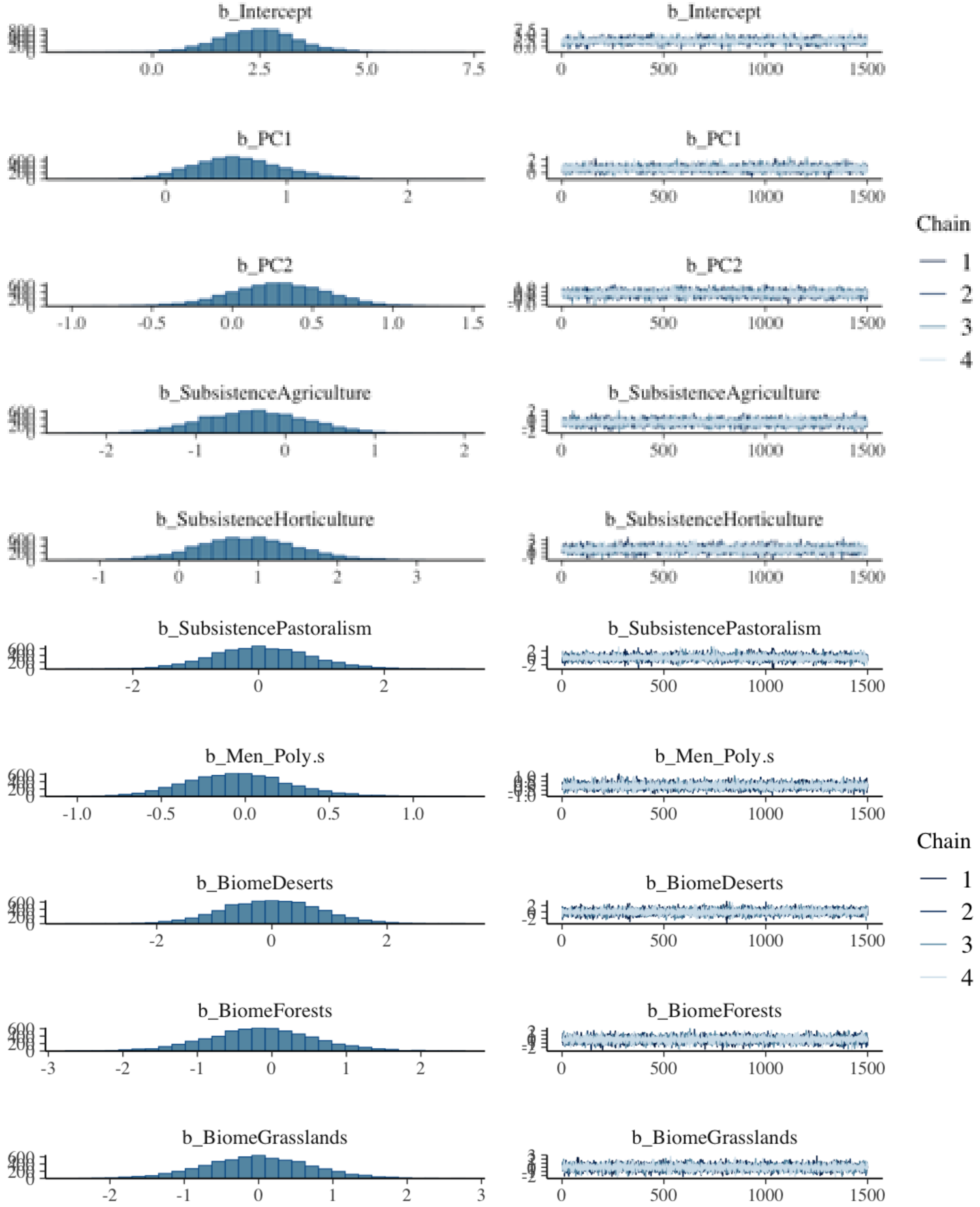
Table C. *Posterior Estimates of Normal (0,4) Priors*

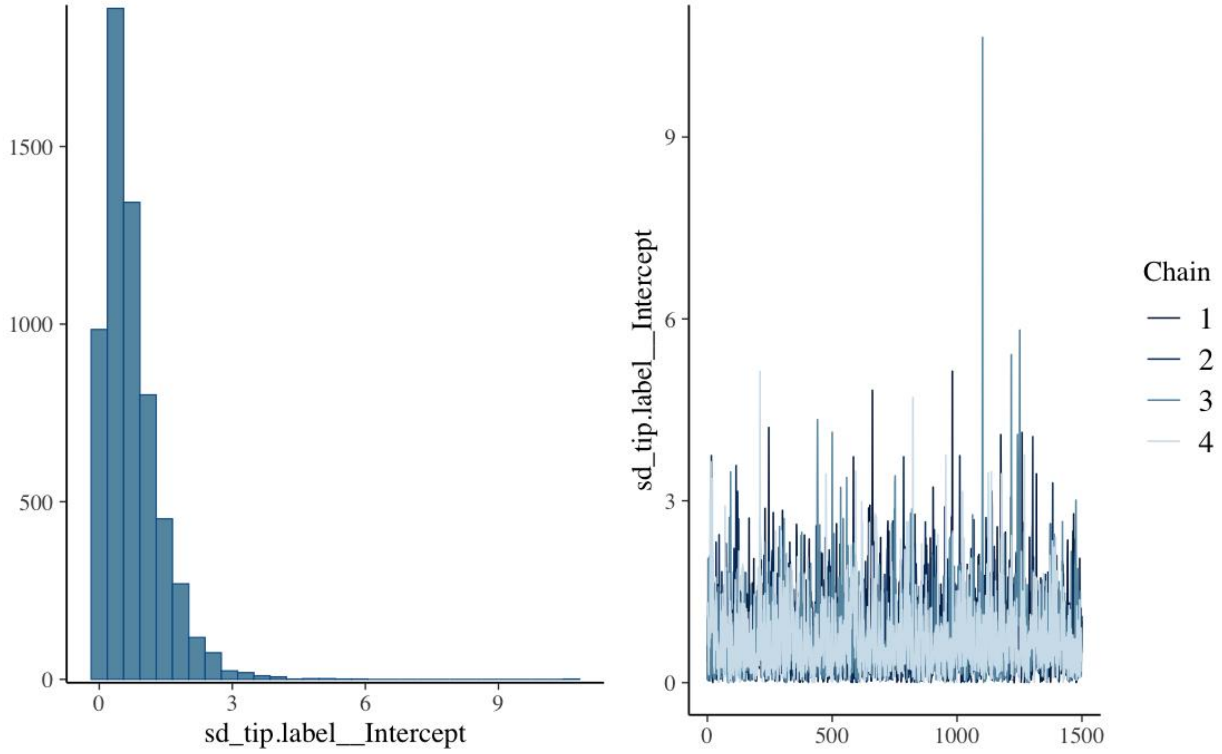
Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.44	0.72	1.09	3.99	1.00	3900
	Temperature Pattern	0.61	0.39	-0.10	1.43	1.00	8057
	Precipitation Pattern	0.28	0.30	-0.31	0.87	1.00	8624
	Agriculture	-0.35	0.58	-1.45	0.82	1.00	7126
	Horticulture	0.84	0.66	-0.42	2.15	1.00	7161
	Pastoralism	0.06	0.80	-1.46	1.69	1.00	9830
	Polygyny	-0.04	0.30	-0.60	0.56	1.00	8583
Group - Level Effects	sd(Ancestral Relatedness)	0.68	0.59	0.02	2.26	1.00	1926

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Appendix J

Trace plots for biome included presence model which depicts the convergence of the chains.




1500
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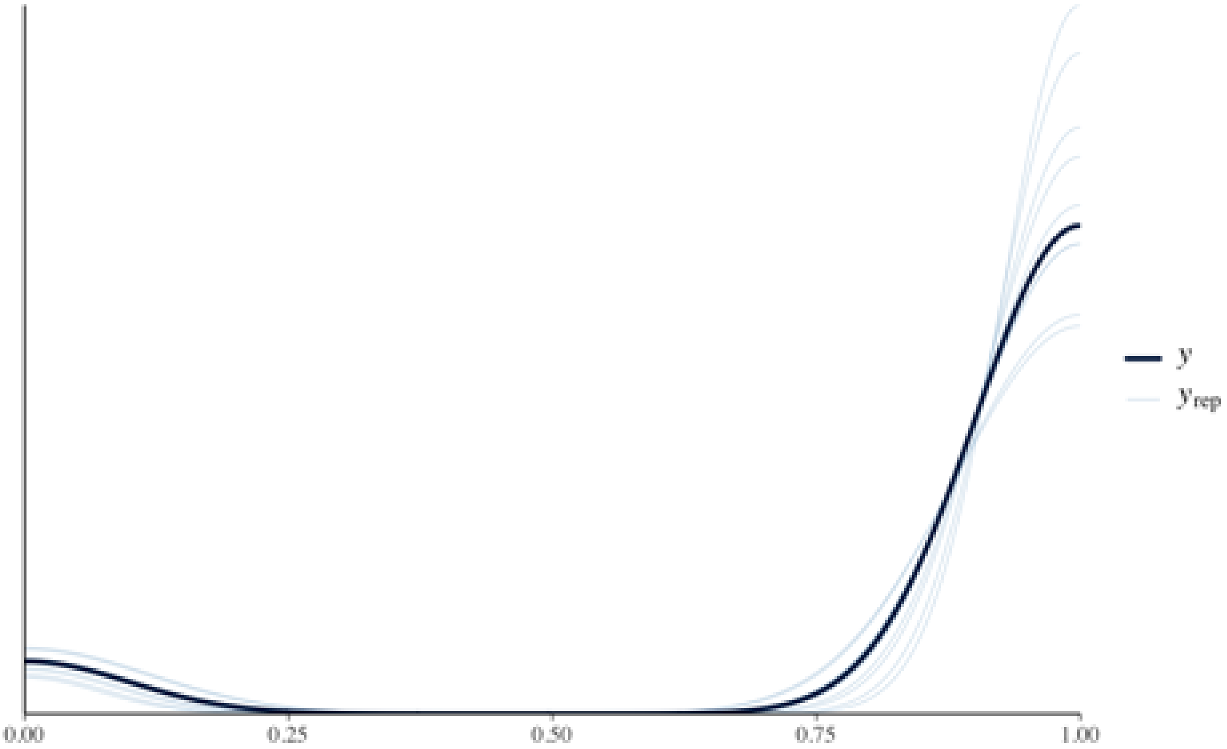
Appendix K

Posterior Predictive Check for Biome Included Presence Model



Appendix L

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the biome included presence model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.45	0.93	0.66	4.31	1.00	4818
	Temperature Pattern	0.60	0.39	-0.09	1.44	1.00	10479
	Precipitation Pattern	0.28	0.31	-0.34	0.87	1.00	11041
	Agriculture	-0.35	0.56	-1.43	0.79	1.00	9071
	Horticulture	0.87	0.64	-0.36	2.18	1.00	9838
	Pastoralism	0.05	0.79	-1.45	1.63	1.00	12244
	Forests	-0.14	0.73	-1.57	1.30	1.00	6683
	Grasslands	-0.01	0.73	-1.42	1.41	1.00	7353
	Deserts	0.01	0.83	-1.60	1.66	1.00	10103
	Polygyny	-0.04	0.32	-0.64	0.62	1.00	11023
Group - Level Effects	sd(Ancestral Relatedness)	0.72	0.62	0.02	2.31	1.00	2260

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.45	0.94	0.98	4.01	1.00	4118
	Temperature Pattern	0.61	0.38	0.02	1.28	1.00	7200
	Precipitation Pattern	0.29	0.31	-0.22	0.78	1.00	7442
	Agriculture	-0.35	0.57	-1.28	0.60	1.00	8894
	Horticulture	0.87	0.65	-0.17	1.94	1.00	8879
	Pastoralism	0.06	0.79	-1.20	1.38	1.00	9763
	Forests	-0.04	0.31	-0.52	0.48	1.00	8936

	Grasslands	0.00	0.83	-1.34	1.37	1.00	8909
	Deserts	-0.14	0.72	-1.32	1.07	1.00	6536
	Polygyny	-0.01	0.71	-1.18	1.16	1.00	7372
Group - Level Effects	sd(Ancestral Relatedness)	0.74	0.65	0.05	1.95	1.00	2189

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

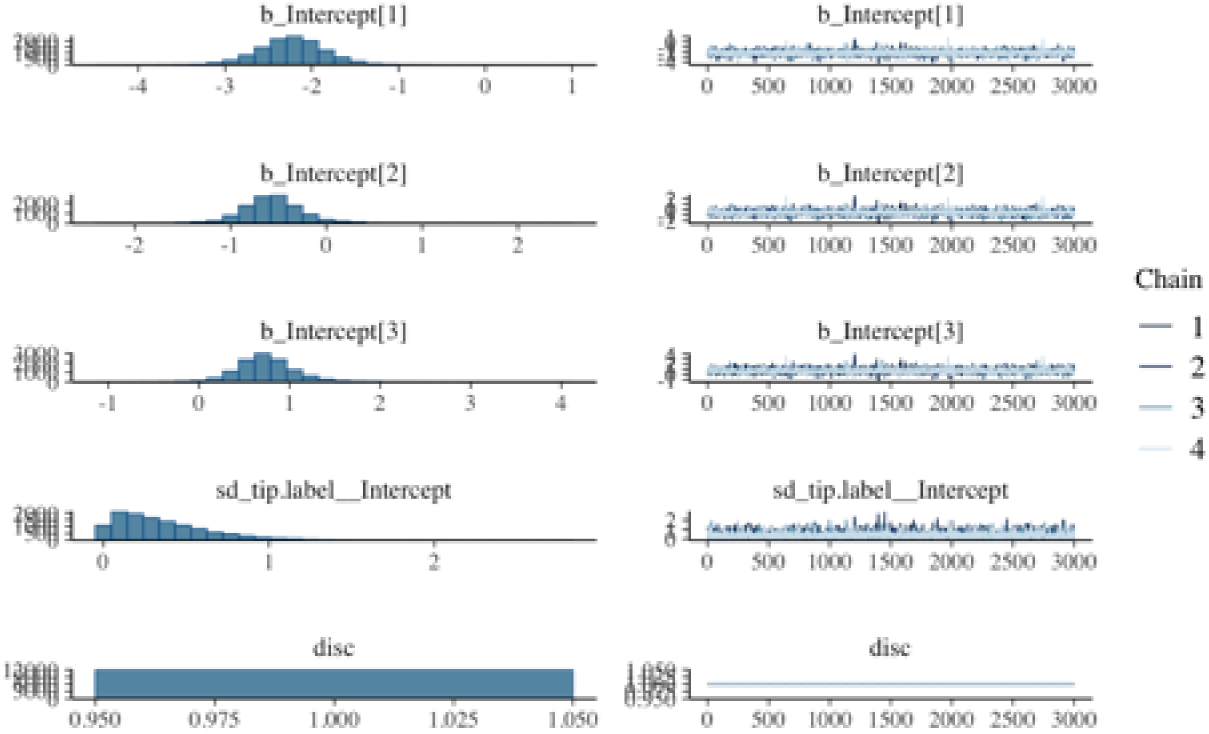
Table C. *Posterior Estimates of Normal (0,4) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population - Level Effects	Intercept	2.54	0.98	0.69	4.64	1.00	5524
	Temperature Pattern	0.63	0.39	-0.07	1.45	1.00	10676
	Precipitation Pattern	0.29	0.32	-0.35	0.91	1.00	9627
	Agriculture	-0.35	0.57	-1.48	0.77	1.00	9202
	Horticulture	0.89	0.66	-0.40	2.19	1.00	9518
	Pastoralism	0.04	0.78	-1.44	1.59	1.00	11685
	Forests	-0.14	0.72	-1.57	0.59	1.00	11092
	Grasslands	-0.02	0.72	-1.45	1.61	1.00	9405
	Deserts	0.01	0.82	-1.58	1.27	1.00	8454
	Polygyny	-0.04	0.31	-0.61	1.42	1.00	8106
Group - Level Effects	sd(Ancestral Relatedness)	0.74	0.62	0.03	2.33	1.00	2751

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

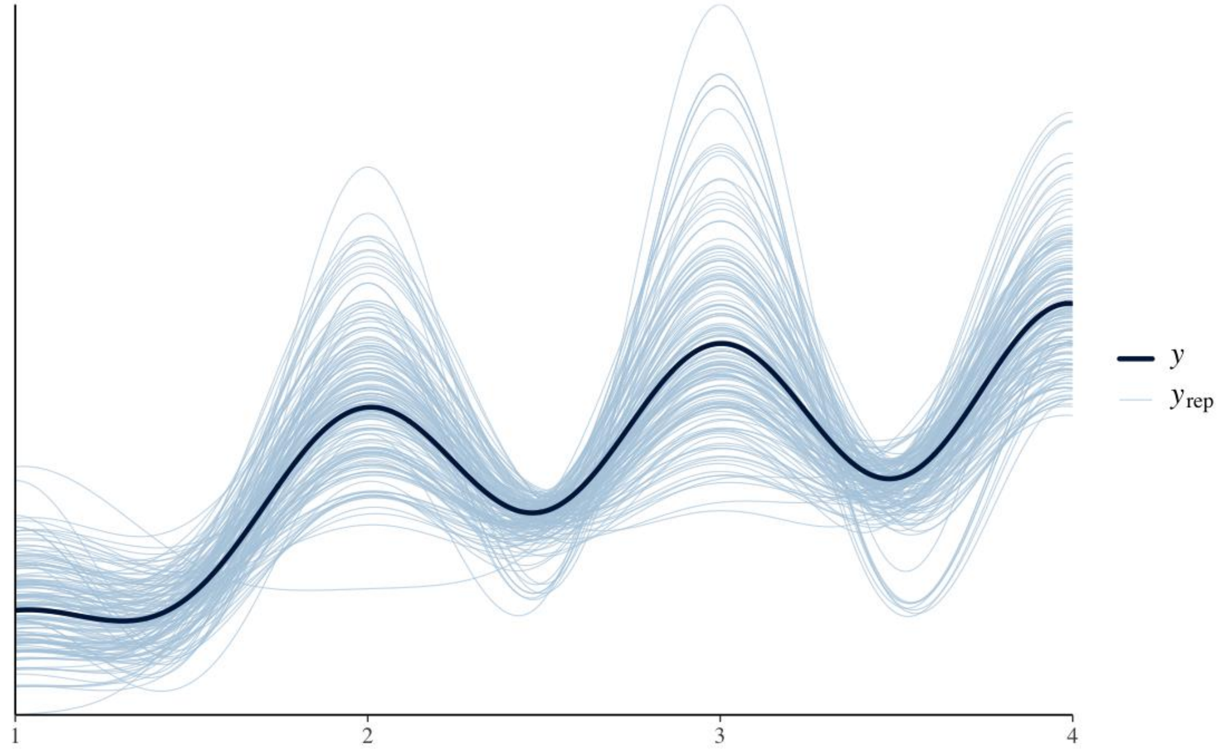
Appendix M

Trace plots for intercept-only presence model which depicts the convergence of the chains.



Appendix N

Posterior Predictive Check for Intercept-Only Restriction Level Model



Appendix O

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the intercept-only restriction model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.19	0.40	-2.98	-1.36	1.00	10781
	Intercept [Minimal to Moderate]	-0.53	0.33	-1.15	0.21	1.00	11019
	Intercept [Moderate to Severe]	0.76	0.34	0.15	1.55	1.00	10820
Group-Level Effects	sd(Ancestral Relatedness)	0.36	0.29	0.01	1.09	1.00	5273

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.23	0.41	-2.88	-1.58	1.00	8488
	Intercept [Minimal to Moderate]	-0.55	0.35	-1.06	0.02	1.00	9049
	Intercept [Moderate to Severe]	0.74	0.35	0.24	1.33	1.00	9298
Group-Level Effects	sd(Ancestral Relatedness)	0.60	0.54	0.04	1.61	1.00	4703

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table C. *Posterior Estimates of Normal (0,4) Priors*

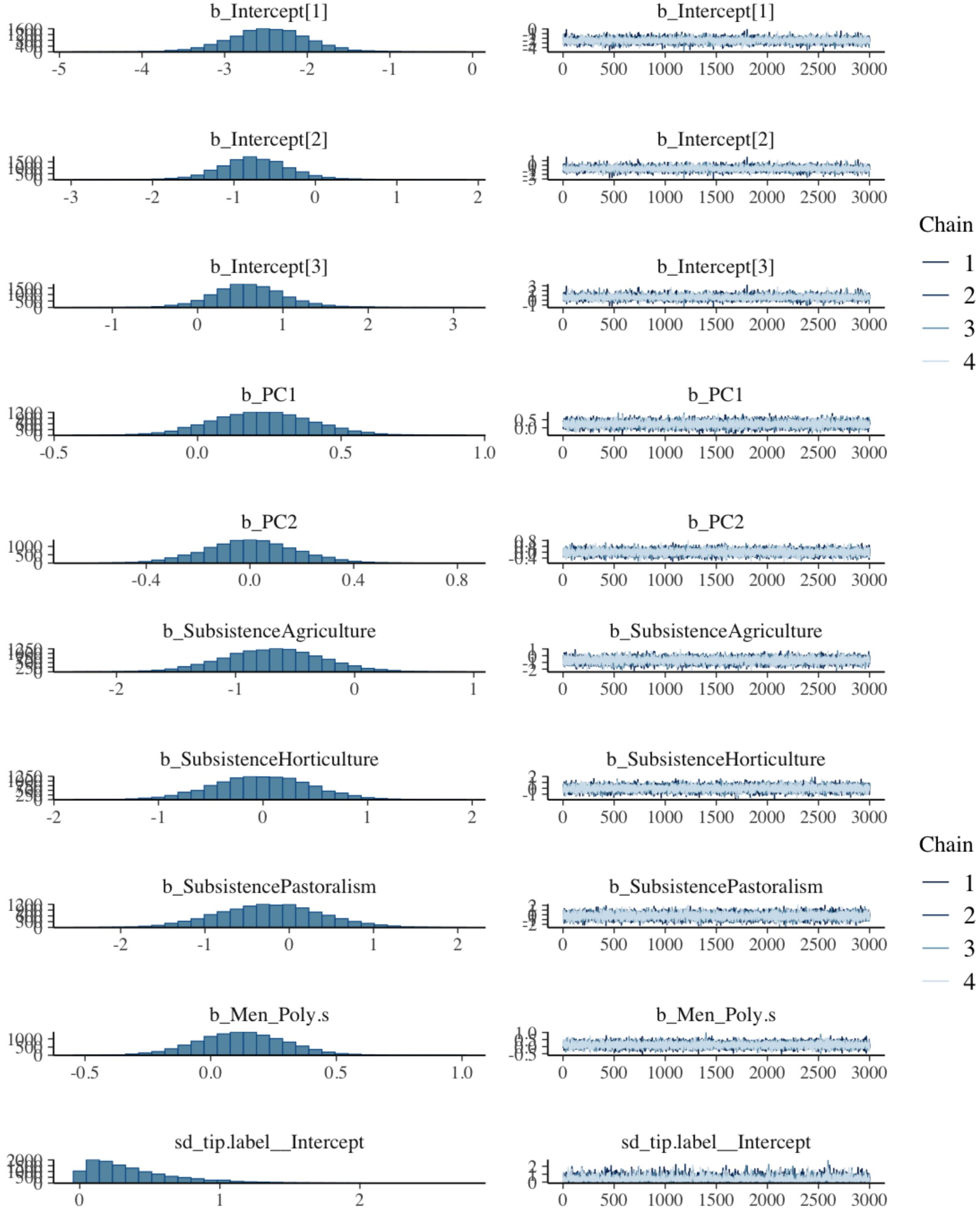
Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.23	0.41	-3.04	-1.40	1.00	8783
	Intercept [Minimal to Moderate]	-0.55	0.34	-1.20	0.20	1.00	9701

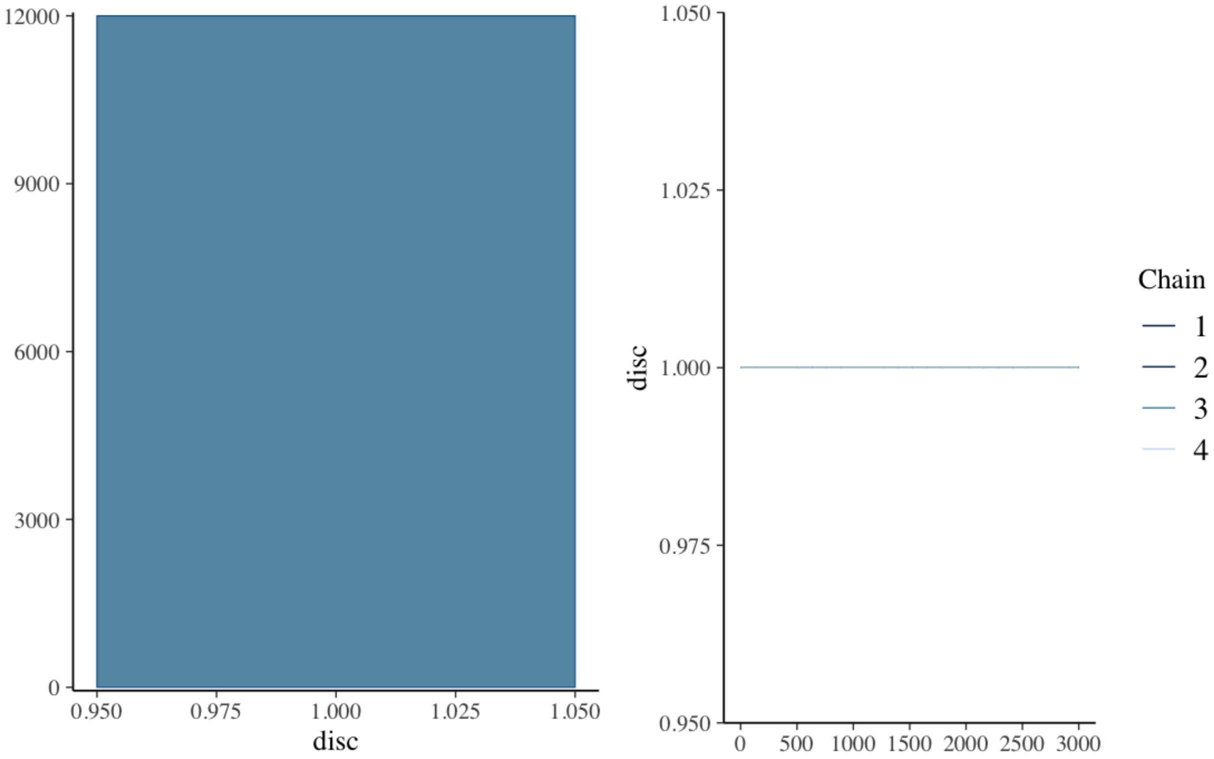
	Intercept [Moderate to Severe]	0.74	0.34	0.12	1.52	1.00	9643
Group-Level Effects	sd(Ancestral Relatedness)	0.36	0.30	0.01	1.11	1.00	4835

Note. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Appendix P

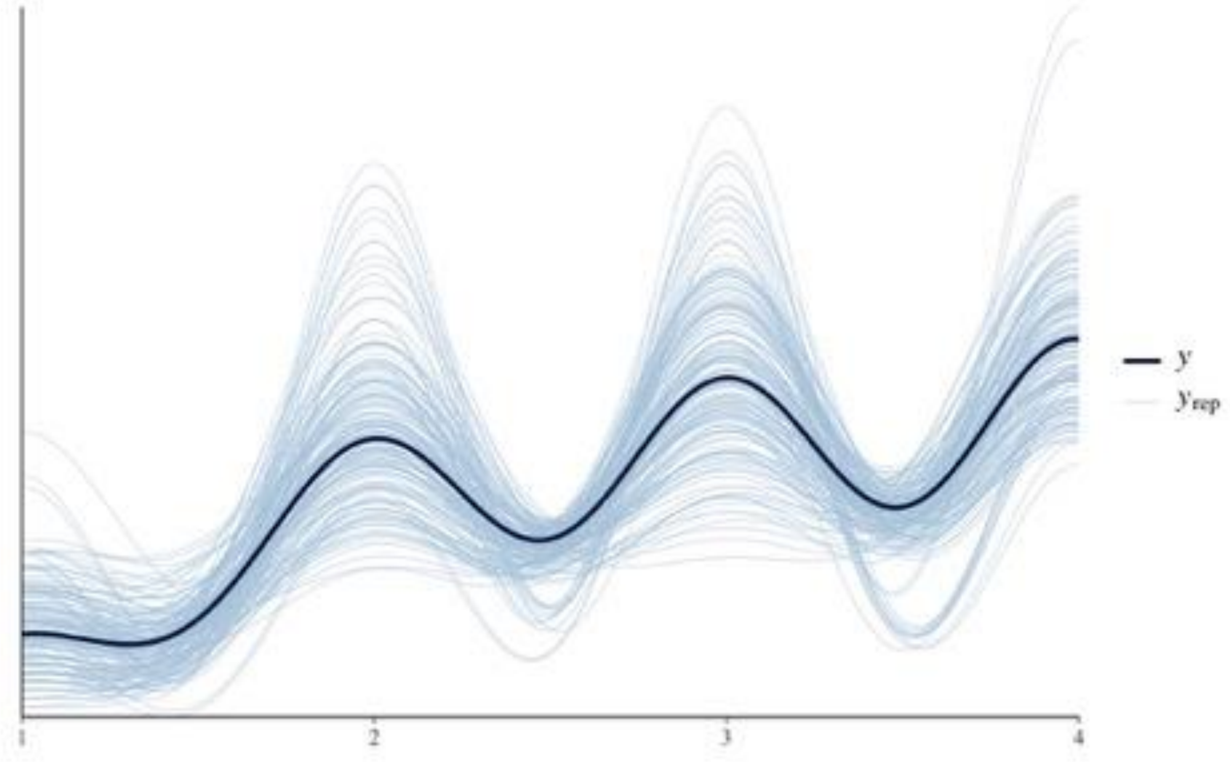
Trace plots for no biome restriction model which depicts the convergence of the chains.




12000
9000
6000
3000
0
0.950
0.975
1.000
1.025
1.050
disc
1.050
1.025
1.000
0.975
0.950
disc
0
500
1000
1500
2000
2500
3000
Chain
1
2
3
4

Appendix Q

Posterior Predictive Check for No Biome Restriction Level Model



Appendix R

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the no biome restriction model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\widehat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.40	0.46	-3.31	-1.48	1.00	11659
	Intercept [Minimal to Moderate]	-0.68	0.41	-1.47	0.18	1.00	11582
	Intercept [Moderate to Severe]	0.66	0.41	-0.10	1.55	1.00	11358
	Temperature Pattern	0.22	0.17	-0.11	0.57	1.00	18890
	Precipitation Pattern	-0.00	0.17	-0.34	0.34	1.00	19376
	Agriculture	-0.58	0.37	-1.32	0.14	1.00	16011
	Horticulture	0.03	0.41	-0.77	0.85	1.00	16232
	Pastoralism	-0.13	0.52	-1.14	0.89	1.00	19760
	Polygyny	0.12	0.17	-0.20	0.45	1.00	20980
Group-Level Effects	sd(Ancestral Relatedness)	0.37	0.32	0.01	1.20	1.00	4902

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\widehat{R}$	ESS
	Intercept [No to Minimal]	-2.46	0.49	-3.25	-1.67	1.00	10244
	Intercept [Minimal to Moderate]	-0.74	0.44	-1.43	-0.02	1.00	10757
	Intercept [Moderate to Severe]	0.61	0.44	-0.07	1.34	1.00	10594
	Temperature Pattern	0.23	0.18	-0.06	0.52	1.00	16372

Population-Level Effects	Precipitation Pattern	0.00	0.18	-0.29	0.30	1.00	16263
	Agriculture	-0.69	0.42	-1.38	-0.00	1.00	14628
	Horticulture	-0.01	0.47	-0.78	0.76	1.00	13594
	Pastoralism	-0.23	0.61	-1.24	0.78	1.00	16065
	Polygyny	0.12	0.18	-0.16	0.41	1.00	19804
Group-Level Effects	sd(Ancestral Relatedness)	0.38	0.33	0.03	1.04	1.00	4157

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

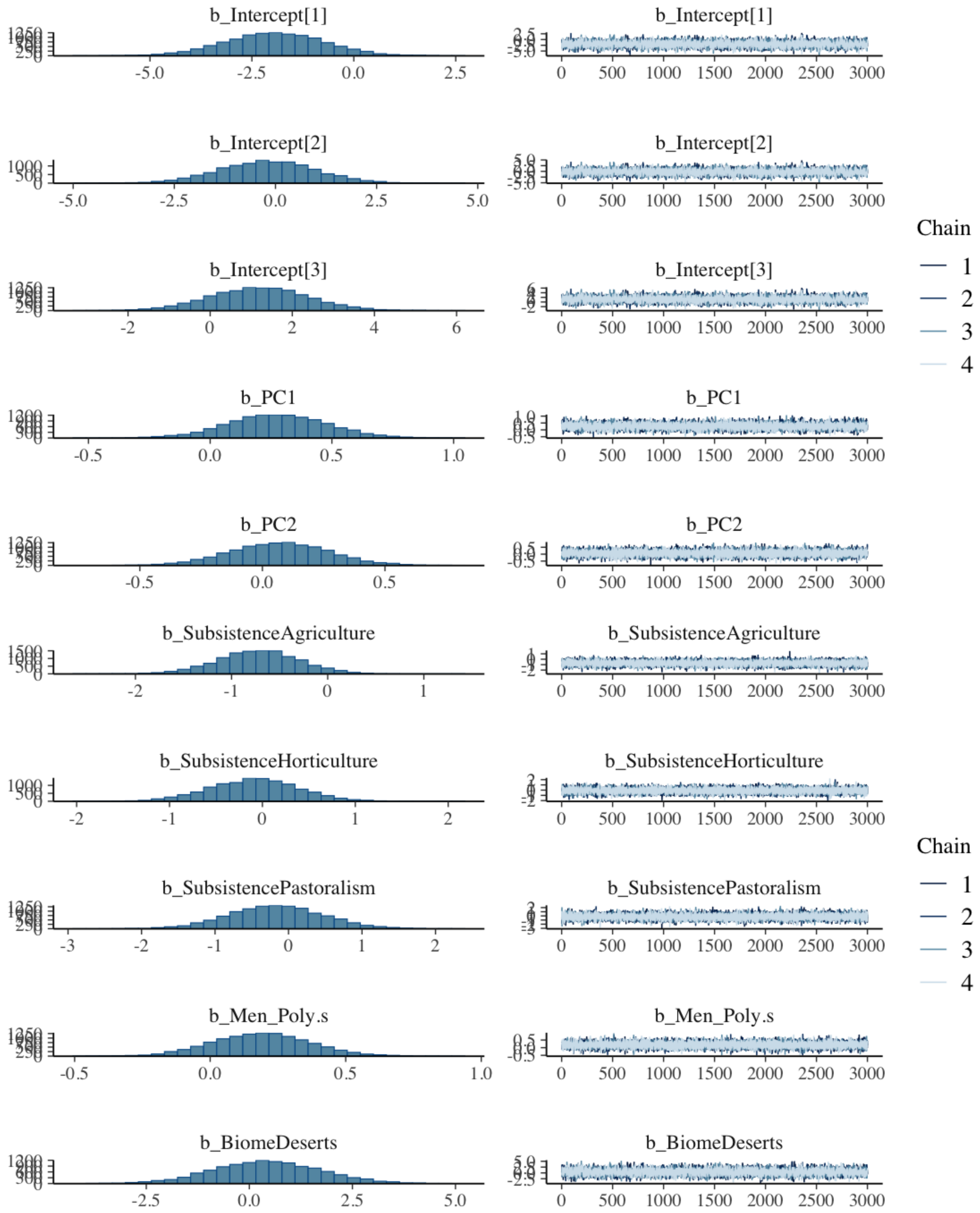
Table C. *Posterior Estimates of Normal (0,4) Priors*

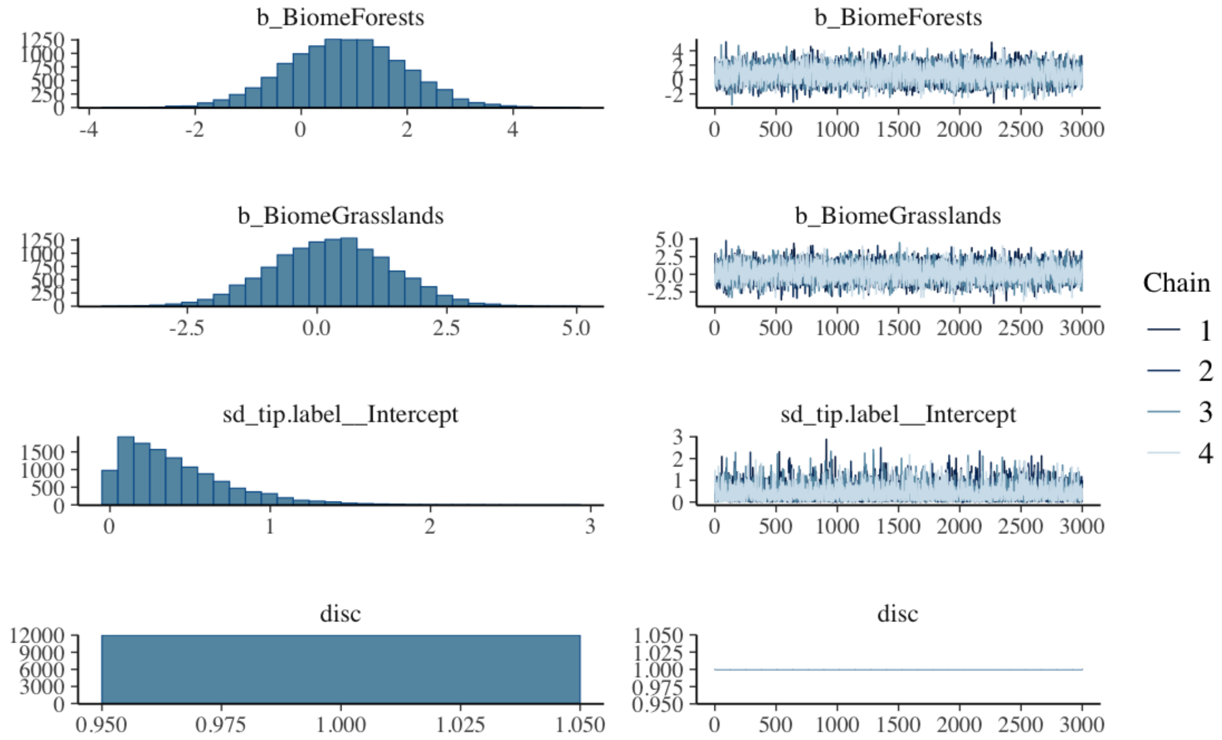
Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.44	0.48	-3.39	-1.50	1.00	9978
	Intercept [Minimal to Moderate]	-0.71	0.42	-1.54	0.14	1.00	10849
	Intercept [Moderate to Severe]	0.64	0.42	-0.17	1.53	1.00	10685
	Temperature Pattern	0.22	0.17	-0.11	0.57	1.00	17829
	Precipitation Pattern	-0.01	0.18	-0.35	0.35	1.00	18133
	Agriculture	-0.59	0.37	-1.32	0.15	1.00	16584
	Horticulture	0.03	0.41	-0.77	0.84	1.00	14554
	Pastoralism	-0.13	0.53	-1.16	0.91	1.00	19732
	Polygyny	0.13	0.17	-0.21	0.47	1.00	19498
Group-Level Effects	sd(Ancestral Relatedness)	0.38	0.33	0.01	1.20	1.00	3886

Note. Subsistence strategy is relative to hunter-gatherers. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Appendix S

Trace plots for biome included restriction model which depicts the convergence of the chains.

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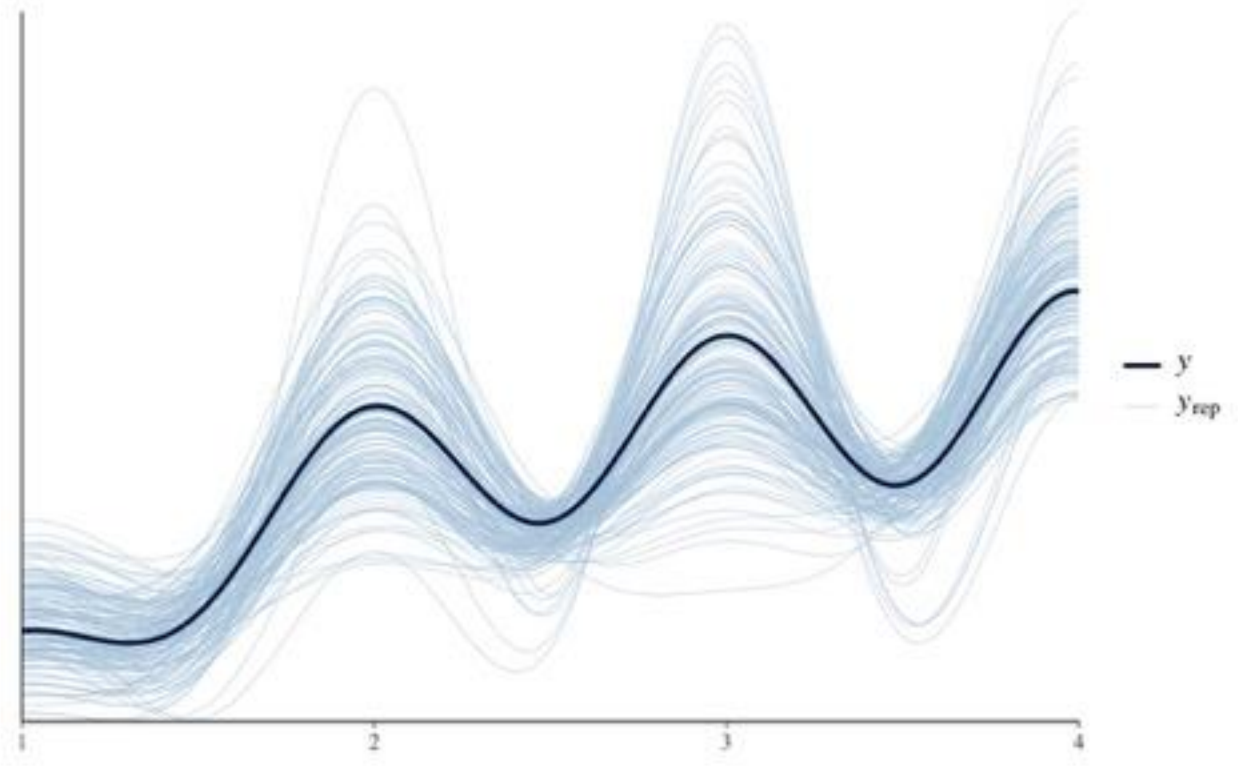
750
500
250
0
-4
-2
0
2
4
b_BiomeForests
4
2
0
-2
0
500
1000
1500
2000
2500
3000
b_BiomeGrasslands
1250
1000
750
500
250
0
-2.5
0.0
2.5
5.0
b_BiomeGrasslands
5.0
2.5
0.0
-2.5
0
500
1000
1500
2000
2500
3000
Chain
1
2
3
4
sd_tip.label__Intercept
1500
1000
500
0
0
1
2
3
sd_tip.label__Intercept
3
2
1
0
0
500
1000
1500
2000
2500
3000
disc
12000
9000
6000
3000
0
0.950
0.975
1.000
1.025
1.050
disc
1.050
1.025
1.000
0.975
0.950
0
500
1000
1500
2000
2500
3000

Appendix T

Posterior Predictive Check for Biome Included Restriction Level Model



Appendix U

Summary tables depicting the posterior estimates for the normal (0,5) priors (A), normal (0,1) (B), normal (0,4) (C) for the biome included restriction model.

Table A. *Posterior Estimates of Normal (0,5) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.25	0.70	-3.62	-0.88	1.00	9490
	Intercept [Minimal to Moderate]	-0.52	0.67	-1.81	0.79	1.00	9780
	Intercept [Moderate to Severe]	0.85	0.67	-0.45	2.18	1.00	9790
	Temperature Pattern	0.24	0.18	-0.11	0.59	1.00	14530
	Precipitation Pattern	0.06	0.19	-0.31	0.44	1.00	20349
	Agriculture	-0.59	0.38	-1.34	0.14	1.00	16066
	Horticulture	-0.03	0.42	-0.83	0.79	1.00	15244
	Pastoralism	-0.08	0.53	-1.10	0.97	1.00	19017
	Forests	0.42	0.57	-0.70	1.54	1.00	10765
	Grasslands	-0.10	0.58	-1.24	1.06	1.00	10380
	Deserts	0.03	0.66	-1.28	1.33	1.00	12962
	Polygyny	0.18	0.58	-1.24	0.53	1.00	20675
Group-Level Effects	sd(Ancestral Relatedness)	0.40	0.33	0.02	1.25	1.00	5153

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table B. *Posterior Estimates of Normal (0,1) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
	Intercept [No to Minimal]	-1.94	1.21	-3.94	0.03	1.00	5024
	Intercept [Minimal to Moderate]	-0.19	1.19	-2.15	1.76	1.00	5002

Population-Level Effects	Intercept [Moderate to Severe]	1.19	1.19	-0.76	3.15	1.00	5002
	Temperature Pattern	0.28	0.20	-0.26	0.61	1.00	8332
	Precipitation Pattern	0.07	0.20	-1.42	0.40	1.00	16096
	Agriculture	-0.72	0.42	-0.88	-0.02	1.00	11473
	Horticulture	-0.09	0.47	-1.21	0.68	1.00	10984
	Pastoralism	-0.17	0.64	-0.11	0.87	1.00	14395
	Forests	0.83	1.10	-0.98	2.63	1.00	5384
	Grasslands	0.28	1.15	-1.58	2.16	1.00	5408
	Deserts	0.43	1.30	-1.66	2.58	1.00	5819
	Polygyny	0.19	0.18	-0.11	0.48	1.00	16895
Group-Level Effects	sd(Ancestral Relatedness)	0.42	0.34	0.03	1.08	1.00	4205

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.

Table C. *Posterior Estimates of Normal (0,4) Priors*

Effect	Parameter	Estimate	Estimate Error	Lower 95 CI	Upper 95 CI	$\hat{R}$	ESS
Population-Level Effects	Intercept [No to Minimal]	-2.31	0.71	-3.71	-0.93	1.00	9355
	Intercept [Minimal to Moderate]	-0.56	0.67	-1.88	0.76	1.00	9511
	Intercept [Moderate to Severe]	0.81	0.67	-0.50	-0.93	1.00	9543
	Temperature Pattern	0.24	0.18	-0.10	0.59	1.00	14440
	Precipitation Pattern	0.06	0.19	-0.32	0.44	1.00	18219
	Agriculture	-0.59	0.38	-1.34	0.14	1.00	14510
	Horticulture	-0.03	0.42	-0.85	0.78	1.00	13878
	Pastoralism	-0.08	0.53	-1.12	0.94	1.00	17532
	Forests	0.41	0.56	-0.70	1.52	1.00	9389
	Grasslands	-0.12	0.58	-1.24	1.01	1.00	9439

	Deserts	0.02	0.67	-1.29	1.32	1.00	11557
	Polygyny	0.19	0.18	-0.16	0.54	1.00	18016
Group-Level Effects	sd(Ancestral Relatedness)	0.40	0.34	0.01	1.26	1.00	3949

Note. Subsistence strategy is relative to hunter-gatherers. Biome is relative to polar environments. Estimates are on the log scale; CI = credible interval. ESS = effective sample size.