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Survival probability of the ancestors of the indigenous people of Canada who migrated during the last glacial maximum

Kibo Nagasaki[1], Shinya Nagasak[2*]

[1]*Mentor College, 40 Forest Avenue, Mississauga, Ontario, L5G1L1, Canada.*
[2]*McMaster University, 1280 Main Street West, Hamilton, Ontario, L8S 4L7, Canada.*

Corresponding author: Shinya Nagasak (*Email: nagasas@mcmaster.ca*)

Abstract

The purpose of this study is to examine the survival probability of the ancestors of the indigenous people of Canada during their migration to the last glacial maximum. The ancestors of the Indigenous people of Canada are believed to have migrated during the Last Glacial Maximum under severe ice-age conditions. However, the possibility of their survival is unclear. Creating a mathematical model, the survival probability of Indigenous ancestors who migrated to Canada and the effects of different factors were studied. Using logistic regression analysis, we evaluated the effects of different factors, such as the mean female life expectancy, average childbirth interval, and marriage age, on their survival probability. The results suggested that a polygamous community was more likely to survive. The survival probability was maximized in the cases of monogamy/unintentional migration (0.60), polygamy/unintentional migration (0.87), and marriage age of 15 years/monogamy/unintentional migration (0.76). However, the survival probability was low for many possible combinations of the mean female life expectancy and the average childbirth interval. The low survival probability would demonstrate the levels of resourcefulness, bravery, and wisdom that the Indigenous ancestors possessed to survive. A problem was that the available data on mortality and fertility were not specific to the ancestors of the Indigenous people of Canada. In the future, the accuracy of the survival probability of the ancestors of the Indigenous people of Canada will improve once quantitative research data on the ancestors' life expectancy and childbirth are available.

Keywords: Indigenous ancestors, Intentional and unintentional migration, Logistic regression analysis, Marriage age, Mathematical model, Monogamy and polygamy, Mortality and fertility, Survival probability.

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1. Introduction

When and how humans spread to the Southern Islands and North America is an interesting subject of population research. In the case of migration to Sahul (Australia and New Guinea) and southern Japan, the initial colonization in Sahul might be able to go back as early as 65,000 years ago [1, 2]. On the other hand, the ancestors of the Indigenous people of Canada are believed to have migrated from an area in the Easternhemisphere to an area in the Western Hemisphere, which are now known as Siberia and Canada, respectively, between 21,000 and 10,000 years Before Common Era (BCE), when the two continents were connected by a massive land bridge called the Bering Plain [3-5], corresponding to the Last Glacial Maximum. In the following centuries, the Indigenous ancestors spread across present-day Canada and the United States to form hundreds of settlements and communities. In New Mexico, Bennett, et al. [5] recently found scores of human footprints that have been dated to 21,000–23,000 years old. Genetic studies [6, 7] also support these.

Raghavan, et al. [8] and Rasmussen, et al. [9] suggested that the ancestors of all present-day Native Americans entered America from Siberia in a single migration wave no earlier than 23,000 years ago. However, it is difficult to believe that large groups of people moved together under the severe conditions of the Last Glacial Maximum. Recent studies have revealed that the common ancestry and primarydistribution of trans-Eurasian languages could be traced back to the first farmers movingacross northeast Asia [10]. Unlike hunting and fishing, agriculture is labor-intensive and requires a large number of workers. Therefore, the movement of a large number of people had to be associated with the expansion of agriculture. Tomimatsu, et al. [11] reported that the spread of relatively large populations in western Canada could be correlated with the expansion of native food species (e.g., *Camassiaquamash*) after the Last Glacial Maximum. An additional supporting example of that contention is an exercise by the Imperial Japanese Army. They conducted a long-term marching exercise over Mt. Hakkoda during the winter of 1902 in preparation for battling Russia in Siberia. A squad of about ten soldiers successfully completed the exercise, but a battalion of 210 soldiers was almost completely wiped out because of the harsh weather [12]. Furthermore, the basic social unit of hunter-gatherers in Africa is the family [13, 14]. In Greenland, the Inuit move together in groups of two or three families during the summer [15]. In Canada, one to four Inuit families gather to fish during the summer and then separate into individual families during the winter [16]. Therefore, it is reasonable to assume that the migration of Indigenous ancestors from present-day Siberia to Canada took place in units of one or two families.

Then, one question was raised here. If the Indigenous ancestors of Canada migrated in small numbers, what was the likelihood that their offspring would survive at their destination? Certain studies have considered the migration of ancient peoples to islands such as Sahul in the early and late Pleistocene. McArthur, et al. [17] studied the demographic trajectory of small, isolated peoples in Polynesia. They concluded that the migration succeeded only when young adults planned to migrate and their ages and sexes were adequately balanced. Bird, et al. [18] also concluded that early migrants to Sahul survived through intentional migration. However, Ruxton and Wilkinson [19] considered the likelihood of unplanned migration to an island. They assumed a relatively large initial population and a single model of mortality and fertility that matched the demographics of Polynesians in the mid-20th century, created the mathematical model, and discussed the survival probability of unintentional migration. On the other hand, to the authors' knowledge, there was no previous study on the survival probability of ancestors of Indigenous people in Canada who migrated during the Last Glacial Maximum.

This study aimed to create and use a mathematical model to estimate the survival probability of the Indigenous ancestors of the people who migrated to Canada and assess the effects of different factors that had not been previously considered. When we consider unintentional migration properly, the age and sex of the migrants should be randomly distributed, and the mortality and fertility should be variable to evaluate their effects on the survival probability. Furthermore, because quantitative statistical data on mortality and fertility of the Indigenous ancestors of Canada during the Last Glacial Maximum were not available, the data obtained from non-indigenous ancestors of Canadian people was used in this study. Therefore, there is a requirement to improve the quantitative values of survival probability using newly published data and evidence in the future. Nevertheless, although the data used were not relevant to the Indigenous ancestors of Canadian people, this study provides a path towards estimating their probability of survival.

2. Method

2.1. Independent Variables

We used the C programming language to create a simulation model based on the following framework: To determine the survival probability of a group, the mean female life expectancy and the average childbirth interval are essential considerations. Other factors, such as weather fluctuations and epidemics, are implicitly included in these parameters. Hence, we set two independent variables to evaluate the survival probability of Indigenous ancestors: the mean female life expectancy and average childbirth interval. However, no data is available on the life expectancy, childbirth interval, or marriage age of Indigenous ancestors in Canada. Thus, we used statistical data on mortality and fertility that were used in previous studies on human migration to islands during the Last Glacial Maximum [20-22]. Because Indigenous newborns have Mongolian spots, we set the marriage age as 17 years old based on the oldest data on the marriage age of Japanese with Mongolian spots [23]. The marriage age is dependent on the culture, social values, and traditions of the community, etc., and not on the Mongolian spots. Therefore, we also studied the late and early marriage cases.

Regarding life expectancy, we referred to the mortality data summarized by Coale, et al. [22], which recommended a mean female life expectancy of 22.5–37.5 years and is consistent with the data of unacculturated hunter-gatherer groups [24]. We used the "West" family because [22] recommended the use of this family of models when no reliable age pattern of mortality is empirically available. We considered seven values for the mean female life expectancy within this range: 22.5, 25, 27.5, 30, 32.5, 35, and 37.5 years, which were set at a 2.5-year interval because 1.5- and 5-year intervals are extremely fine and coarse, respectively. The corresponding mean life expectancies used for males were linked to those of females [22].

For the average childbirth interval, Henry [20] developed a table of age-specific natural fertility, and Coale and Trussell [21] proposed a model of fertility. Konner [25] quantified the data on female childbirth intervals ranging from 3–4 years in six hunting tribes. We referred to the studies of Henry [20] and Coale and Trussell [21], which assumed that females gave birth at intervals in the range of 2.6–4.4 years; thus, cases in which a married female gave birth to one child on average every 2.6, 2.9, 3.2, 3.5, 3.8, 4.1, or 4.4 years were used.The assumption of maintaining a constant childbirth interval from first birth to last birth is not realistic, but we considered that this approached a value close to the maximum survival probability. We set the minimum and maximum values of 2.6 and 4.4 years because they completely covered the range of 3–4 years and at an appropriate resolution that matched that of the female life expectancy. The sex of the newborn children was randomly distributed. The data on mortality and fertility used in this study were used in previous studies conducted on human migration to islands, such as Sahul. Considering the difference in weather severity, the real survival probability might be smaller than the survival probability estimated in this study.

2.2. Model Premises

In addition to the above independent variables, we considered the effects of multiple different premises: unintentional vs. intentional migration, polygamy vs. monogamy, late vs. early marriage age, small vs. large families, the initial number of families, and the minimum survival threshold.

We considered the difference between unintentional migration (e.g., hunting and fishing) and intentional migration (i.e., preplanned). Unintentional migration was assumed to comprise two families. The ages of the children were randomly distributed from 0 to 1 year before marriage age. The sex of the children was randomly distributed. The ages of parents were randomly distributed between twice the marriage age and 50 years old at the start of migration. The minimum age of the parents was set because the oldest child had a maximum age of 1 year before marriage, and pregnancy from conception to childbirth can be approximated as 1 year. The maximum age was set by referring to previous studies, which concluded that the probability of females ≥50 years old giving birth was zero [20, 21]. For intentional migration, all members were assumed to be unmarried, the numbers of females and males were the same, and the ages were randomly distributed between 17 and 25 years old. Since the marriage age was set at 17 years old, the youngest age in the intentional migration case was set at 17 years old. The oldest age was set as 25 years old because the age-specific fertility rate was about the same as that of 17 years old after it reached its maximum at around 20 years old.

The effects of polygamy and monogamy were considered [26]. For monogamy, one female and one male were randomly married. If there was a surplus of males or females, they remained unmarried until the following year. Then, the males or females who reached marriage age were added to the group of unmarried adults and randomly paired off. If a spouse died, remarriage was allowed. For polygamy, multiple females could select the same male. The same procedure as in the case of monogamy was followed when there were surplus males or a male died.

The marriage age was set at 17 years, as previously mentioned. However, the effect of lowering the marriage age to 15 years or raising it to 19 years was studied. Coale and Trussell [21] reported a positive fertility rate between 15 and 16 years old. Thus, the early marriage case was set to 15 years old (2 years younger than 17 years old), and then the late marriage case was set to 19 years old (2 years older than 17 years old). Marriages between a father and daughter, mother and son, and brother and sister were considered unlikely; however, a marriage between cousins might take place [26]. Thus, marriage between cousins was accepted as possible in this study.

There are multiple opinions on the minimum number of people for ethnic minorities to prosper without extinction (i.e., the survival threshold). In this study, the minimum number of people was set to 500 because the population of the endangered Aleut people, which is a representative ethnic minority of Russia, was 482 in 2010 [27]. In the model, if the total population was >500, the group was concluded to have successfully survived, and calculations were terminated. If the total population became zero, the group was concluded to have failed to survive, and calculations were terminated. If neither termination condition occurred, the model proceeded with calculations for the following year until time t = 10,000 years because the ancestors of Indigenous people are believed to have migrated to present-day Canada sometime between 21,000 and 10,000 BCE. However, Bradshaw, et al. [28] reported a survival threshold of 1300–1550 individuals for immigration in Sahul. As of 2016, 977,230 Indigenous people live in Canada in >630 communities [29, 30]. Therefore, current Indigenous communities average ~1500 people per community. There are no reports on the extinction of Indigenous communities in Canada at this moment; however, the effect of the minimum survival threshold was considered by varying the value to 1500 rather than 500.

We assumed that a small group of people, such as one to two families, migrated. Because we did not consider marriage within a nuclear family, we considered migration by two families. Moreover, because no reliable data is available on how many people comprised a nuclear family of ancestors of Indigenous people during the Last Glacial Maximum, we assumed that one family comprised the parents and three children for a total of five members, as suggested by Racette [26].

2.3. Simulation Model

On the basis of the abovementioned premises, the distributions of the sexes and ages of the migrating group at time t = 1 year were determined and used as the initial values. Next, the number of births was determined on the basis of the average childbirth interval; moreover, the new babies were added to the population the following year with an age of 0 years. Third, deaths were randomly determined according to the mean life expectancy by age and sex. Finally, females and males who reached marriage age were paired.

The model was executed using the GCC compiler and Visual Studio Code. The model was executed 1,000 times for each parameter combination to determine the number of successful survivals, and the survival probability was calculated as the number of successful survivals out of 1,000 times. This calculation was repeated 10 times for each parameter combination, and the mean and deviation of the survival probability were estimated. The results obtained from 1,000 executions were quantitatively similar to those from 10,000 and 100,000 executions for representative parameter combinations, which suggested that 1,000 executions were sufficient. The model was verified using simple inputs, for which the results could be clearly predicted. The model was validated by reproducing the results of Ruxton and Wilkinson [19].

The model created in this study was considered an extension of the general framework of the Ruxton and Wilkinson [19] in the following three points: First, the Ruxton and Wilkinson model assumed that a group of completely unrelated people unintentionally moved. Our model could consider family migration and intentional migration. Second, in the Ruxton and Wilkinson model, only one fixed value was set for life expectancy and childbirth interval. Our model could consider the distributions of life expectancy and childbirth interval. Finally, the Ruxton and Wilkinson model considered marriages such as a sister and a brother, a father and a daughter, and an uncle and a niece. For our model, we listened to the opinions of Indigenous people [26] and allowed marriage between cousins, but we did not allow marriage between siblings or parents and children in the model.

2.4. Model Cases

For the model, we set the independent variables as follows: the mean female life expectancy was 22.5–37.5 years old (2.5-year interval), and the average childbirth interval was 2.6–4.4 years (0.3-year interval). We set the reference case as follows: initial population of 10 individuals (two families with five members each); marriage age of 17 years old; monogamy; unintentional migration; and minimum survival threshold of 500. Then, the following cases were considered: Unless stated otherwise, the conditions were the same as in the reference case. Figure 1 shows a flowchart of the model.

1. Intentional migration: initial population of five unmarried females and five unmarried males aged 17–25 years old.
2. Polygamy.
3. Marriage age: 19 years (late) or 15 years (early).
4. Initial population size: two families had a total of four, six, or eight people, and each family had two members (only parents), three members (parents and one child), or four members (parents and two children).
5. Number of families: three to six families; monogamy and polygamy.
6. Minimum survival threshold: 1500.

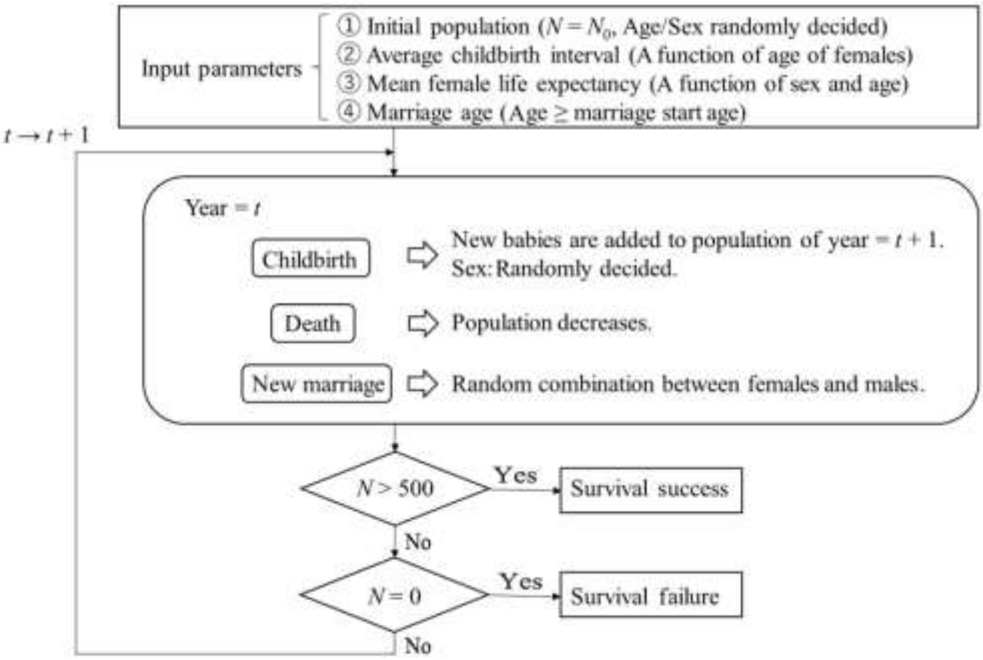

Figure 1.
Flowchart of model.
Note: N: Population at year = t; N_0: Initial population.

3. Results

3.1. Verification and Validation

For model verification, three simple cases were calculated under the following conditions: two families with 10 members in total, unintentional migration, and a constant childbirth interval of 3.5 years. In the first case, all people quickly died. In the second case, the life expectancy was 35 years (constant). In the third case, the life expectancy was 50 years (constant). In the first case, no one survived, and therefore the survival probability should be zero. For the second case, the survival probability should be greater than zero but much smaller than that for the third case. All cases were calculated twice, and all calculations were performed without error messages. Table 1 summarizes the survival probability for each case, and the model results agree with the abovementioned predictions. Hence, the model was verified.

For model validation, the number of survival cases was compared with that obtained by Ruxton and Wilkinson [19]. They considered the case of unintentional migration by 2*N* people (*N* = 1–10). Their focus was on migration to islands rather than Canada, but their model had a framework similar to ours, e.g., the initial age and sex were randomly determined, and they calculated the number of successful colonisations out of 1,000 calculations. Table 2 summarizes the number of survival cases out of 1,000 calculations for our model and that of theRuxton and Wilkinson [19] model. The absolute values are not identical, but the trends of the two models demonstrated strong consistency. Therefore, the model was validated.

Table 1.
Survival probability in verification cases.

Case	Died quickly	Life expectancy: 35 years	Life expectancy: 50 years
Survival probability	0	0.183	0.780
	0	0.169	0.745

Table 2.
Survival cases for 1,000 calculations with our model and the Ruxton and Wilkinson [19] model.

N	This study	Ruxton and Wilkinson [19]	N	This study	Ruxton and Wilkinson [19]
1	21	17	6	277	269
2	55	44	7	351	359
3	99	108	8	376	387
4	113	131	9	473	445
5	210	203	10	493	489

Note: Initial migration = 2*N*.

3.2. Intentional Vs. Unintentional Migration

Figures 2(a) and (b) show the survival probability for unintentional migration and intentional migration, respectively. The plots and error bars represent the mean and deviation, respectively. In both cases, the survival probability increased with an increase in mean female life expectancy and a decrease in average childbirth interval. However, the survival probability was considerably lower for unintentional migration than for intentional migration.

To examine the effects of intentional migration, female life expectancy, and childbirth interval on the survival probability, logistic regression analysis was performed as per the following equation:

$$y = \frac{1}{1+\exp\left[-\{\alpha+\beta\times(\text{mean female life expectancy})+\gamma\times(\text{childbirth interval})+\delta\times(\text{migration})\}\right]} \quad (1)$$

Where y is the survival probability; α, β, γ, and δ are regression coefficients; and (migration) is a dummy variable representing the migration scenario (unintentional = 0, intentional = 1). Logistic regression is a statistical analysis method to predict a binary outcome, such as yes or no, based on prior observations of a data set. A logistic regression model predicts a dependent data variable by analyzing the relationship between two or more existing independent variables.

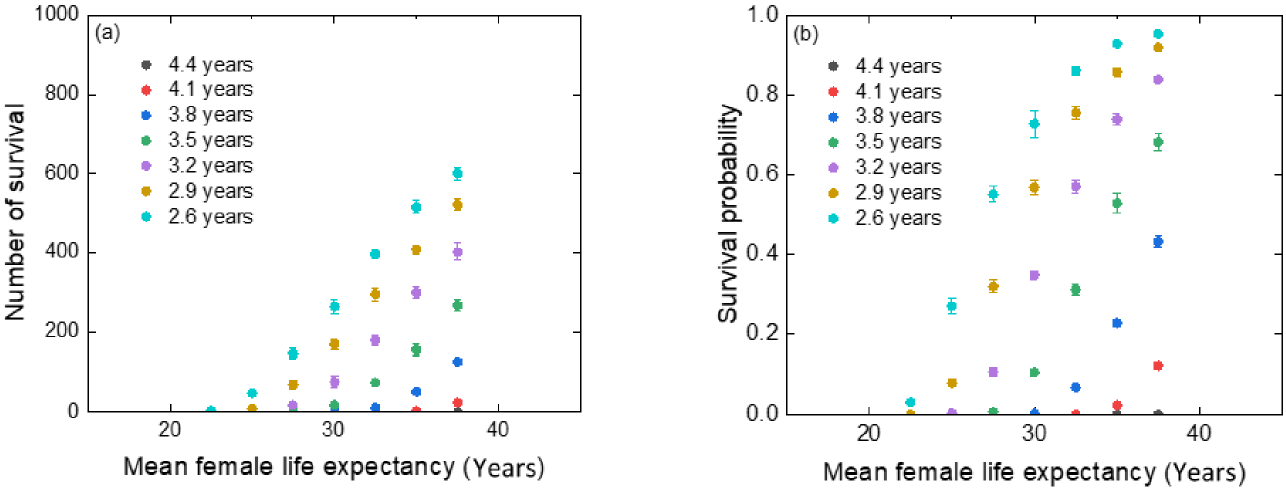

Figure 2.
Effects of mean female life expectancy and average childbirth interval on survival probability: (a) unintentional migration and (b) intentional migration. The plotted data points and error bars represent the mean and deviation, respectively, of the survival probability.

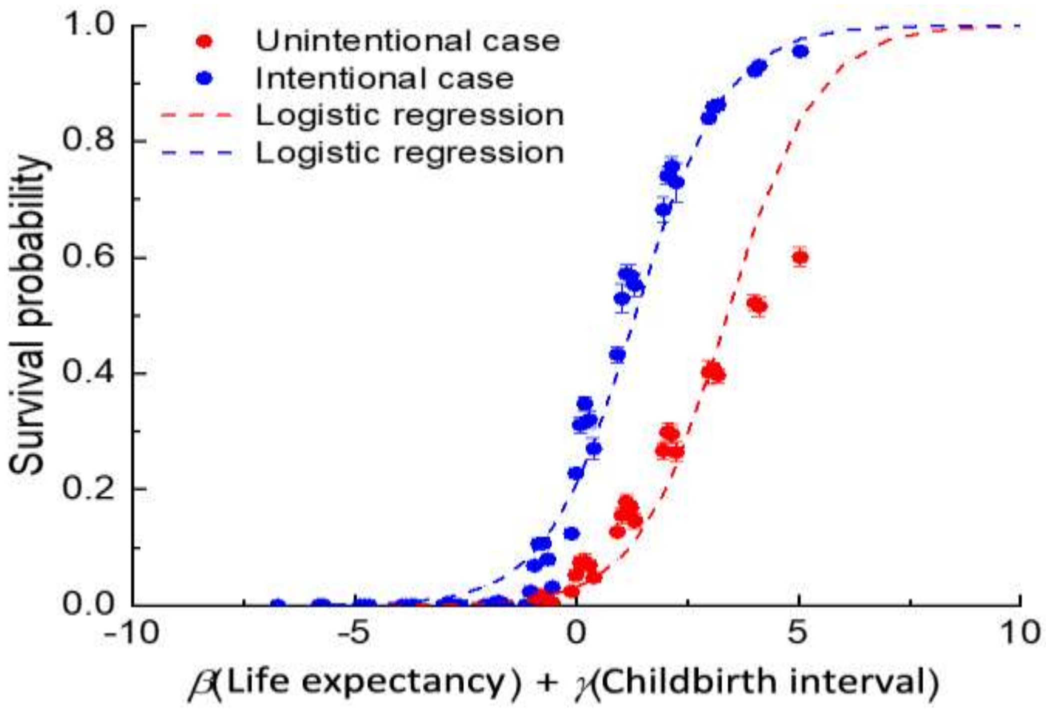

Figure 3.
Effects of unintentional and intentional migration on survival probability.

Note: The plots represent the mean values calculated by the model, and the dashed lines represent the logistic regression results. β and γ are regression coefficients for the mean female life expectancy and average childbirth interval, respectively, and their values are summarized in Table 3.

Figure 3 shows the survival probability out of 1,000 calculations by the model and the fitting results with the logistic regression analysis for unintentional and intentional migration. The model and logistic regression results fit relatively well. Figures 4 and 5 show the number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for unintentional and intentional migration, respectively. Table 3 summarizes the estimated values of the regression coefficients α, β, γ, and δ. The regression coefficients for the mean female life expectancy (β) and average childbirth interval (γ) had positive and negative values, respectively. In other words, the survival probability increased with an increasing mean female life expectancy and a decreasing average childbirth interval. These results are reasonable and agree with expectations. The odds can be defined as the ratio of the probability of success to the probability of failure, and the odds ratio can be defined as the ratio of the odds of event 1 to the odds of event 2. In this case, the odds ratio can be calculated using Equation 2:

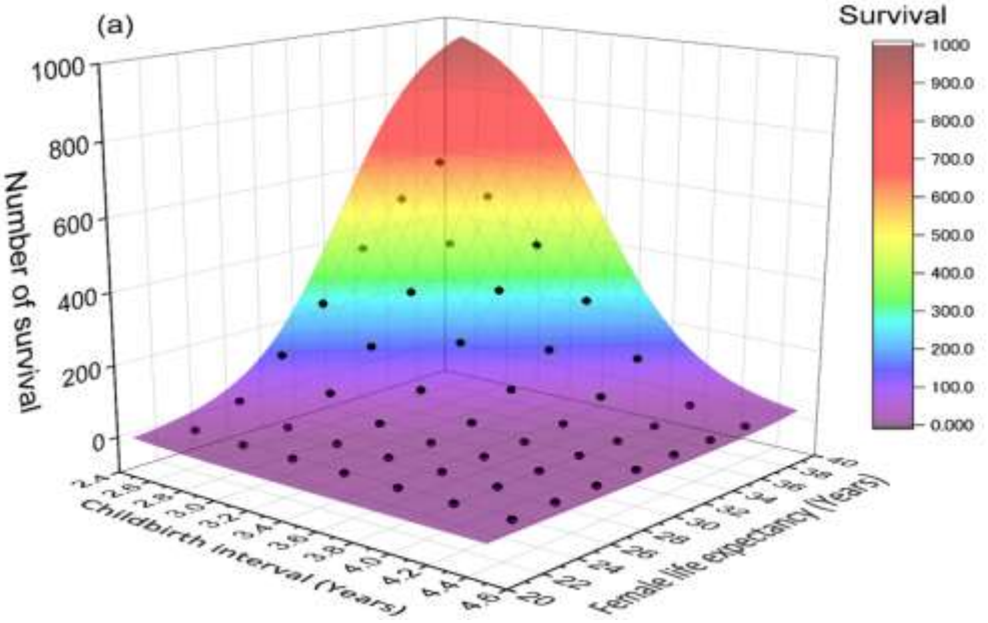

Figure 4.
Number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for unintentional migration.

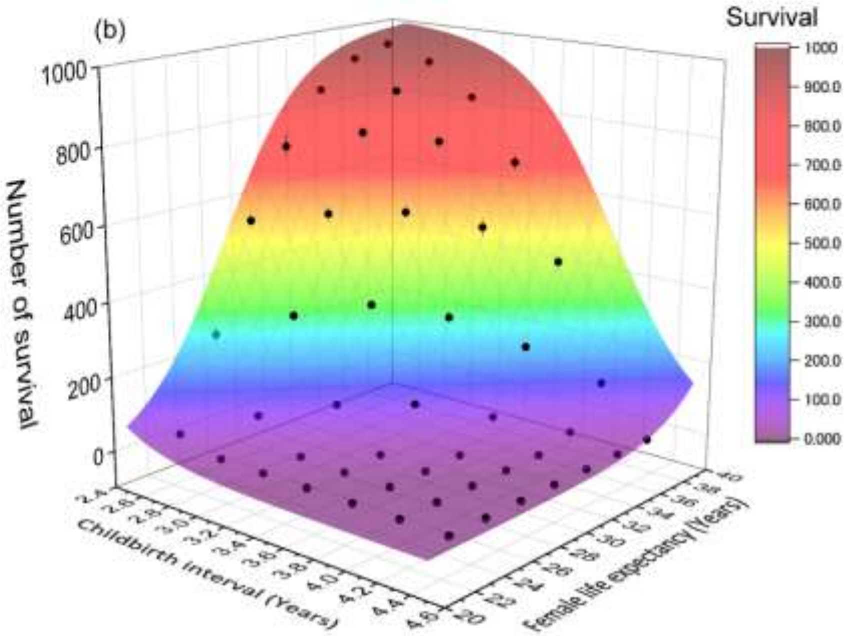

Figure 5.
Number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for intentional migration.

$$\text{Odds ratio} = \frac{\left(\frac{\text{Probability of success for intentional migration}}{\text{Probabilty of failure for intentional migration}}\right)}{\left(\frac{\text{Probability of success for unintentional migration}}{\text{Probability of failure for unintentional migration}}\right)} \quad (2)$$

Because the term (migration) in Equation 1 is a dummy variable representing the migration scenario, where intentional = 1 and unintentional = 0, exp(δ) can calculate the odd ratio for intentional migration and unintentional migration as 7.900. This suggests that the survival probability is strongly correlated with whether or not the migration was intentional or unintentional. It is considered that long-distance migrations were conducted in stages rather than haphazard, and unmarried people might be more likely to migrate than others. Therefore, the survival probability of intentional migration might be greater than that calculated in this study. It is necessary to consider these effects in the future.

Table 3.
Estimated values of regression coefficients.

Regression coefficient	Intentional case	Polygamy case	Late marriage case	Early marriage case
α	−3.38 (−3.58, −3.19)	−3.53 (−3.71, −3.34)	−3.56 (−3.70, −3.41)	−3.20 (−3.63, −2.77)
β	0.373 (0.367, 0.378)	0.260 (0.254, 0.265)	0.322 (0.317, 0.327)	0.290 (0.281, 0.298)
γ	−3.44 (−3.50, −3.37)	−2.13 (−2.20, −2.06)	−2.81 (−2.86, −2,75)	−2.57 (−2.62, −2.51)
δ	2.07 (2.03, 2.11)	2.57 (2.53, 2.61)	−1.39 (−1.43, −1.36)	1.07 (1.01, 1.13)

Note: Values in brackets represent the 95% confidence interval.

3.3. Polygamy Vs. Monogamy

Figure 6 displays the model's prediction of the chance of the survival and the results of the fitting it with logistic regression analysis using Equation 1. The term (migration) is a dummy variable that stands for the migration scenario (monogamy = 0, polygamy = 1). Figures 7 and 8 show the numbers of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for the monogamy case and polygamy case, respectively. The results demonstrated that survival was much more likely for polygamous communities than for monogamous communities. For the polygamy case, we made the simple assumption that one male could have any number of wives and that the life expectancy and childbirth interval were unaffected. In other words, if at least one male survived to marriage age, he could marry all remaining females at least at marriage age. This assumption does not seem realistic but may provide the upper limit of the effect of polygamy on survival.

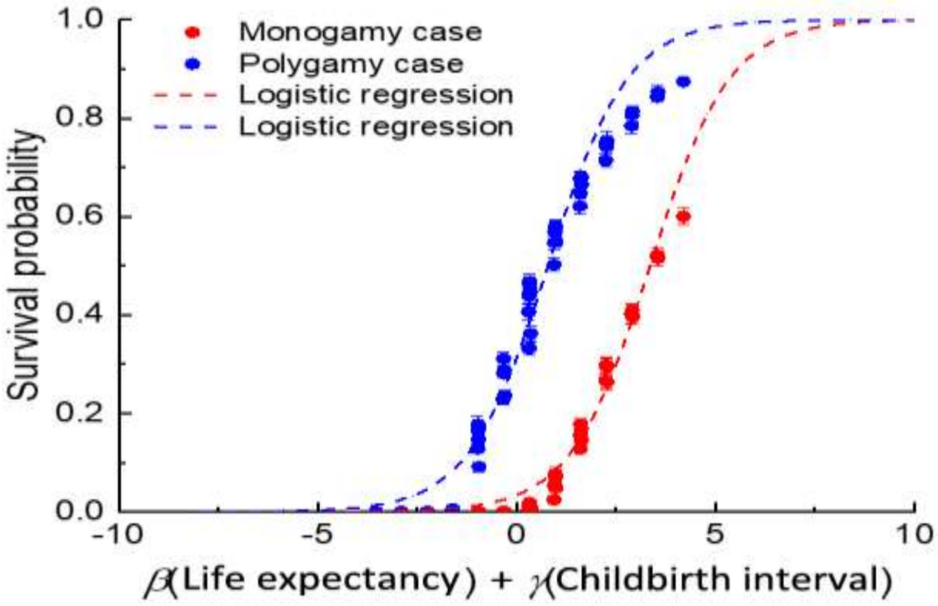

Figure 6.
Effects of monogamy and polygamy on survival probability.

Note: The plots represent the mean values calculated by the model, and the dashed lines represent the logistic regression results. β and γ are regression coefficients for the mean female life expectancy and average childbirth interval, respectively, and their values are summarized in Table 3.

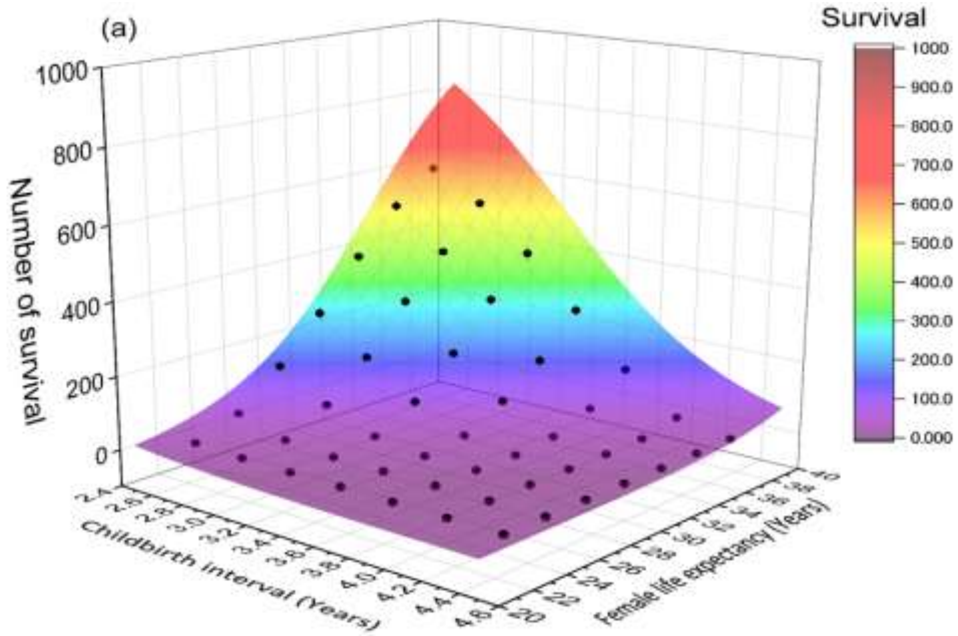

Figure 7.
Numbers of survivals, as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for monogamy case.

The estimated regression coefficients are summarized in Table 3. Both the positive effect of mean female life expectancy and negative effect of average childbirth interval were smaller than the effects in the intentional migration case (i.e., β: 0.2595 vs. 0.3727; γ: −2.132 vs. −3.437), suggesting that the survival probability of the unintentional migration in the polygamous community was less dependent on female life expectancy and childbirth interval than that of the intentional migration in the monogamous community. The odds ratio for polygamy/unintentional migration to monogamy/unintentional migration was 13.04, whereas the odds ratio for monogamy/intentional migration to monogamy/unintentional migration was 7.900 (see Section 3.2). These values suggest that the unintentional migration of a polygamous community has a higher chance of survival than the intentional migration of a monogamous community. The highest survival chance found for the unintentional migration of a polygamous community under the study conditions of a long female life expectancy and a short childbirth interval was 0.87. This is less than the highest survival chance found for international migration of a monogamous community under the same conditions of a long female life expectancy and a short childbirth interval, which was 0.95.

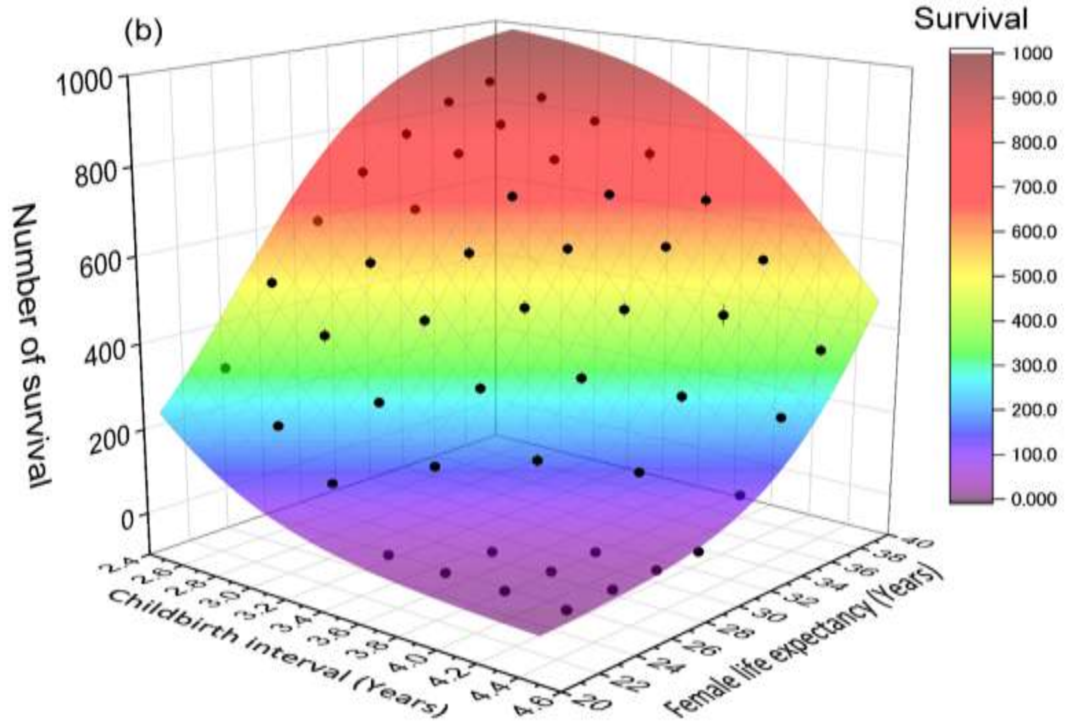

Figure 8.
Numbers of survivals, as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for polygamy case.

3.4. Late Marriage Vs. Early Marriage

Figure 9 displays the model's estimated survival probability and the fitting outcomes from logistic regression analysis for marriage between the ages of 17 and 19 with unintentional migration and monogamy. Figures 10 and 11show the number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis of marriage ages of 17 and 19 years, respectively.

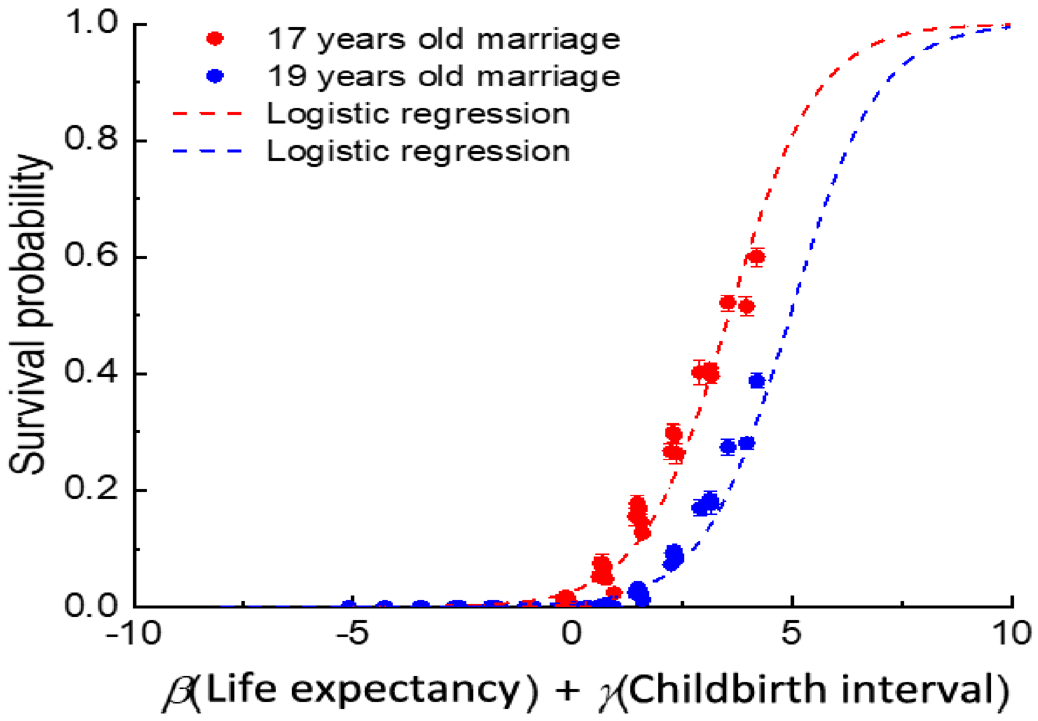

Figure 9.
Effects of marriage age (17 vs. 19 years) on survival probability.

Note: The plotted data show the mean values calculated by the model, and the dashed lines show the logistic regression results. The mean female life expectancy and average childbirth interval are represented by the regression coefficients β and γ, respectively, and their values are summarized in Table 3.

In Equation 1, the term (migration) is a dummy variable representing the migration scenario (marriage age of 17 = 0, marriage age of 19 = 1). For a marriage age of 17, the highest survival probability was ~0.60. For a marriage age of 19, the survival probability decreased to a maximum of 0.39. Table 3 summarizes the estimated values of the regression coefficients. The values of β and γ were 0.3216 and −2.805, respectively, for the late marriage case, which are between those for intentional migration ($\beta = 0.3727$ and $\gamma = -3.437$) and polygamy ($\beta = 0.2595$ and $\gamma = -2.132$). According to these findings, the average female life expectancy and childbirth interval had the least impact on the survival probability for the polygamous community, then the community with late marriage, and finally the intentional migration. The odds ratio for the late marriage case (19 years old; monogamy; unintentional migration) to the reference case (marriage age of 17; monogamy; unintentional migration) was 0.2480, which is <1. Thus, the survival probability was lower in the late marriage case than in the reference case.

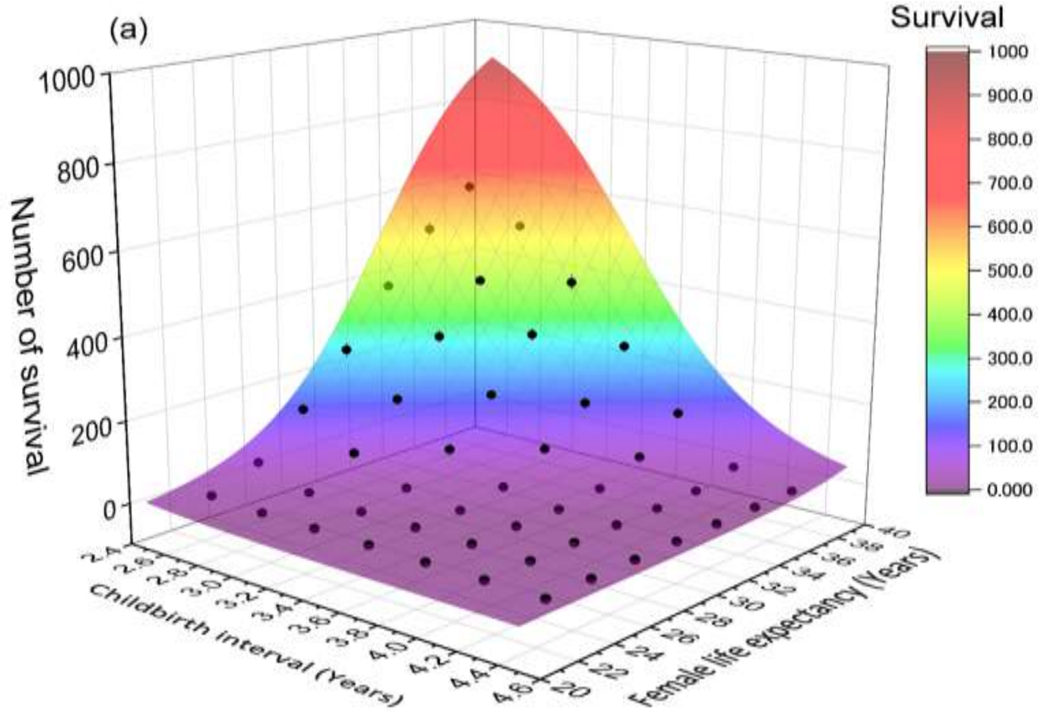

Figure 10.
Number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis of marriage ages of 17 years old.

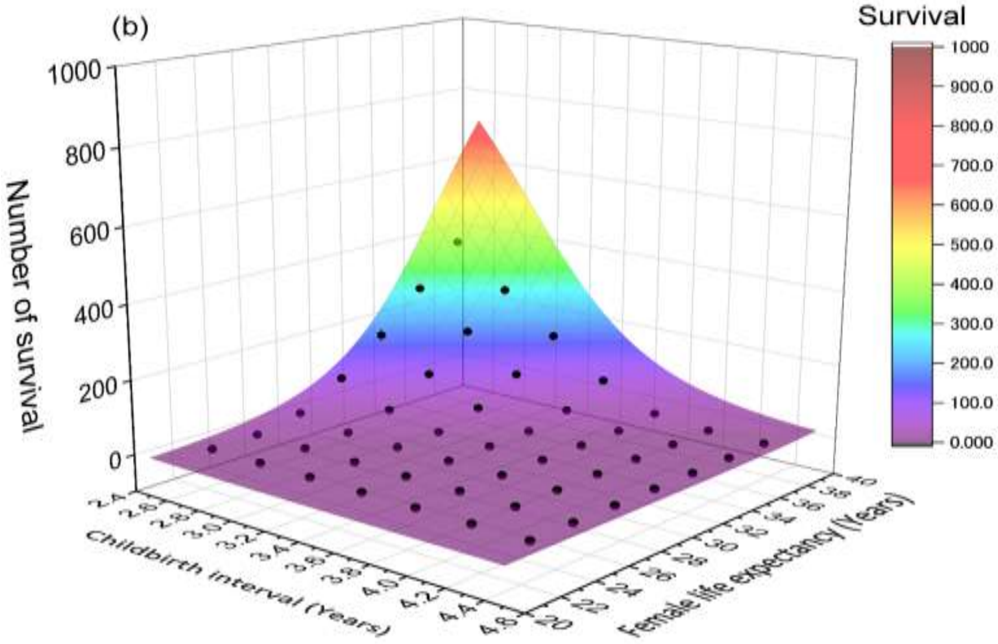

Figure 11.
Number of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis of marriage ages of 19 years old.

Figure 12 shows the survival probability calculated by the model and the fitting results obtained by the logistic regression analysis for the marriage ages of 17 and 15 years old. Figures 13 and 14 show the numbers of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for marriage at 17 and 15 years, respectively. The maximum survival probability was 0.76 at a marriage age of 15. In Equation 1, the term (migration) is a dummy variable representing the migration scenario (marriage age of 17 = 0, marriage age of 15 = 1). The survival probability was greater at a marriage age of 15 than at 17. Table 3 summarizes the estimated values of the regression coefficients. The values of β and γ for the early marriage case ($\beta = 0.2897$; $\gamma = -2.568$) were between those for the intentional migration case ($\beta = 0.3727$ and $\gamma = -3.437$) and polygamy case ($\beta = 0.2595$ and $\gamma = -2.132$). The odds ratio for the early marriage case (age 15; monogamy; unintentional migration) to the reference case (age 17; monogamy; unintentional migration) was 2.924.

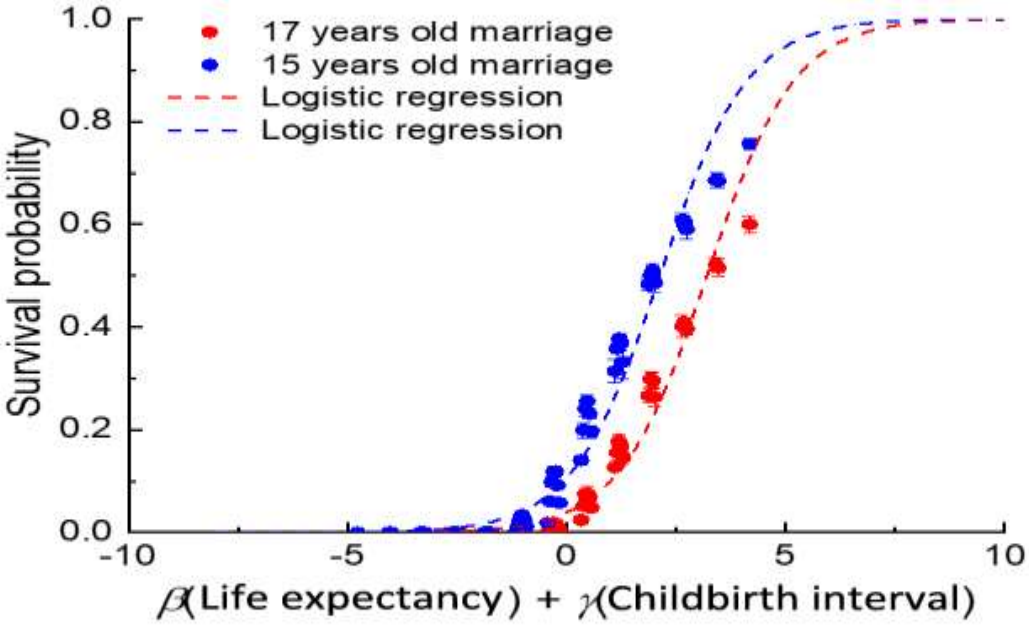

Figure 12.
Effects of marriage age (17 vs. 15 years) on survival probability.

Note: The plots represent the mean values calculated by the model, and the dashed lines represent the logistic regression results. The mean female life expectancy and average childbirth interval are represented by the regression coefficients of β and γ, respectively, and their values are summarized in Table 3.

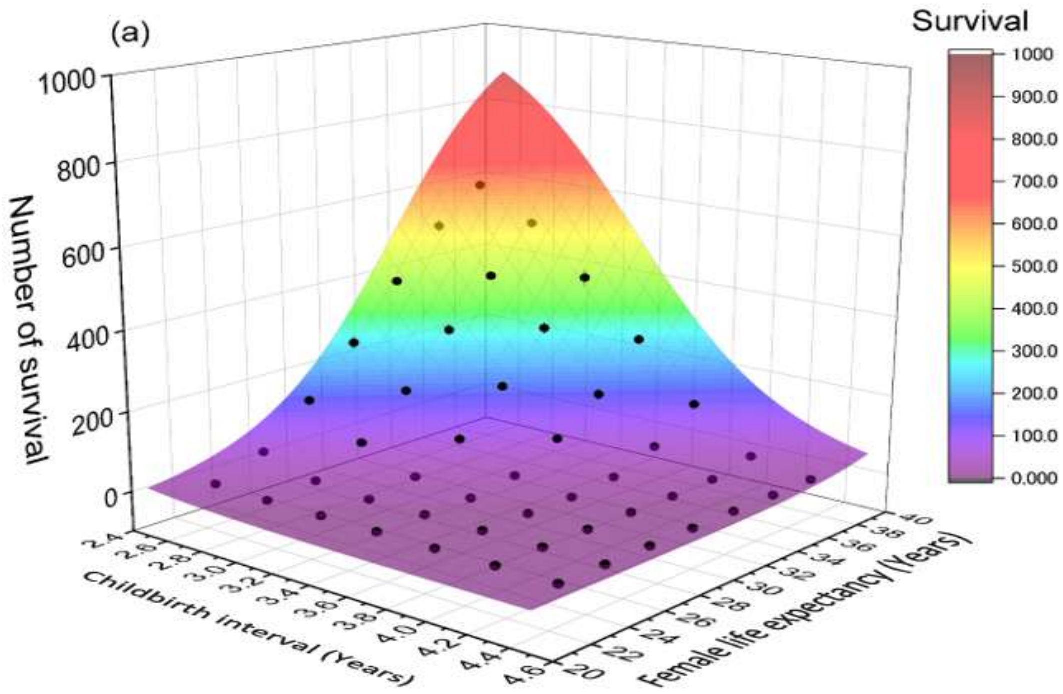

Figure 13.
Numbers of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for marriage at 17 years old.

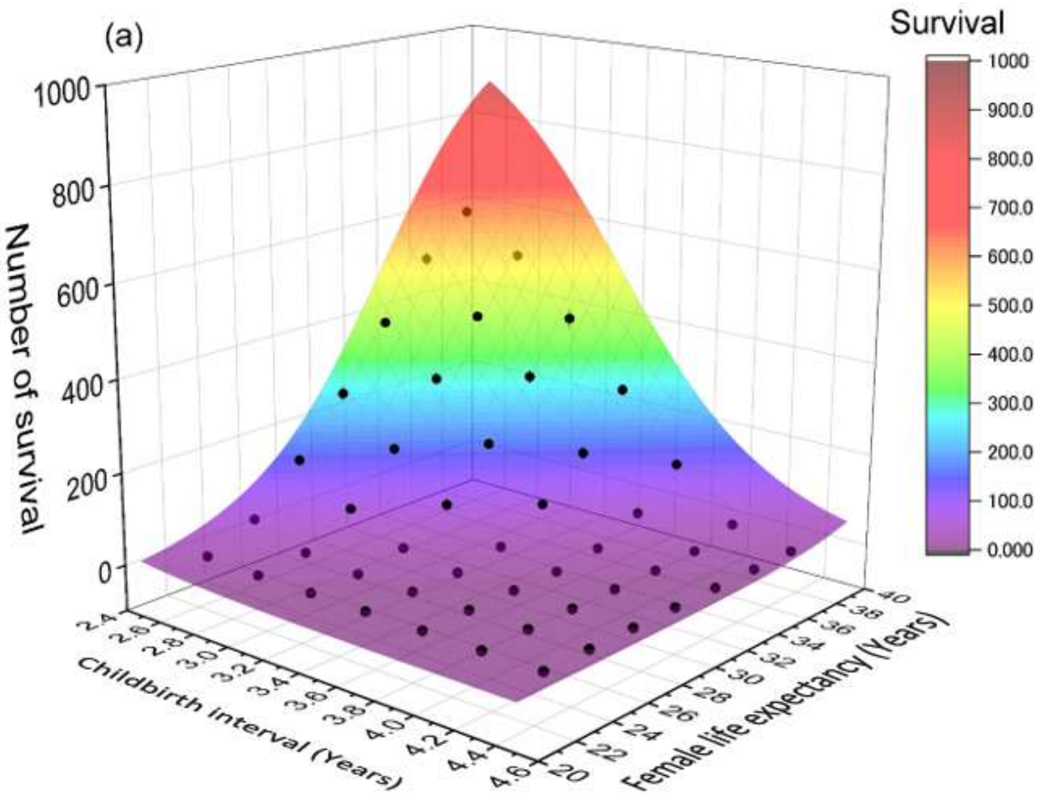

Figure 14.
Numbers of survivals as a function of mean female life expectancy and average childbirth interval by logistic regression analysis for marriage at 15 years old.

From the odds ratios and values of regression coefficients, a polygamous community was most likely to survive. However, the model calculations are based on statistical data on mortality and fertility, which were used in previous studies on human migration to islands during the Last Glacial Maximum, and were not based on the data for ancestors of the Indigenous people of Canada.

The result for the polygamous community demonstrates the upper limit of the effect of polygamy on survival. The maximum survival probability for the polygamous community was 0.87, which is smaller than the 0.95 probability calculated for the intentional migration. Therefore, additional research on archaeological and ethnographic evidence about the ancestors of the Indigenous people of Canada is required to improve the discussion on their survival probability.

3.5. Initial Population Size

The effect of the initial population size on the survival probability was calculated by varying the number of members in each family: two (only parents), three (parents and one child), and four (parents and two children). Two families were assumed to migrate together, and therefore the total populations were four, six, and eight, respectively. The other conditions of the reference case were retained such as unintentional migration, monogamy, and a marriage age of 17 years. Figure 15 shows the calculated survival probability, including the results of the reference case (initial population: 10 people). The survival probability decreased with decreasing initial population size. The survival probability was practically zero for an initial population size of four or six people.

Unintentional migration by an initial population size of eight people could only produce survival by increasing the mean female life expectancy and decreasing the childbirth interval. Moreover, this was true for unintentional migration by ten people, but the large survival probability with a long female life expectancy and short childbirth interval appeared to be an outlier in both cases.

For unintentional migration with two families, an initial population size of eight or more people was the minimum requirement for survival. However, the survival probability was still low, with mean and median values of 0.05 and 0.0023, respectively, for 8 people and 0.11 and 0.010, respectively, for 10 people.

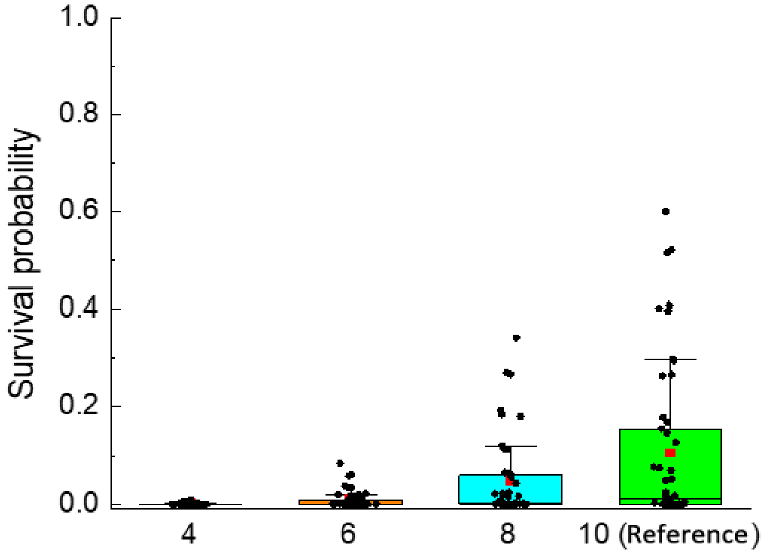

Figure 15.
Effect of initial population size on survival probability.
Note: The red square represents the mean survival probability.

3.6. Number of Families

Figures 16(a) and (b) show the survival probability when the number of families migrating together was increased for monogamy and polygamy, respectively. For monogamy, the survival probability increased with the initial number of families. However, even with six families (a total of 30 people), only 25% of the plots exceeded a survival probability of 0.50. If we define a high survival probability as when both the mean and median exceed 0.50, the survival probability is still low even with six families (mean = 0.25, median = 0.064). Considering the lives of Inuit people in Greenland [15] and Canada [16] and of hunter-gatherers in Africa [13, 14], migration with ≥20 people does not seem realistic. However, if the Indigenous ancestors migrated in groups of two or three families, the survival probability was low but not negligible.

In polygamous communities, the survival probability increased with the initial number of families. With four or more families, both the mean and median of the survival probability exceeded 0.50, and therefore the survival probability was high. However, the probability of extinction could not be ignored, even with six families (7 out of 49 plots failed to survive). As discussed previously, migration for many people does not seem realistic. The corresponding mean and median of the survival probability were 0.40 and 0.44 with two families and 0.48 and 0.58 with three families. Therefore, when the initial migration was by two or three families, the model indicated that the survival probability was low even for a polygamous community. Furthermore, the calculation results for the polygamy case indicate the upper limit of the survival probability. In addition, as mentioned in Section 2.1, the data on mortality and fertility used in this study were used in the previous studies conducted on human migration to islands under weather conditions that might not have been as severe as when the Indigenous ancestors of Canada migrated. Figure 16 may have overstated the actual survival probability of a polygamous community.

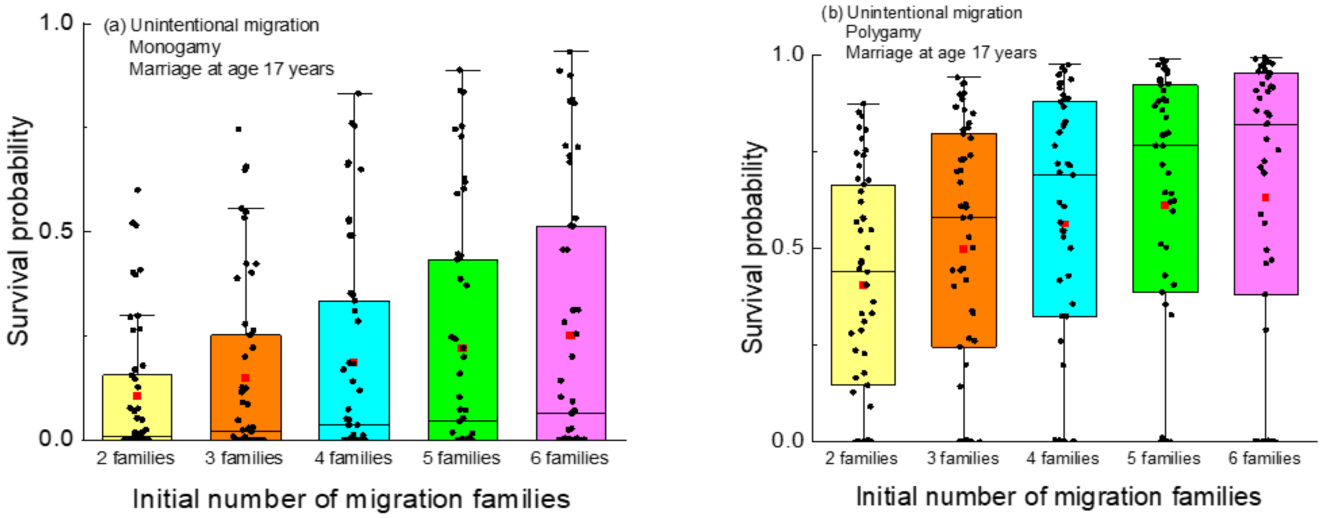

Figure 16.
Effect of initial number of migrating families on survival probability: (a) monogamy and (b) polygamy. One family was assumed to comprise the parents and three children.
Note: The red square represents the mean survival probability.

The lower survival probabilities strongly imply that the ancestors of Indigenous people survived in Canada by making full use of their wisdom, experience, knowledge, and other traits beyond the factors considered in this study. In the future, we would like to investigate the wisdom and knowledge used by the Indigenous ancestors to survive and incorporate them into the model to make it more comprehensive. We would also examine the actual quantitative data on the mortality and fertility of the ancestors of Indigenous people who migrated to Canada.

3.7. Minimum Survival Threshold

The effect of changing the minimum community population survival threshold from 500 to 1500 was then investigated. Two cases were considered: monogamy and polygamy. The other conditions were the same as in the reference case; Figure 17 shows the results. In both cases, the survival probability did not considerably change when the threshold was increased from 500 to 1500 people. This suggests that if the Indigenous ancestors successfully increased their community to 500 people, the risk of extinction was negligible, and they could continue to increase their population steadily. The minimum number of 500 people was obtained from the population of the endangered Aleut people, which was 482 in 2010 [27]. The true threshold may be <500. However, an additional consideration is that current medical care and technology were not available during the Last Glacial Maximum, and therefore the true threshold may have been higher at this time. To evaluate the survival probability of Indigenous ancestors, the true threshold should be investigated, but this will be left for a future study.

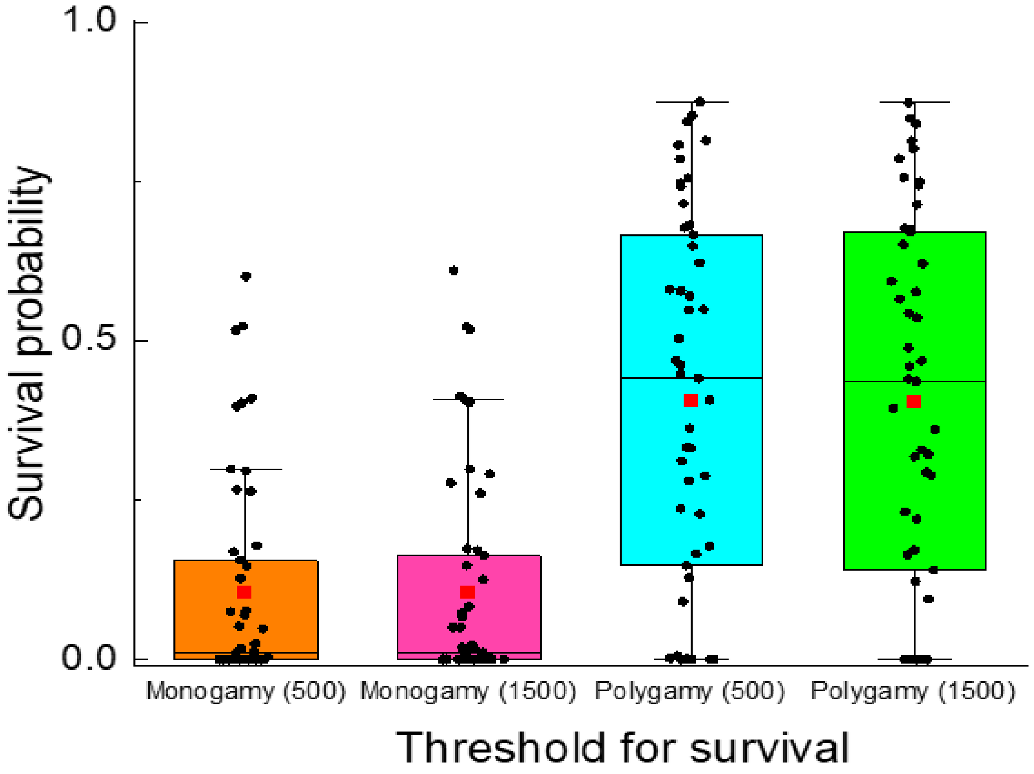

Figure 17.
Effect of the minimum survival thresholds of 500 and 1500 community people on the survival probability of monogamous and polygamous communities.
Note: The red square represents the mean survival probability.

4. Conclusion and Discussion

The ancestors of the Canadian Indigenous people are believed to have migrated from an area in the Eastern Hemisphere (now known as Siberia) to an area in the Western Hemisphere (now known as Canada) during the Last Glacial Maximum. There are many studies on migration during the Last Glacial Maximum, but no previous study has considered the survival success rate of this migration and the effects of different factors. We created a mathematical model to evaluate the survival probability of Indigenous ancestors who migrated during the Last Glacial Maximum and the effects of intentional migration, polygamy, marriage age, initial population size, and survival threshold on the survival probability. Quantitative mortality and fertility statistical data for the ancestors of the Canadian Indigenous people during the Last Glacial Maximum is not available; thus, we used the statistical data on human migration to islands during the Last Glacial Maximum, which were used in previous studies. Within such a clear limitation, the following suggestions were obtained in this study:

1. When compared with the reference case (two families with 10 people in total, unintentional migration, monogamy, and a marriage age of 17), the survival probability was increased by intentional migration, polygamy, and lower marriage age.

2. Among the factors of intentional migration, polygamy, and marriage age, polygamy was the most effective at increasing the survival probability. A polygamous community was the most robust for survival against a reduction in the mean female life expectancy and an increase in the average childbirth interval.
3. The survival probability was negligible for small initial population sizes of four or six people. Families had to have four or five members for a total population size of eight or 10 people to have a chance at survival.
4. The survival probability increased with the initial number of families. However, the survival probability was low even with six families for monogamy. For polygamy, the survival probability was high with four or more families. However, the conditions used for the polygamy case represent the upper limit of the survival probability, and hence the actual survival probability may have been considerably lower.
5. Increasing the survival threshold from 500 people to 1500 people did not change the survival probability.

The accuracy of survival probability in this study will be improved by further studying the archaeological and ethnographic evidence on ancestors of the Canadian Indigenous people and quantifying their mortality, fertility, and marriage age.

Our goal in this study was to estimate the survival probability of the Indigenous ancestors of the people who migrated to Canada and assess the effects of different factors, such as the effect of unintentional or intentional migration, with a mathematical model that was based on an extension of the general framework of the Ruxton and Wilkinson [19] model. Since the mortality and fertility rates during the Last Glacial Maximum are not known, as we repeated in this paper, we considered wider mortality and fertility rates than Ruxton and Wilkinson [19] study. However, our calculation results provided new basic insights into the migration of the Indigenous ancestors to Canada. Firstly, it is reasonable to consider that the migration of the Indigenous ancestors started with a relatively small group. Secondly, the unintentional migration was less successful because our calculation result suggested the unintentional migration was much less likely to succeed than the intentional migration (odds ratio = 7.900). On the other hand, thirdly, there were possible conditions under which the unintentional migration could be non-negligibly successful if the Indigenous ancestors lived in the polygamy communities or they married early. As Racette [26], who is an Indigenous person of Anishinaabe descent, pointed out, the possibility of polygamy communities could not be excluded. Therefore, we believe that the hypothesis of unintentional migration should be fully considered in research on the migration of Indigenous peoples.

Bradshaw, et al. [28] concluded that a population size of 1300-1550 was required to succeed in the first colonisation of Sahul. They considered a single combination of mortality and fertility rates, like the female life expectancy of 31 years old and the stable population growth rate of 0.0037. We calculated the survival probability of Indigenous ancestors with the morality and fertility rates, which were consistent with the rates [28] used, and found that the probability was zero even when the unintentional migration started with 20 families. Regarding the minimum survival threshold, it is desirable to quantify a reasonable estimate value based on the environmental conditions, mortality, and fertility during the Last Glacial Maximum in the future instead of the assumed value of 500 people used in this study.

We have to touch on three limitations of our present study. Firstly, we are not confident that the mortality and fertility we used accurately approximate the demography of the population size of ancestors of Indigenous people during the Last Glacial Maximum. We also do not know sufficiently the uniqueness of ecological and environmental conditions in Canada during the Last Glacial Maximum. In order to reduce the uncertainties derived from these, mortality and fertility were carefully selected in this study, and calculation results were discussed across the ranges of mortality and fertility that were consistent with those of present-day hunter-gatherers. However, the mortality (West family) and the fertility models were cited from the Coale, et al. [22] and the Coale and Trussell [21], respectively, meaning that only one combination of mortality and fertility was studied. Although the robustness of our findings was partially checked by the comparison with the results of Ruxton and Wilkinson [19], the dependence of robustness on the selection or combination of mortality and fertility models has to be investigated in the future. Secondly, intentional migration and unintentional migration were distinguished by age distribution, sex ratio, and kinship, for example. However, in the unintentional migration case, there was an opportunity that two independent migration groups accidentally met at the same location in Canada at the same time. In such a case, the survival probability of unintentional migration may increase. To improve the survival probability quantitatively, we must consider the possible migration scenarios more in the future. Thirdly, Bittles and Black [31] argued that there is little information on inbreeding during the critical early years of human existence, but, given the small founding group sizes and restricted mate choices, it seemed inevitable that intrafamilial reproduction occurred and the resultant levels of inbreeding would have been substantial, and that mortality in first-cousin progeny was approximately 3.5% higher than in nonconsanguineous offspring, although demographic, social, and economic factors could significantly influence the outcome. The inbreeding effect was not considered in this study. Since consanguineous marriages were considered to occur more often in unintentional migration than in intentional migration, the survival probability of unintentional migration in this study might be overestimated.

Therefore, we concluded that even in the communities that allowed polygamy and early marriage, the chance of survival of the ancestors of the Indigenous people of Canada was small, implying that they survived in Canada by making full use of their wisdom, experience, knowledge, and other traits beyond the factors considered in this study.

References

[1] K. Norman, J. Inglis, C. Clarkson, J. T. Faith, J. Shulmeister, and D. Harris, "An early colonisation pathway into Northwest Australia 70-60,000 years ago," *Quaternary Science Reviews*, vol. 180, pp. 229-239, 2018. https://doi.org/10.1016/j.quascirev.2017.11.023

[2] S. Kealy, J. Louys, and S. O'Connor, "Least-cost pathway models indicate northern human dispersal from Sunda to Sahul," *Journal of Human Evolution,* vol. 125, pp. 59-70, 2018. https://doi.org/10.1016/j.jhevol.2018.10.003

[3] M. Rasmussen *et al.*, "The genome of a Late Pleistocene human from a Clovis burial site in western Montana," *Nature,* vol. 506, no. 7487, pp. 225-229, 2014. https://doi.org/10.1038/nature13025

[4] M. Sikora *et al.*, "The population history of northeastern Siberia since the Pleistocene," *Nature,* vol. 570, no. 7760, pp. 182-188, 2019. https://doi.org/10.1038/s41586-019-1279-z

[5] M. R. Bennett *et al.*, "Evidence of humans in North America during the last glacial maximum," *Science,* vol. 373, no. 6562, pp. 1528-1531, 2021.

[6] B. Herrera, T. Hanihara, and K. Godde, "Comparability of multiple data types from the Bering Strait region: Cranial and dental metrics and nonmetrics, mtDNA, and Y-chromosome DNA," *American Journal of Physical Anthropology,* vol. 154, no. 3, pp. 334-348, 2014. https://doi.org/10.1002/ajpa.22513

[7] J. Lindo *et al.*, "Ancient individuals from the North American Northwest Coast reveal 10,000 years of regional genetic continuity," *Proceedings of the National Academy of Sciences,* vol. 114, no. 16, pp. 4093-4098, 2017. https://doi.org/10.1073/pnas.1620410114

[8] M. Raghavan *et al.*, "Genomic evidence for the Pleistocene and recent population history of Native Americans," *Science,* vol. 349, no. 6250, p. aab3884, 2015.

[9] M. Rasmussen *et al.*, "The ancestry and affiliations of Kennewick Man," *Nature,* vol. 523, no. 7561, pp. 455-458, 2015. https://doi.org/10.1038/nature14625

[10] M. Robbeets *et al.*, "Triangulation supports agricultural spread of the Transeurasian languages," *Nature,* vol. 599, no. 7886, pp. 616-621, 2021. https://doi.org/10.1038/s41586-021-04108-8

[11] H. Tomimatsu, S. R. Kephart, and M. Vellend, "Phylogeography of Camassia quamash in western North America: Postglacial colonization and transport by indigenous peoples," *Molecular Ecology,* vol. 18, no. 18, pp. 3918-3928, 2009. https://doi.org/10.1111/j.1365-294X.2009.04341.x

[12] Museum of Marching in Snow at Hakkoda Mountain, *Museum of Marching in Snow at Hakkoda Mountain.*Retrieved: http://www.moyahills.jp/koubataboen/. [Accessed December 10, 2021], 2017.

[13] R. B. Lee, *The! Kung San: Men, women and work in a foraging society*. Cambridge: Cambridge University Press, 1979.

[14] J. Tanaka, *The San: Hunter-gatherers of the Kalahari, a study in ecological anthropology*. Tokyo: University of Tokyo Press, 1980.

[15] M. Mauss and H. Beuchat, "Essay on seasonal variations: Eskimo societies: Study of social morphology," *The Sociological Year*, vol. 9, pp. 39–132, 1904.

[16] N. Kishigami, "*Far North people Canada Inuit* (*Kyokuhoku no Tami Canada Inuit*). Japanese: Kobundo, 1998.

[17] N. McArthur, I. Saunders, and R. Tweedie, "Small population isolates: A micro-simulation study," *The Journal of the Polynesian Society,* vol. 85, no. 3, pp. 307-326, 1976.

[18] M. I. Bird *et al.*, "Early human settlement of Sahul was not an accident," *Scientific Reports,* vol. 9, no. 1, p. 8220, 2019. https://doi.org/10.1038/s41598-019-42946-9

[19] G. D. Ruxton and D. M. Wilkinson, "Population trajectories for accidental versus planned colonisation of islands," *Journal of Human Evolution,* vol. 63, no. 3, pp. 507–511, 2012. https://doi.org/10.1016/j.jhevol.2012.05.013

[20] L. Henry, "Some data on natural fertility," *Eugenics Quarterly,* vol. 8, pp. 81–91, 1961. https://doi.org/10.1080/19485565.1961.9987465

[21] A. J. Coale and T. J. Trussell, "Model fertility schedules: Variations in the age structure of childbearing in human populations," *Population Index,* vol. 40, no. 2, pp. 185-258, 1974. https://doi.org/10.2307/2733910

[22] A. J. Coale, P. Demeny, and B. Vaughan, *Regional model life tables and stable populations,* 2nd ed. New York: Academic Press, 1983.

[23] K. Imazu, "Women's life cycle in ancient Japan. Open seminar. Interdisciplinary study on gender multi-layer," Retrieved: https://ousar.lib.okayama-u.ac.jp/files/public/5/56887/20190703101639578970/rpkj_2019_013_025.pdf. [Accessed December 11, 2021], 2016.

[24] M. Gurven and H. Kaplan, "Longevity among hunter-gatherers: A cross-cultural examination," *Population and Development Review,* vol. 33, no. 2, pp. 321–365, 2007. https://doi.org/10.1111/j.1728-4457.2007.00171.x

[25] M. Konner, "Hunter-gatherer infancy and childhood. In B. S. Hewlett & M. E. Lamb (Eds.), Hunter-gatherer childhoods." New York: Routledge, 2005, pp. 19–64.

[26] J. Racette, "Private communication," 2021.

[27] Russia Beyond, "Minorities in Russia," Retrieved: https://jp.rbth.com/arts/82393-roshia-choushousuu-minzoku. [Accessed December 11, 2021], 2019.

[28] C. J. Bradshaw *et al.*, "Minimum founding populations for the first peopling of Sahul," *Nature Ecology & Evolution,* vol. 3, no. 7, pp. 1057-1063, 2019. https://doi.org/10.1038/s41559-019-0902-6

[29] Statistics Canada, "National indigenous peoples day by the numbers," Retrieved: https://www.statcan.gc.ca/en/dai/smr08/2018/smr08_225_2018. [Accessed December 10, 2021], 2018.

[30] Government of Canada, "First nations," Retrieved: https://www.rcaanc-cirnac.gc.ca/eng/1100100013791/1535470872302. [Accessed December 10, 2021], 2021.

[31] A. H. Bittles and M. L. Black, "Consanguinity, human evolution, and complex diseases," *Proceedings of the National Academy of Sciences,* vol. 107, no. suppl_1, pp. 1779-1786, 2010. https://doi.org/10.1073/pnas.0906079106