

Chapter 10

Revisiting the Dynamics Between Two Ancient Japanese Descent Groups:

What Happened from the Jomon to the Yayoi Periods in Japan

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10.1 Introduction

The Yayoi period (300 BC–250 AD) was an era that marked the onset of rice-based agriculture in Japan. The Yayoi culture was established consequent to the integration of the Jomon hunter–gatherer culture, an antecedent of Yayoi culture, in the region. The agrarian culture is reported to have been imported from China-Korea. Additionally, investigations in anthropological morphology have revealed differences in human bones from the Yayoi period and the Jomon period (14,000 BC–300 BC). Therefore, it is believed that Chinese and Korean genetic influences on the Yayoi people were significant.

Thus, the presence of Chinese-Korean immigrants (*Trai-zin* in Japanese) was evidently of importance during the establishment of the Yayoi culture when agriculture became the social and economic foundation of society. However, several factors pertaining to these immigrants remain unclear within Japanese anthropology and archaeology. Specifically, these relate to the immigrants' place of origin, the initial immigrant population size, the sex ratio of the immigrants, and whether native Jomon people or immigrants played a formative role in the establishment of agrarian culture during the Yayoi period.

Anthropological and archaeological research indicates that the Korean Peninsula was the immigrants' place of origin. However, there are two competing hypotheses

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281

proposing that the immigrant population was either large or small in size. The difference between human bones of the Yayoi and Jomon periods provides the rationale for the hypothesis positing a larger immigrant population size. Hanihara (1987) has estimated that the total size of the immigrant population over a period of 1,000 years ranged from about 310 million people based on a back calculation of the estimated population during the subsequent period. In contrast, the hypothesis of a smaller immigrant population size at the beginning of the Yayoi period is based on the characteristics of pottery and stone tools which retained the characteristic style of the Jomon period. Consequently, the size of the immigrant population was not considered sufficiently large to change the characteristics of the pottery and stone tools at the beginning of the Yayoi period. Moreover, pottery and tools in the immigrant style predominated during the subsequent middle Yayoi period (200 BC–0 AD).

Regarding the sex ratio of the immigrants, a leading hypothesis postulates that the immigrants were primarily male (Kanaseki 1976). One reason for this hypothesis is that, as mentioned, the characteristics of pottery and stone tools retained the Jomon style at the onset of the Yayoi period. Tsude (1982) has stated that pottery was made by females during the Yayoi period. This contention was based on the emergence of an extensive body of ethnographic literature reiterating that pottery was made by females (Murdok and Provost 1973). Therefore, Japanese archeologists have generally accepted that pottery was made by females during ancient times. Based on these studies, they have argued that the female ratio of the immigrants was not sufficiently high to change the characteristics of pottery from the Jomon to the Yayoi style. Further, this hypothesis postulates that even if the population was large, given that immigrants were primarily male, the characteristics of pottery and stone tools did not evidence rapid change at the onset of the Yayoi period.

The most pertinent question of whether native Jomon people or Chinese-Korean immigrants played a formative role in the establishment of agrarian culture during the Yayoi period has long been a source of controversy. This is an important research problem within Japanese anthropology and archaeology (Fujio 1999). Some archaeologists have suggested that the native Jomon people assimilated the new agrarian culture, thus assuming a key role in Yayoi agrarian culture. However, as previously discussed, this assertion is based on the characteristics of pottery and stone tools which retained the Jomon style at the inception of the Yayoi period. Consequently, it has been assumed that the immigrant population was small in size and that native Jomon people, comprising the majority of the population, played a major role in establishing the Yayoi agrarian culture. Conversely, some anthropologists have insisted that during ancient times, Chinese-Korean immigrants to Japan brought with them a systematic agrarian culture. As the population grew, their descendants became the key players in establishing the Yayoi agrarian culture (Kataoka and Iizuka 2006). This insistence can once again be attributed to differences found in human bones of the Yayoi and Jomon periods, revealed through investigations in anthropological morphology. Based on this finding, the immigrant population size was assumed to be sufficiently large to have had a significant

genetic impact. Thus, according to this view, immigrants played a predominant role in the evolution of Yayoi agrarian culture. However, this dualistic conception has recently been revised. It is now thought that the evolution of the agrarian society was a collaborative process that was initiated by both Jomon people and immigrants (Fujio 1999).

To resolve these problems, an examination of population trends and of the food production systems of the Jomon people and of the descendants of the immigrants since the inception of agriculture is required. However, in the Northern Kyushu region where the agrarian culture took root, human bone material from the late Jomon period (1000 BC–300 BC) up to the early Yayoi period (300 BC–200 AD) is missing, despite the onset of the agrarian culture during this time.

10.2 Related Work

Nakahashi and Iizuka (1998, 2008) have provided insights into the initial size of the immigrant population and which group played a formative role in establishing Yayoi agrarian culture, based on their discriminant analysis of human bone material. They have indicated that people bearing similar traits to those of the immigrants accounted for approximately 80 % of the total population during the middle Yayoi period. Furthermore, they applied a mathematical equation model to propose features of ancient population dynamics up to the middle of the Yayoi period. Considering the differences in the population growth rates of the native Jomon people (0.1 % per annum) and immigrants (1.3 % per annum), they suggested that even a small number of immigrants could account for the large majority that prevailed a few hundred years later. That is, in contrast to conventional studies, these studies have demonstrated the possibility that even a small initial immigrant population could explain why anthropological investigations of the morphology of human bones have revealed differences during the Yayoi and Jomon periods. Kataoka and Iizuka (2006) have also estimated the population growth rate based on the inhabitants of excavated houses, determined by house plans, site locations, and settlement composition. They have suggested that only immigrants could account for the large majority that prevailed a few hundred years later. Therefore, only the immigrants could have played a key role in establishing the Yayoi agrarian culture.

These studies (Nakahashi and Iizuka 1998, 2008; Kataoka and Iizuka 2006) are remarkable in that they have adopted a quantitative approach, using mathematical models, to present objective results. However, a few unresolved issues remain. First, these studies are premised on a model that partially segregates native Jomon people and immigrants. Even assuming the composition of a mixed group of Jomon people and immigrants, a small sized mixed group population has been estimated with a low ratio of native Jomon people within the group. This assumption would be unreasonable if there was no barrier prohibiting marriage and inter-group contact, and if mating was possible between Jomon people and immigrants. That is, the effects of random mating between these groups have been ignored. Second, these

studies have assumed that genetic traits and the food production system were not separated. Therefore, they did not consider the diffusion of the food production system. The fertility rate of a population depends on its food production system (Bentley et al. 1993). Thus, it is possible that the population growth rate also depended on a subsistence culture. These studies are, therefore, unable to address the fundamental question of who played a formative role in the establishment of the agrarian culture.

Additionally, the immigrant sex ratio remains an important unresolved factor. As previously mentioned, one leading hypothesis postulates that the immigrants were primarily male (Kaneseiki 1976), based on the assumption that pottery and stone tools were primarily produced by females (Tsude 1982), and on the evident characteristics of pottery and stone tools that retained the Jomon style at the onset of the Yayoi period. This implies that, if native Jomon females produced pottery, then male immigrants mated with native Jomon females. Nakahashi and Iizuka (1998, 2008) have calculated that the majority of females in the mixed group population comprising native Jomon people and immigrants were Jomon females. However, these studies originally assumed the existence of a small mixed group. Thus, they were unable to estimate the sex ratio of the totality of immigrants. Furthermore, this hypothesis is inconsistent with studies that show that the haplotype frequency of the maternal mitochondrial DNA (mtDNA) of Jomon people differs significantly from that of people of the Yayoi period because of the genetic influence of Chinese-Koreans (Shinoda 2006). We, therefore, posit that the low ratio of immigrant females made it difficult to change the frequency of mtDNA between Jomon people and people of the Yayoi period. That is, at the beginning of the Yayoi period, the argument that pottery and stone tools retained the characteristics of Jomon style is inconsistent with the significant changes that occurred in the haplotype frequency of mtDNA between populations of the Jomon and Yayoi periods. Therefore, the problem of the immigrant sex ratio cannot be resolved through the application of a conventional static model.

In this study, we propose an alternative view of Japanese history using agent-based modeling techniques instead of using the mathematical model developed by Nakahashi and Iizuka (1998, 2008). In formulating this model, based on the reviewed literature, we assumed the following four points: (1) A large number of native Jomon people and a small number of Chinese-Korean immigrants coexisted in the Northern Kyushu region. (2) During the 300 years that followed immigration, people bearing immigrant traits accounted for 80 % of the total population. (3) The model incorporates both random mating and random diffusion of the agrarian culture. (4) We further examined the immigrant sex ratio by adding the pottery style and mtDNA inheritance. We used these assumptions and agent-based simulation (ABS) to examine the issue of who played a formative role in establishing Yayoi agrarian culture.

10.3 The Simulation Model

Our simulation model follows the Overview, Design concepts, and Details (ODD) protocol (Grimm et al. 2010). This protocol is intended to address the criticism that agent-based models lack reproducibility. Furthermore, it aims to improve the integrity and standardization of the model description.

10.3.1 Agent and State Variables

The agent in our model was defined as an ancient person with the following variables.

10.3.1.1 Identity (ID) Number and Spatial Placement

The following information was assigned to an agent: an *ID number* and a *coordinate position* (X: 50 cells, Y: 50 cells) within a two-dimensional space. This space represented only the Northern Kyushu region (a small portion of Japan) and not the entire chain of Japanese islands. The Northern Kyushu region is situated close to the Korean Peninsula and is the location where agriculture was first introduced and from where it rapidly diffused outward. In our simulation model, the simulation space is so abstract that the model space is not directly related to the real geographical one. Our study intends to provide an alternative perspective regarding the conclusions offered by Nakahashi and Iizuka (1998, 2008). Thus, we mainly focus on discussing the relative diffusion between agrarian culture and trait genes. Further, as described below, the diffusion speed of agriculture in our simulation model is determined by the probability of agricultural introduction and the range of diffusion. Therefore, considering the gene flow relative to the speed of agricultural diffusion, this abstract space is sufficient to discuss the issues at hand. The size of the space within our simulation is determined by the speed of diffusion of agrarian culture as described below.

10.3.1.2 Sex

The agent was *Male* or *Female*.

10.3.1.3 Life Expectancy and Age

Upon creation (birth), an agent was given a *life expectancy* based on the mortality table. If the *age* of the agent exceeded the *life expectancy*, the agent was removed

(died). We created the mortality table by reflecting an infant mortality rate of 20 % up to recent years on that of the Jomon people (Nagaoka et al. 2008). We also presumed in our simulation model that the mortality table was the same for both the Yayoi and Jomon people.

10.3.1.4 Food Production System

The food production system variables were *hunting and gathering* or *agriculture*. This system changed from *hunting and gathering* to *agriculture* through the diffusion of agriculture based on the assumption that the cold climate from the late Jomon to the early Yayoi period introduced an opportunity for this conversion process (Miyamoto 2009). However, we assumed that the opposite condition did not hold, because there is no evidence of the diffusion of hunting and gathering during this period in the literature.

10.3.1.5 Marriage Institution

The marriage institution variable for the male agent was *monogamous* or *polygamous* for the Yayoi period. Polygamous marriage was assumed to occur based on descriptions of this type of marriage contained in “Gishi-Wazin-Den,” an ancient Chinese text on Yayoi period customs. According to this text, some men of high status had four or five wives, and there were even some men of normal status who had two or three wives. To date, the type of marriage institution that prevailed during the Jomon period has not been ascertained. While both polygamy and polyandry may have existed during this period, the mathematical model formulated by Nakahashi and Iizuka (1998, 2008) assumed that monogamy prevailed among the Jomon people. Therefore, to present a clear alternate perspective in our study, we also assumed that monogamy was the marriage institution of the Jomon people. Additionally, we postulated that sustaining more than one wife—polygamous marriage—requires a surplus of food. Therefore, in our simulation model, if the male agent included both of the following variables: *polygamous* and a high yielding food production system, namely *agriculture*, then the agent was assumed to be married to three female agents. A new agent (child) inherited the father agent’s marriage institution.

10.3.1.6 Pottery Style

The pottery style variable was either the *Jomon style* or the *immigrant style*. In our simulation model, for the sake of convenience, we restricted the pottery style to either the Jomon or immigrant styles. We assumed a continuous change in the characteristics of the pottery style and focused on the issue of which style was

dominant. This did not mean that the distinction between these two styles was a discontinuous one.

The argument made by Tsude (1982) that females produced pottery during the Yayoi period is supported by an extensive ethnographic literature (Murdok and Provost 1973). Therefore, within the field of Japanese archaeology, it has generally been held that females produced pottery during ancient times. Additionally, Tanaka and Ozawa (2001) have discussed how cultural diffusion occurred through a vertical transmission process within society during the Yayoi period. Based on these descriptions in the literature, we assumed in our simulation model that the new agent (child) borne by a female inherited the mother agent's pottery style.

10.3.1.7 Trait Genes

Trait genes determine trait characteristics. Originally, it was thought that trait characteristics are determined through the involvement of many genes in a complex manner. However, to simplify this for the simulation, in our simulation model, following Nakahashi and Iizuka (1998, 2008), it is assumed to be composed of a major pair of alleles: the Jomon-type gene (J) and immigrant-type gene (T). When a new agent (child) is created (born), the agent inherits either of the father agent's and either of the mother agent's alleles. That is, the combination of alleles of an agent is JJ, TT, or JT. In accordance with these combinations, each agent is classified as one with Jomon or immigrant traits. Specifically, a JJ agent comprises traits of the Jomon people, a TT agent comprises immigrant traits, and a JT agent displays mixed traits (mixed people). Mixed people are also determined as those comprising a given ratio of immigrant traits.

10.3.1.8 mtDNA Macrohaplogroup

The mtDNA macrohaplogroup variable for an agent was *macrohaplogroup N* or *macrohaplogroup M*. The mtDNA, which is the cell organelle DNA of mitochondria, is inherited maternally and is relatively easy to extract from human bone remains. Therefore, mtDNA analysis is a useful way of investigating the origin of the maternal line of ancient peoples. The mtDNA of East Asian populations has been broadly classified into two groups: macrohaplogroup N and macrohaplogroup M (Kivisild et al. 2002; Kong et al. 2003). Results of mtDNA analyses of human bone remains have recently been compiled in Japan. The frequency of mtDNA macrohaplogroups N and M indicates major differences between people of the Jomon and Yayoi periods (Shinoda 2006). Specifically, for populations during the Jomon period, the frequency of mtDNA macrohaplogroups N and M were each about 50 %. In contrast, for populations during the Yayoi period, the frequency of mtDNA macrohaplogroups N and M were about 20 % and 80 %, respectively. In our simulation model, when a new agent (child) was created (born), the agent inherited the mother agent's mtDNA macrohaplogroup as described below.

10.3.2 *Process Overview and Scheduling*

Our simulation model proceeded according to annual time steps. Thus, the annual time step was a year. Each year, the three submodels of each agent were executed in turn as follows: diffusion of the agrarian culture rule, the marriage rule, and the moving rule. Additionally, agents were processed in a random order during each year.

10.3.3 *Design Concepts*

Our simulation model corresponded to seven out of the eleven design concepts contained in the ODD protocol (Table 10.1). The model was simple, and we considered that the description of the model and design concepts were sufficient to indicate reproducibility.

10.3.4 *Submodels*

10.3.4.1 *Diffusion of the Agrarian Culture Rule*

The diffusion of agrarian culture occurred through neighboring agents and inheritance from a parent agent. In our simulation model, we assumed that these very simple patterns of cultural transmission followed the conventional susceptible-infectious (SI) model of infectious diseases.

In the case of diffusion from a neighboring agent, if the agent's food production system was *hunting and gathering*, while that of all the other neighboring agents was *agriculture* within a given cell radius (the extent of diffusion occurring within a cell range was: one cell [narrow], three cells [moderate], and five cells [wide]), the agent's food production system would then be transformed into *agriculture*. This transformation was based on a given probability (introduction rate: impossible [0 %], difficult [0.1 %], middle [0.5 %], and easy [1.0 %]). Conversely, in the case of inheritance from a parent agent, and according to the marriage rule described below, when a new agent (child) was created (born), the agent inherited the food production system from either the father or mother agent. In this study, inheritance from the father or mother agent was simulated.

10.3.4.2 *Marriage Rule*

A new agent (child) was created (born) as a result of the marriage of a male and a female agent. The male agent was married to a female agent randomly selected

Table 10.1 Design concepts

No.	Design concepts	Elements
1	Basic principles	Trait gene, mitochondrial DNA (mtDNA) haplogroup, and pottery style was diffused under the increased population based on the food production system by the diffusion of agriculture
		• For the diffusion of agrarian culture, we apply the infection model (SI model)
		• For the increase of people, we apply Malthus' theory
		• For the inheritance of the trait gene, we apply Mendel's laws
2	Emergence	Diffusion of agrarian culture changes the composition ratio of each trait gene type of agrarian culture holders, the diffusion ratio of Jomon-style pottery and the frequency of mitochondrial DNA macrohaplogroup M
3	Adaptation	If an agent is near the other agent with agrarian culture, it introduces an agrarian culture in a given rate
4	Sensing	• Recognizing whether a male agent is near the other agent with agrarian culture
		• Recognizing whether an agent is near the female agent
5	Stochasticity	• Life expectancy
		• Spatial placement at the start of the simulation
		• Allocation of mtDNA macrohaplogroup at the start of the simulation
		• Introduction of agriculture
		• Selection of female agent for marriage
		• Sex of child agent
		• Combination of trait gene
		• Move in random direction
6	Collectives	Number of agents created is determined by the number of agents with "hunting and gathering" and "agriculture"
7	Observation	• Ratio of people with immigrant trait
		• Diffusion ratio of agrarian culture
		• Composition ratio of each descendant of agrarian culture holders
		• Diffusion ratio of Jomon-style pottery
		• Frequency of mitochondrial DNA macrohaplogroup M

from all of the female agents within three surrounding cells. Furthermore, a new agent was created according to the population growth rate of the mother agent's food production system and at the same spatial placement as that of the mother agent. The sex of the new agent was allocated according to a 50 % probability of being male or female, along with a life expectancy and age of 0. For the trait gene, as previously explained, the new agent inherited either of the father agent's alleles and either of the mother agent's alleles. Additionally, the new agent inherited the food production system from either the father or mother agent, the marriage institution from the father agent, and the pottery style and mtDNA

macrohaplogroup from the mother agent. Moreover, as mentioned earlier, the male agent could be simultaneously married to three female agents only when associated with both the *polygamous* and *agriculture* variables.

10.3.4.3 Moving Rule

Within each step, an agent moved one cell in random directions within the simulated space.

10.3.5 Initialization

10.3.5.1 Time Span of the Simulation

The time span of our simulation was 300 years (300 steps), extending from the early to the middle Yayoi period. This value was the same as that of the calculated representative example in Nakahashi and Iizuka (1998, 2008). While a new hypothesis, based on Accelerator Mass Spectrometry radiocarbon dating, postulates the start of the Yayoi period to be 500 years earlier than the date suggested by conventional hypotheses, no clear conclusions have been reached. Therefore, in this study, the time span was 300 years which is a more stringent condition for a demographic transition in which the small size of the immigrant population could account for the large majority a few hundred years later.

10.3.5.2 Population Growth Rate Based on the Food Production System

The population growth rate of agriculturalists was higher than that of hunters and gatherers. We simulated two cases relating to the growth rate of each of the above populations as follows. The growth rate of each population for the first (high rate) case had the same value as that of the example of a representative calculation provided by Nakahashi and Iizuka (1998). The growth rate for each population in the second (low rate) case exhibited the lowest value shown in Nakahashi and Iizuka (1998).

- First (high rate) case: the growth rate of the hunting and gathering population was 0.1 % per year, while that of the agriculturalist population was 1.3 % per year.
- Second (low rate) case: the growth rate of the hunting and gathering population was 0.1 % per year, while that of the agriculturalist population was 0.5 % per year.

10.3.5.3 Speed of the Diffusion of Agrarian Culture

The speed of diffusion of agrarian culture in our simulation model comprised the range of cells associated with the diffusion and introduction rate. The range of diffusion cells corresponded to the distance within which cultural exchange would occur while they were in contact with each other. We assumed three degrees: narrow (one cell), moderate (three cells), and wide (five cells). The introduction rate corresponded to the difficulty associated with the introduction of an agrarian culture. Here, we assumed four degrees: impossible (0 %), difficult (0.1 %), medium (0.5 %), and easy (1 %). The level of difficulty did not relate to agricultural techniques, but rather to the adequacy of the environment and culture required for the acceptance of the new agrarian culture. These values were set assuming that even when the range of cells was narrow and the introduction rate was difficult, approximately 300 years were required for the majority of agents to have agriculture.

10.3.5.4 Inheritance of the Food Production System from a Parent

The inheritance of a food production system from a parent was unknown. Therefore, to investigate the extent to which the simulation result was impacted by inheritance from either the father or the mother, we simulated two cases as follows.

- First case (father): a new agent (child) inherited the food production system from the father agent.
- Second case (mother): a new agent inherited the food production system from the mother agent.

10.3.5.5 State Variables of the Initial Jomon People and Immigrants

The simulation run commenced with the initial Jomon people and immigrants whose state variables are described below.

Initial Jomon People

- Trait gene: *JJ*
- Food production system: *hunting and gathering*
- Marriage Institution: *monogamous*
- Pottery style: *Jomon style*
- MtDNA macrohaplogroup: with reference to Shinoda (2006), 50 % had *macrohaplogroup N* and 50 % had *macrohaplogroup M*.

Initial Immigrants

- Trait gene: *TT*
- Food production system: *agriculture*
- Marriage institution: *monogamous* or *polygamous* in each simulation case
- Pottery style: *immigrant style*
- MtDNA macrohaplogroup: In total, 62.5 % had *macrohaplogroup M* and 37.5 % had *macrohaplogroup N*. The haplogroup frequency of the immigrants' mtDNA is unknown. However, because immigrants are believed to have arrived via the Korean Peninsula, in this study, the frequency of macrohaplogroups within the current population of the Korean Peninsula (Shinoda 2006) was considered to be the same as that of the immigrants.

10.3.5.6 Spatial Placement of the Initial Jomon People and Immigrants

It is assumed that the immigrants initially arrived from northern coastal areas at the earliest stage. Therefore, in this study, the first immigrants were densely positioned in one area at the start of the simulation run. To investigate the extent to which the simulation result was influenced by this assumption, we simulated two cases pertaining to the spatial placement of the initial Jomon people and immigrants as follows.

- First (dense distribution) case: the initial Jomon people were uniformly randomly placed, while the initial immigrants were placed in the center of the upper side of the simulated space (X: 25, Y: 50), assuming that they came from the northern coastal area.
- Second (dispersed distribution) case: Both the initial Jomon people and immigrants were uniformly randomly placed.

10.3.5.7 Initial Numbers of Jomon People and Immigrants

The initial number of Jomon people was 200 agents and that of immigrants was 1,800 agents referring to the ratio of 9:1 of initial Jomon people and immigrants shown by Nakahashi and Iizuka (1998) in their example of a representative calculation. We set these absolute numbers of agents as the minimum numbers that were sufficient for matching the results of the numerical calculation provided by Nakahashi and Iizuka (1998) with those of our simulation runs. We used the same population growth rates but did not include the gene flow and agricultural diffusion between the two populations.

10.3.5.8 Sex Ratio of Initial Jomon People and Immigrants

A leading hypothesis states that the immigrants were primarily male (Kenasaki 1976). Therefore, to examine the sex ratio of the initial immigrants, we simulated three cases for the initial immigrants' sex ratio as follows. By contrast, the ratio of Jomon males and females was equal.

- First case (same): the number of males among the initial immigrants was 100 agents and the number of females was also 100 agents.
- Second case (more): 150 male agents and 50 female agents among the initial immigrants.
- Third case (majority): 175 male agents and 25 female agents among the initial immigrants.

10.3.5.9 Ratio Determining Mixed *JT* Individuals as Those with Immigrant Traits

If agents were genetically mixed, possessing the *JT* trait gene, then they displayed immigrant traits according to the given ratio. We simulated two cases for this ratio as follows.

- First case (100 %): individuals with immigrant traits at 100 %.
- Second case (50 %): individuals with immigration traits at 50 %.

In the first case, the individuals were determined to be immigrants based on the assumption that a person with even a small amount of immigrant traits is an immigrant.

10.3.6 *The Number of Simulation Cases and the Evaluation Index*

The total number of simulation cases was 441. This figure refers to cases combining each of the above parameters (Table 10.2) added to the representative example of a simple increase of calculation shown in Nakahashi and Iizuka (1998). The simple increase of calculation is a model based on the assumption that numbers of Jomon people and immigrants increased separately without random mating and cultural exchange occurring between them.

For the number of simulation runs, cases that combined a 1.3 % agriculturalist population growth rate with a dispersed spatial distribution of the initial Jomon people and immigrants were run once, considering computational costs. The other cases were run ten times. The random seed value of these ten runs was the same across cases.

Table 10.2 Values of parameters

Initialization parameters	Values
Time span of simulation	[300 years (steps)]
Population growth rate of hunting and gathering people	[0.1 %]
Population growth rate of agricultural people	[1.3 %], [0.5 %]
Range of cells of the diffusion	[Narrow: 1 cell], [Moderate: 3 cells], [Wide: 5 cells]
Introductory rate of agrarian culture	[Impossible: 0 %], [Difficult: 0.1 %], [Middle: 0.5 %], [Easy: 1.0 %]
Inheritance of food production system from a parent	[Father], [Mother]
Institution of marriage of the initial Jomon people	[Monogamous]
Institution of marriage of the initial immigrants	[Monogamous], [Polygamous]
Spatial placement of the initial Jomon people	[Dispersed distribution]
Spatial placement of the initial immigrants	[Dispersed distribution], [Dense distribution]
Sex ratio of the initial immigrants (Male, Female)	[Same: 100, 100], [More: 150, 50], [Majority: 175, 25]
Sex ratio of the initial Jomon people (Male, Female)	[900, 900]
Ratio determines the mixed people as those with immigrant traits	[100 %], [50 %]

The main evaluation index in our simulation results was the ratio of people with immigrant traits across all agents. Regarding the demographic transition that occurred during the middle Yayoi period, Nakahashi and Iizuka (1998) reported that 80 % or more people had immigrant traits. Therefore, determining whether this figure was close to 80 % or more after 300 years (steps) provided a measure of demographic transition in our simulation. In this study, we referred to the ratio of people with immigrant traits for each run of each case. Additionally, in simulation cases entailing demographic transition, to assess which group played a formative role in Yayoi agrarian culture, we depicted a time series of the diffusion ratio of agrarian culture and the composition ratio of each descendant of the agrarian culture holders.

The diffusion ratio of immigrant-style pottery and the frequency of the mtDNA macrohaplogroup M among the cases were also compared. We assumed that at the onset of the Yayoi period most pottery retained the characteristics of the Jomon style, with the immigrant-style pottery achieving predominance during the middle Yayoi period. Thus, starting with a situation in which immigrant-style pottery was

less prevalent compared with Jomon-style pottery, we investigated whether the diffusion ratio of the immigrant-style pottery was higher 300 years later. Furthermore, considering that the frequency of macrohaplogroup M within the population during the Yayoi period was about 80 %, we determine whether the frequency of mtDNA macrohaplogroup M was higher 300 years later.

10.4 Results and Discussion

Of the 441 simulated cases, 111 demonstrated that more than 80 % of people exhibited immigrant traits after 300 years (steps). In the case of the representative example of a simple increase of calculation provided by Nakahashi and Iizuka (1998), based on the assumption that numbers of Jomon people and immigrants increased separately without random mating and cultural exchange occurring between them, 78.9 % of people had immigrant traits. This case did not include random mating and cultural exchange between native Jomon people and immigrants. The simulation result was very similar to the numerical calculations of Nakahashi and Iizuka (1998) based on the same population growth rate. Therefore, the result showed that the calculation of our simulation model was consistent with that of the mathematical model and that the initial absolute number of agents was appropriate.

In the following sections, we refer to differing results for cases relating to the spatial placement of the initial immigrants, the marriage institution, speed of the diffusion of agriculture, and sex ratio. Consequently, we only describe the results of cases combining inheritance of the food production system from the mother and 100 % determination of *JT* mixed individuals as those with immigrant traits.

10.4.1 *Spatial Placement of the First Immigrants*

In cases where both the initial Jomon people and immigrants were uniformly randomly placed, less than 80 % of people had immigrant traits. This could be used as a measure of demographic transition (Figs. 10.1 and 10.2). A summary of the results for cases combining a 1.3 % agricultural population growth rate and a dispersed distribution of the spatial placement of the initial Jomon people and immigrants is presented in Fig. 10.1. Considering other simulation results, even if these were each run 10 times, the stochasticity would not significantly change the ratio of people with immigrant traits after 300 years and we would observe less than 80 %.

In general, cases in which the speed of the diffusion of agrarian culture was slow (e.g., a narrow [one cell] range of diffusion cells and a difficult introduction rate

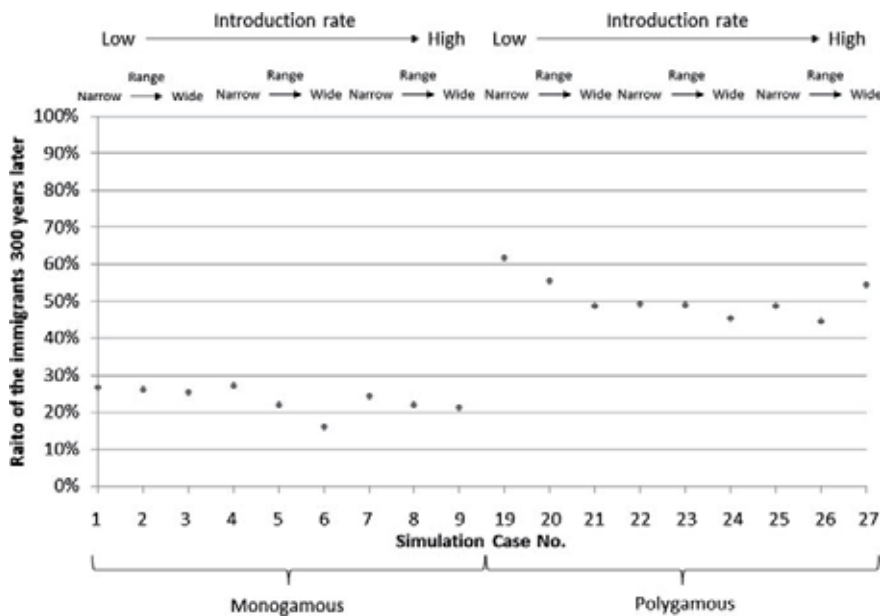


Fig. 10.1 Percentages of people with immigrant traits after 300 years in cases combining dispersed distribution, a 1.3 % agricultural population growth rate, and equal numbers of males and females

[0.1 %]) indicated a higher ratio of people with immigrant traits. Conversely, cases in which the speed of the diffusion of agrarian culture was rapid (e.g., a wide [five cells] range of diffusion cells and an easy introduction rate [1 %]) indicated a lower ratio of people with immigrant traits.

Some cases indicated the dense distribution of immigrants, with 80 % of people exhibiting immigrant traits 300 years later. This served as a measure of the demographic transition (Figs. 10.3 and 10.4). The immigrants in these cases were all *polygamous*. We elaborate on these cases in the following sections.

Demographic transition did not occur in cases where both the initial Jomon people and immigrants were uniformly randomly placed because there were many points of diffusion of agrarian culture. During an early stage, agrarian culture diffused among the native Jomon people and there was a high rate of increase of agriculturalists within the Jomon population. Therefore, even when the population growth rate of agriculturalists differed, the same result was obtained (Figs. 10.3 and 10.4). To generate demographic transition in which people with immigrant traits reached 80 % 300 years later, our results show that population densities of immigrants were probably high and that only a section of the neighboring native Jomon population made contact with them.

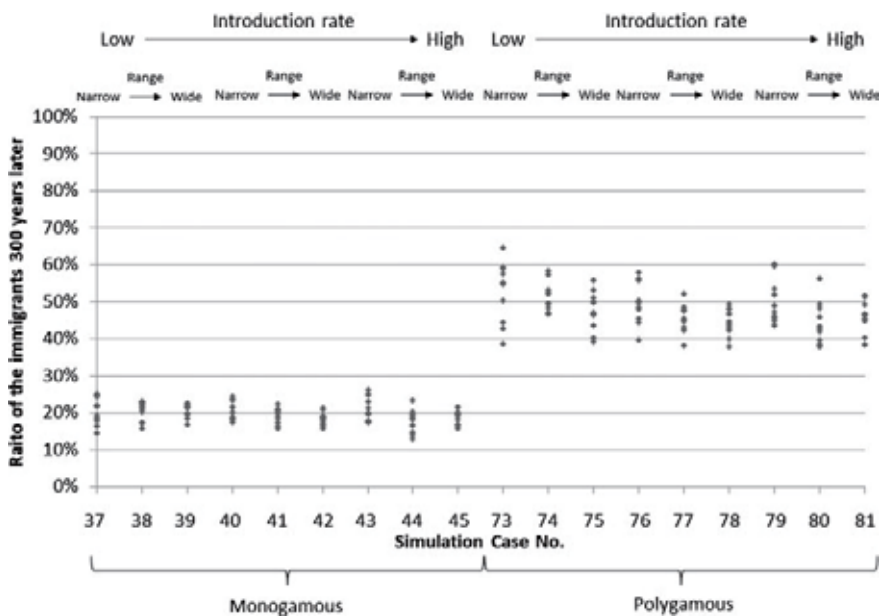


Fig. 10.2 Percentages of people with immigrant traits after 300 years in cases combining dispersed distribution, a 0.5 % agricultural population growth rate, and equal numbers of males and females

10.4.2 Marriage Institution and Speed of Agricultural Diffusion

10.4.2.1 Cases of Monogamous Marriage and Diffusion from Neighboring Agents

For cases combining dense distribution of immigrants, monogamous marriage, and the diffusion of agriculture from neighboring agents, the percentage of people with immigrant traits, 300 years later, was below the 80 % figure that indicated demographic transition (Figs. 10.3 and 10.4). The reason is the same as that described earlier. Once an agrarian culture had diffused among native Jomon people at an early stage, their population increased at the high rate of agricultural population growth. Therefore, cases entailing the slow diffusion of agrarian culture also indicated a high ratio of people with immigrant traits, while cases entailing the rapid diffusion of agrarian culture evidenced a low ratio of people with immigrant traits. Considering these results, even if we assume that preferential marriage occurred within the population, because the agrarian culture was diffused among native Jomon people, when the trait gene was diffused only within the population, demographic transition would not have occurred.

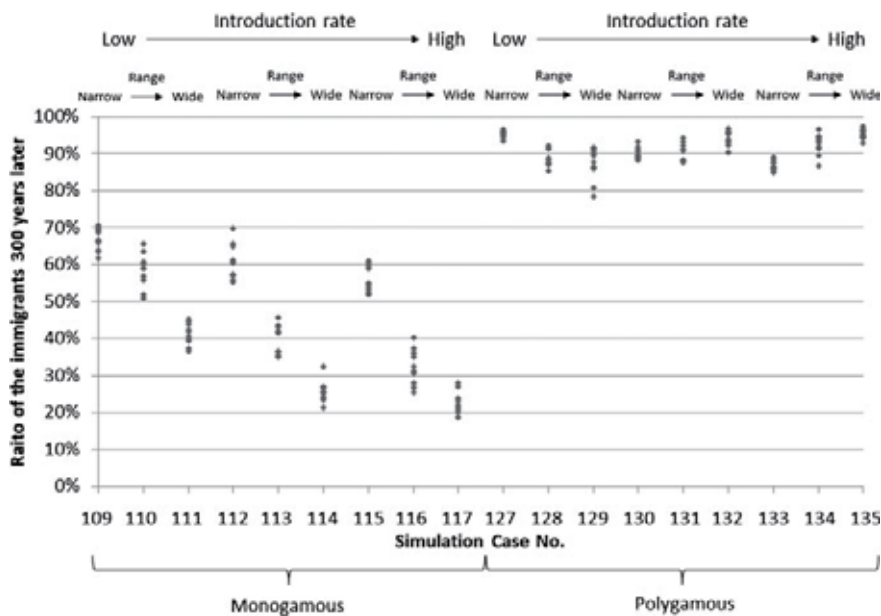


Fig. 10.3 Percentages of people with the immigrant traits after 300 years in cases combining dense distribution, a 1.3 % agricultural population growth rate, and equal numbers of males and females

10.4.2.2 Polygamous Marriage and Exclusive Inheritance from a Parent Agent

There were cases entailing polygamous immigrants and inheritance of the agrarian culture from only a parent agent (not diffused from a neighboring agent). Even with a lower growth rate (0.5 %) of the agriculturalist population, in some cases of immigrants reached the 80 % 300 years later (Fig. 10.4, No. 194). If the initial immigrants were polygamous, demographic transition would be probable. Additionally, considering these results, even if the population growth rate of agriculturalists was low (0.5 %), it would be sufficient to infer that demographic transition had occurred. That is, demographic transition in which people with immigrant traits came to constitute the majority a few hundred years later could occur through the diffusion of the trait gene within polygamous marriage, assuming the low population growth rate of agriculturalists. Given that agricultural technology had not attained maturity at this time, a 1.3 % agriculturalist population growth rate may be considered too high. Therefore, these results indicate high consistency for demographic transition even with a low growth rate of the agricultural population. Additionally, as described above, if we accept the hypothesis that the inception of the Yayoi period was 500 years earlier than commonly thought, even the lower rate of population growth could generate demographic transition.

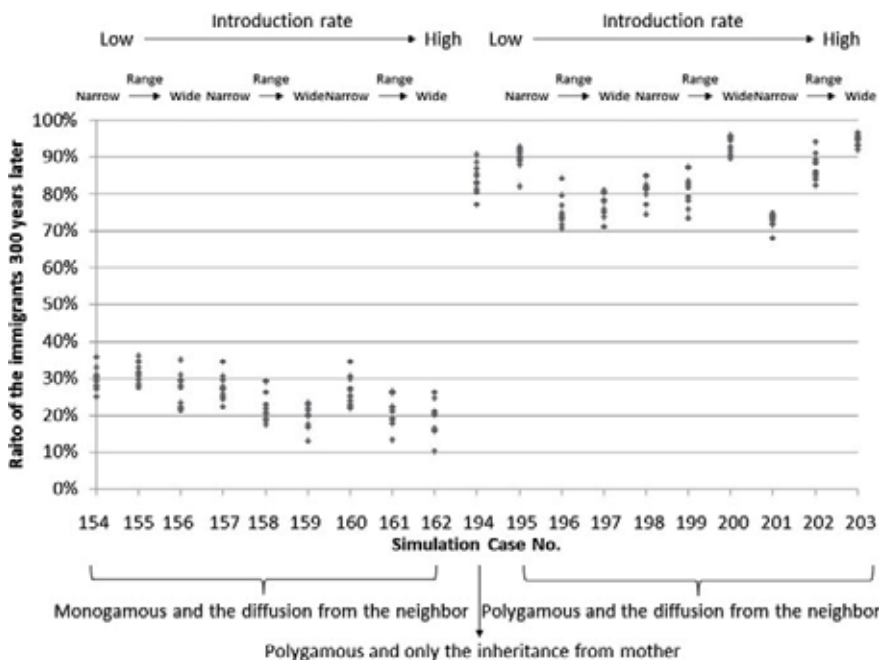


Fig. 10.4 Percentages of people with immigrant traits after 300 years in cases combining dense distribution, a 0.5 % agricultural population growth rate, and equal numbers of males and females

However, in these cases, the diffusion rate of the agrarian culture was very low (about 25 %) after 300 years, because the agrarian culture was only inherited from either the father or mother. Moreover, the composition ratio of descendants of these agriculturalists consisted of immigrants or both immigrants and Jomon people. These cases suggest, as our first hypothesis, that *immigrants played a formative role in the establishment of agrarian culture*.

10.4.2.3 Polygamous Marriage and Diffusion from Neighboring Agents

We now turn to cases entailing polygamous immigrants and agriculture that was not only inherited from a parent agent, but also diffused from neighboring agents. In such cases, the percentage of people with immigrant traits after 300 years varied depending on the speed of the diffusion of agrarian culture. When the population growth rate of agriculturalists was 0.5 % (the lower rate), some cases of slow-speed diffusion of agrarian culture did not attain the 80 % figure for people with immigrant traits after 300 years (Fig. 10.4). By contrast, cases demonstrating a significant speed of agrarian culture diffusion evidenced 80 % of the population with immigrant traits after 300 years. When the population growth rate of the

agriculturalists was 1.3 % (the higher rate), regardless of the speed of the agrarian culture diffusion, 80 % of individuals in all cases evidenced immigrant traits after 300 years (Fig. 10.3). Nevertheless, the rapid speed of the diffusion of agrarian culture exceeded the percentage of people with immigrant traits 300 years later.

These results demonstrate that in cases in which polygamous marriage was combined with the diffusion of agriculture, demographic transition was facilitated by the wider diffusion of agrarian culture. This could be attributed to a time lag between the diffusion of agrarian culture and polygamous marriage, which influenced the increasing populations of Jomon people and immigrants. Specifically, the density distribution of immigrants meant that the number of immigrants increased during the earliest stage, and that in this process, the agrarian culture diffused among the Jomon people. However, polygamous marriage remained an immigrant trait because it was inherited from fathers. Consequently, the neighboring Jomon people came to possess an agrarian culture. Furthermore, in a situation in which immigrant neighbors, engaged in an agrarian culture, displayed a higher population growth rate, the immigrant trait gene type was diffused through polygamous marriage. That is, for wider diffusion of the immigrant trait gene type to occur, it was necessary for immigrant neighbors to demonstrate an agrarian culture and a higher population growth rate.

The composition ratio of descendants of those practicing an agrarian culture showed a slight degree of mixing of Jomon people and immigrants in cases that entailed slow diffusion of the agrarian culture at the early stage. Both groups of descendants thus came to account for most of those engaged in an agrarian culture by marriage (Fig. 10.5). These results suggest, as our second hypothesis, that *immigrants played a formative role in the establishment of agrarian culture*.

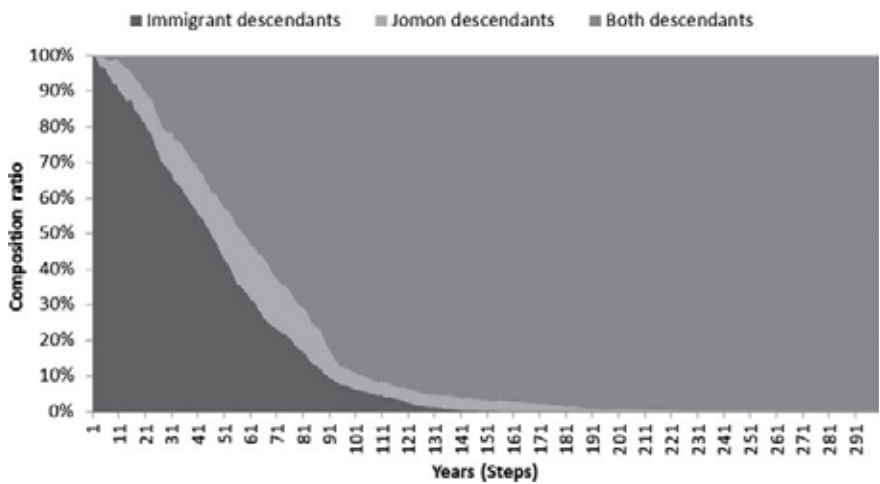


Fig. 10.5 Composition ratio of agrarian culture holders (No. 196)

In contrast, for cases demonstrating significant and rapid diffusion of the agrarian culture, and demographic transition, at the earliest stage, only the descendants of immigrants were the holders of the agrarian culture. However, shortly thereafter, Jomon descendants constituted the majority (Fig. 10.6). Consequently, both immigrant and Jomon descendants became the majority group through marriage. These results indicate that it is probable that even if the agrarian culture was widely diffused among the Jomon people, demographic transition could occur. These results suggest, as our third hypothesis, that *Jomon people played a formative role in the establishment of agrarian culture*.

10.4.3 Sex Ratio of Initial Immigrants

In general, cases involving primarily male immigrants demonstrated a slightly higher ratio of individuals with immigrant traits after 300 years than cases with equal numbers of males and females (Fig. 10.3 Nos. 127–135, Fig. 10.4 Nos. 195–203, Figs. 10.7 and 10.8). This was irrespective of the population growth rate of agriculturalists and the inheritance of agriculture either from the father or mother. However, regarding immigrant-style pottery, cases in which immigrants were primarily male after 300 years showed a lower ratio (Figs. 10.9, 10.10, and 10.11). Conversely, these results showed that even if the number of female immigrants was small, immigrant-style pottery predominated after 300 years. In our simulation study, we only considered the vertical transmission of a pottery style. Had we also considered horizontal transmission, the diffusion of the immigrant-style pottery

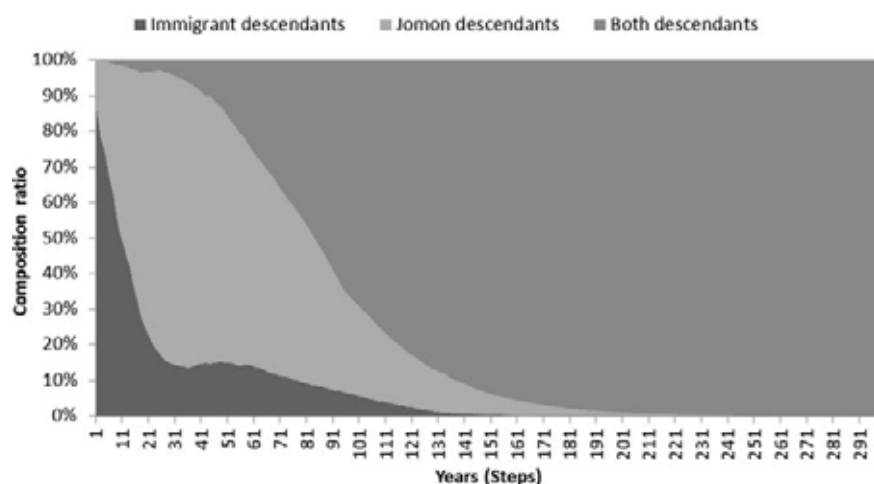


Fig. 10.6 Composition ratio of agrarian culture holders (No. 203)

would, in this case, have evidenced wider distribution than was indicated in our study. This would have more closely approximated the actual situation.

Moreover, regarding the frequency of the mtDNA macrohaplogroup, we found no clear difference between cases in which immigrants were primarily male and cases entailing equal numbers of males and females (Figs. 10.12, 10.13, and 10.14). The reason for this result was that the frequency of the mtDNA macrohaplogroup was largely influenced by random genetic drift. Conversely, these results show that when the immigrants were primarily male, the haplogroup frequency of the maternal mtDNA could significantly change. Our results indicate that even when the number of female immigrants was one-tenth that of female Jomon people, the frequency of the mtDNA macrohaplogroup changed significantly when the number of immigrants increased.

Based on these findings, it is evident that our simulation did not provide clear results regarding the sex ratio of the initial immigrants. On the one hand, when we examine the simulation results for the percentage of people with immigrant traits after 300 years, our results support the hypothesis that the immigrants were primarily male. On the other hand, when we examine the simulation results regarding the prevalence of immigrant-style pottery after 300 years, our results do not support the hypothesis that the immigrants were primarily male.

However, we only considered the vertical spread of the pottery style through inheritance from the mother. We did not consider the horizontal spread of a pottery

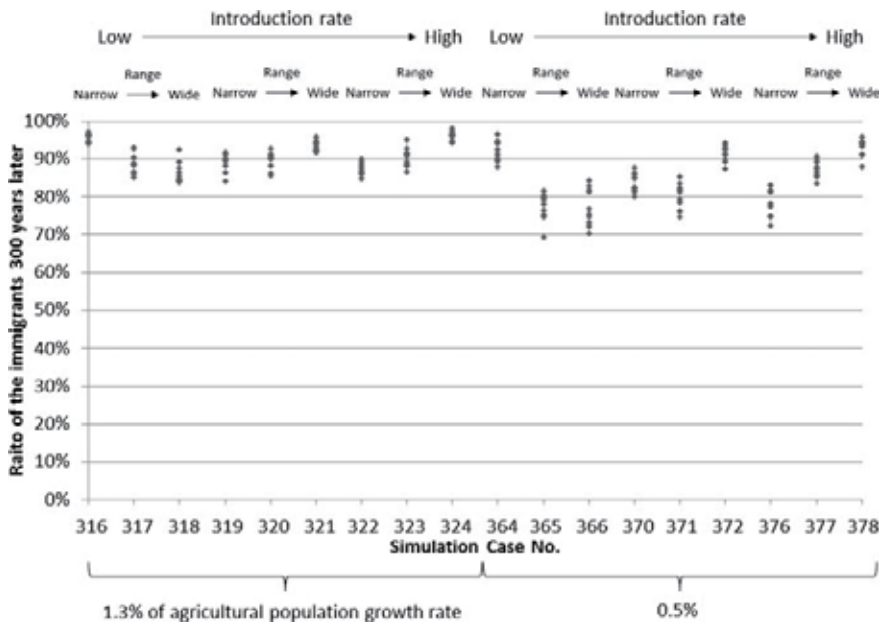


Fig. 10.7 Percentages of people with immigrant traits after 300 years in cases with more males than females

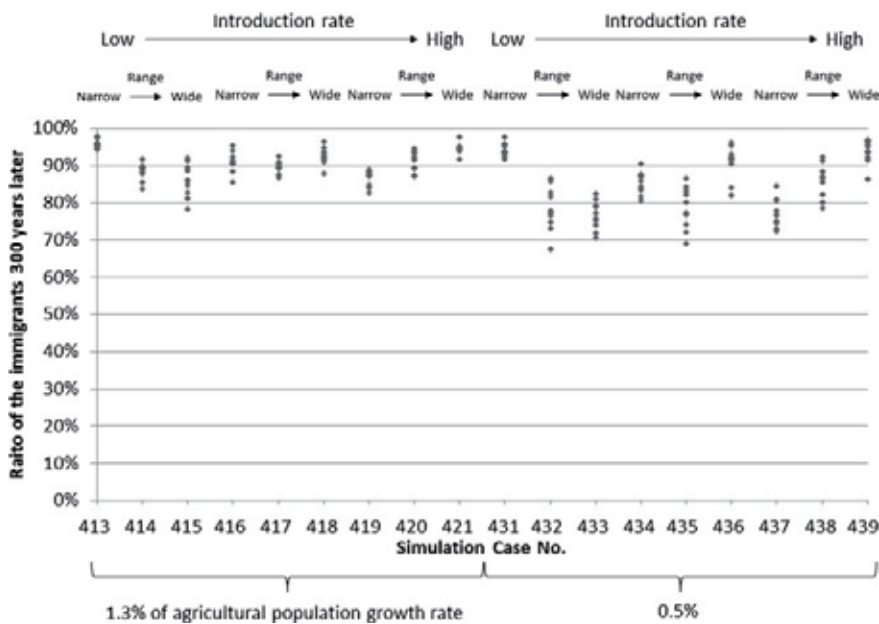


Fig. 10.8 Percentages of people with immigrant traits after 300 years in cases with a majority of males

style through diffusion from neighbors. Therefore, considering only the vertical spread of a pottery style in our simulation model led to a clear finding of a higher ratio of immigrant-style pottery 300 years later compared with the model described in our study. Much remains unknown regarding the manner of diffusion of a pottery style. Thus, our simulation model was inadequate in this regard, leaving room for improvement.

Therefore, considering the other more conclusive findings, our simulation results support the hypothesis that the immigrants were primarily male.

10.4.4 Who Played a Formative Role in the Establishment of Agrarian Cultures?

We now return to the problem of who played a formative role in the establishment of agrarian cultures during the Yayoi period. We simulated a situation initially entailing the coexistence of a large number of native Jomon people and a small number of immigrants, and the subsequent predominance of people with immigrant traits who accounted for 80 % of the total population a few hundred years later. The results of our simulation indicated the three probable cases described above. In the first, immigrants were polygamous and the agrarian culture was only inherited from

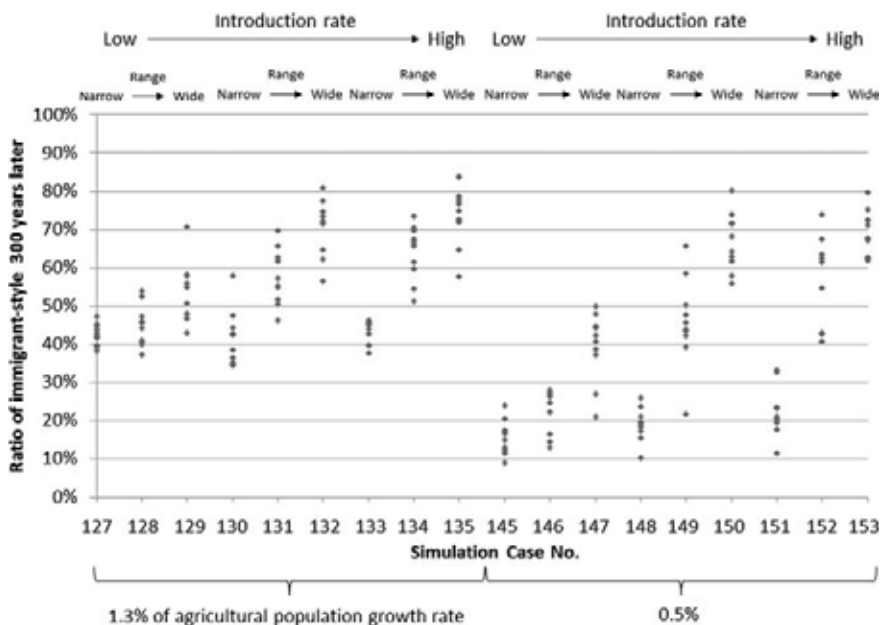


Fig. 10.9 Percentages of immigrant-style pottery after 300 years in cases with equal numbers of males and females

a parent agent (not diffused from neighboring agents). In this case, the descendants of agriculturalists at an early stage were either immigrants or both immigrants and Jomon people. Thus, immigrants played a formative role in the establishment of an agrarian culture. In the second case, immigrants were polygamous and the agrarian culture was inherited from a parent agent as well as diffused from neighboring agents. However, the diffusion of the agrarian culture occurred slowly. In this case, the descendants of the agriculturalists at an early stage were mostly immigrants with few Jomon people. As in the first case, immigrants played a formative role in the establishment of an agrarian culture. In the last case, the diffusion of the agrarian culture was significantly more rapid. In this case, the majority of descendants of agriculturalists were immigrants at the earliest stage, but shortly thereafter, Jomon descendants were evident during a subsequent early stage. Here, mostly Jomon people and a few immigrants played a formative role in the establishment of an agrarian culture.

Of these three probable cases, the last is the most consistent with anthropological and archaeological evidence for the following reasons. In the first case, the diffusion rate of agriculture was too low. Considering that the diffusion of agrarian culture began in the North Kyushu region, it is implausible to assume that the diffusion ratio at the place of origin of agriculture in Japan was low. Comparing the second and third cases, even when the population growth rate of agriculturalists was high, the rapid speed of diffusion of the agrarian culture was higher in the percentage of

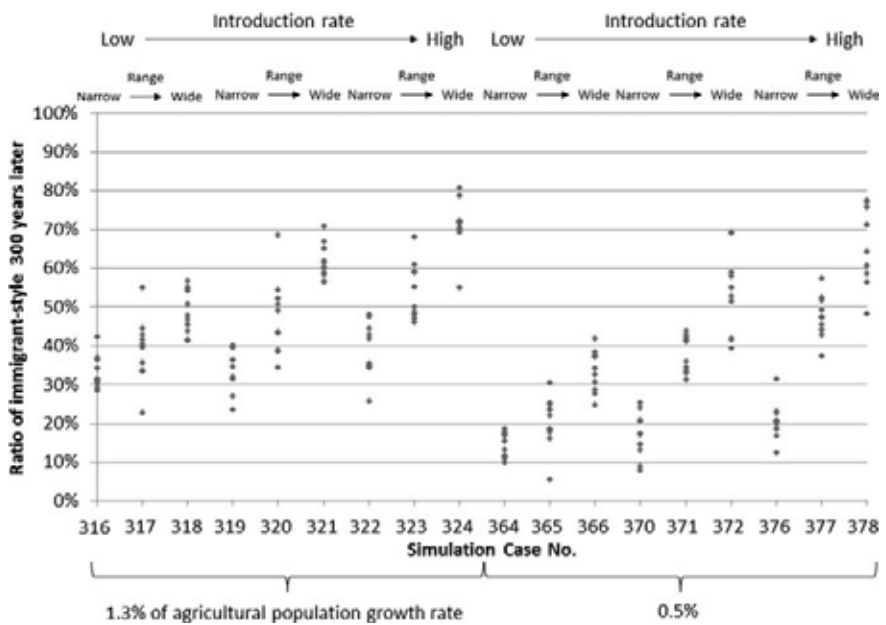


Fig. 10.10 Percentages of immigrant-style pottery after 300 years in cases with more males than females

people with immigrant traits after 300 years. When the population growth rate of agriculturalists was low, some of the cases demonstrating slow diffusion of the agrarian culture did not attain the 80 % figure in relation to immigrants after 300 years. As previously mentioned, considering that agricultural technology had not reached maturity at that time, the 1.3 % population growth rate of agriculturalists may have been too high. Therefore, the highest consistency occurred regarding cases in which even a lower population growth rate could generate demographic transition through rapid diffusion of the agrarian culture. Additionally, our investigation of immigrant-style pottery after 300 years revealed that the number of cases of rapid diffusion of agrarian culture exceeded that of cases demonstrating slow diffusion (Figs. 10.9, 10.10, and 10.11). However, in relation to immigrant-style pottery after 300 years, there were slightly fewer cases in which immigrants were primarily male (Fig. 10.3 No. 127–135, Fig. 10.4 No. 195–203, Fig. 10.7, and Fig. 10.8). However, of note is the finding that even when only inheritance of pottery style from the mother was considered, and the number of female immigrants was small, our simulation results indicated the predominance of immigrant-style pottery after 300 years.

Thus, our simulation results are consistent with anthropological and archaeological evidence that people with immigrant traits became the majority. In cases of rapid diffusion of agrarian culture, even if immigrant males constituted a majority and females were a minority, the immigrant-style pottery prevailed.

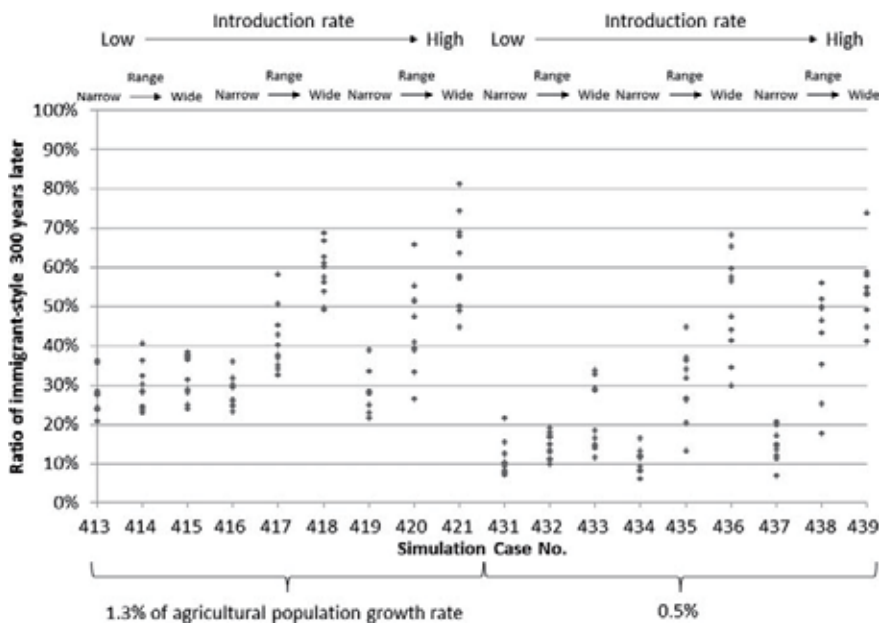


Fig. 10.11 Percentages of immigrant-style pottery after 300 years in cases with a majority of males

10.5 Concluding Remarks and Future Research

In this paper, we have described ABS and discussed its application in relation to historical and archaeological literature. We presented a simple model and extreme settings aimed at enhancing understanding of the factors affecting the behavior of the simulation results. Our results showed that in the case of initial coexistence of a large number of native Jomon people and a small number of immigrants, people with immigrant traits became the majority group a few hundred years later. Based on the simulation results, we offered three conjectures, or new falsifiable hypotheses for further discussion. The first relates to the following hypotheses: the population density of immigrants was high, and only a section of the neighboring native Jomon people made contact with them. Immigrants were polygamous and primarily male. Another conjecture related to the hypothesis that when an agrarian culture diffused among the native Jomon people, it was mostly Jomon people and only a few immigrants who played a formative role in the establishment of an agrarian culture.

Regarding the hypothesis that the population density of immigrants was high and that only a section of the neighboring native Jomon people made contact with them, there is no archaeological evidence that indicates the existence of an immigrant-only colony (Fujio 1999; Nakahashi and Iizuka 1998). However, our results relating to this hypothesis could be explained by an extremely low population density of Jomon people at the time that resulted in immigrant settlements

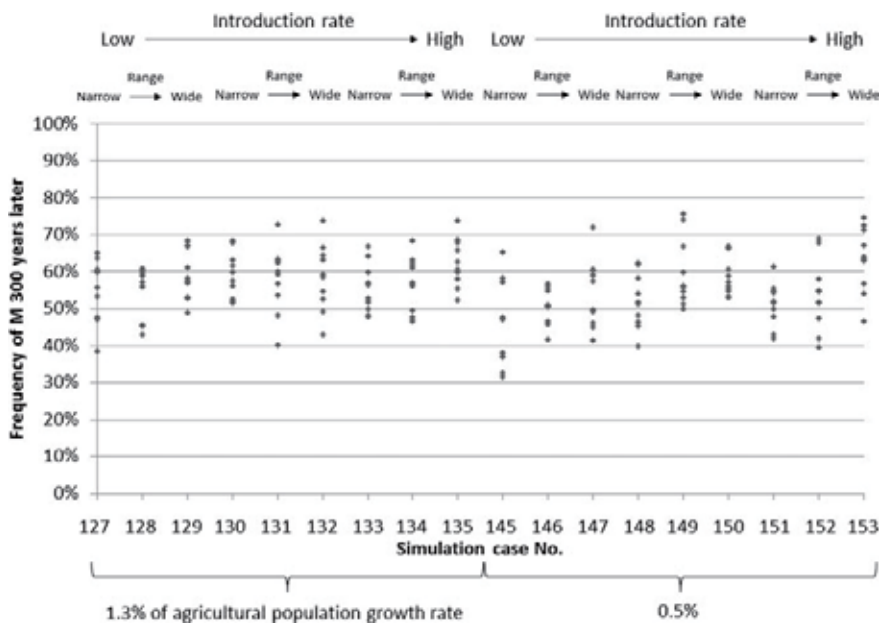


Fig. 10.12 Frequencies of macrohaplogroup M after 300 years in cases with equal numbers of males and females

(Kataoka and Iizuka 2006). There is also the possibility that the Jomon population significantly decreased, as evidenced by the small number of remains of the late Jomon period (Koyama 1984).

The discovery of bone remains of people with Jomon traits, along with artifacts verifying the existence of an agrarian culture, could support the hypothesis that when agriculture diffused among native Jomon people, it was mostly Jomon people and a few immigrants who played a formative role in the establishment of an agrarian culture. In fact, although agricultural artifacts have not been found, human bone remains characteristic of Jomon people were discovered in a Korean-style tomb at the Otomo site in Northern Kyushu.

Our simulation results indicate that mostly Jomon people and a few immigrants played a formative role in the establishment of an agrarian culture during the Yayoi period. This finding shows that within a context in which even a small number of immigrants generated demographic transition (Nakahashi and Iizuka 1998, 2008), the idea that agricultural society was a collaborative process initiated by both Jomon people and immigrants making up a living population (Fujio 1999) is highly plausible.

The hypotheses examined in this study have only offered some probabilities. The results of our simulation were generated through the application of a model based on several assumptions, with some of the simulation parameters based on those of Nakahashi and Iizuka (1998, 2008). These include the following: pottery was

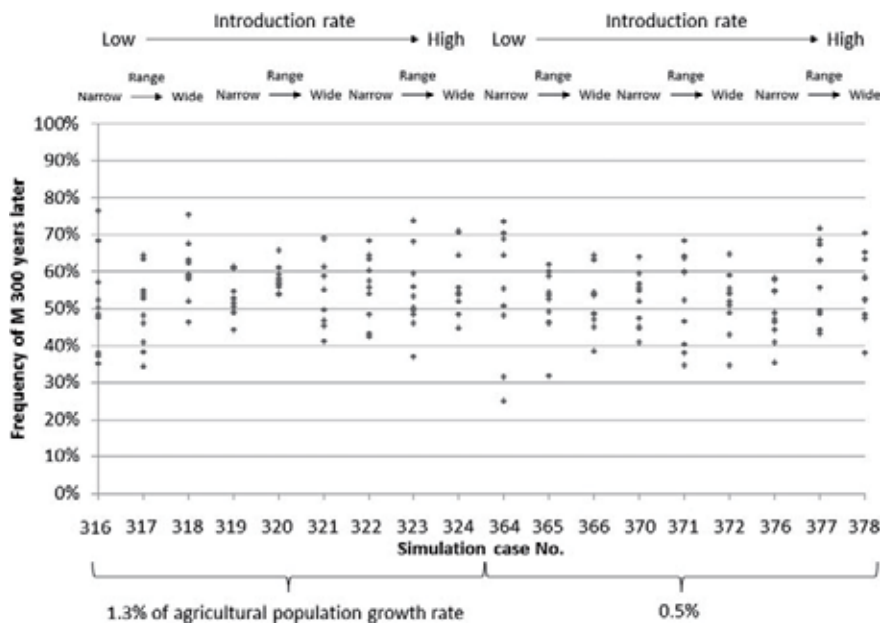


Fig. 10.13 Frequencies of macrohaplogroup M after 300 years in cases with more males than females

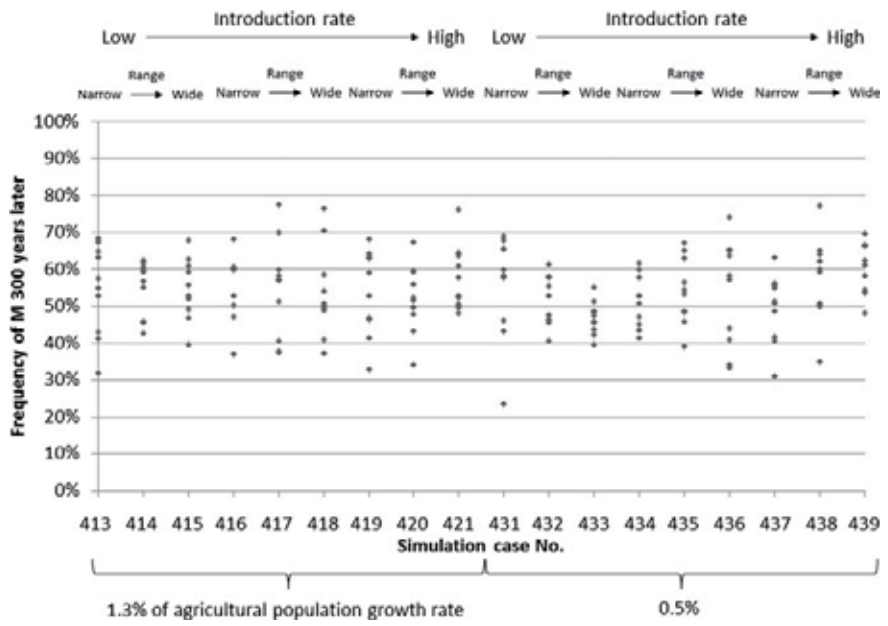


Fig. 10.14 Frequencies of macrohaplogroup M after 300 years in cases with a majority of males

inherited matrilineally, monogamy was the marriage institution within Jomon society, polygamy necessitated highly productive agriculture, and cultural transmission was based on a very simple pattern vis-à-vis the SI model of infectious diseases. These results could change if we employed different assumptions. These assumptions require further discussion as future issues. In the near future, some assumptions will be clarified through the analysis of ancient DNA. Specifically, an analysis of the diversity of Y chromosomes (paternally inherited) and mitochondrial DNA (maternally inherited) from human remains within a settlement will answer the question of whether the marriage institution within Jomon society was monogamy, polygamy, or polyandry. Additionally, the percentage of immigrants after 300 years, a prerequisite of our simulation, relied on the results of Nakahashi and Iizuka (1998). Therefore, any variation of the discriminant used in their study would require a different interpretation of the results of our study. It should be noted that demographic transition may also be caused by plague and war in addition to differing population growth rates. However, because there is no archaeological evidence to support these events (Nakahashi and Iizuka 1998), they were not considered in our simulation model.

The first objective of this study was to explore new simulation cases that matched the archeological evidence, and to investigate their underlying processes. Therefore, this paper does not include a detailed discussion of the validation work related to the exploration of the parameters. However, to investigate which conditions accord with archaeological evidence, further parameter tuning should be performed. These include developing regression trees with a random forests algorithm that could uncover which variables are more or less important, as well as Bayesian approximation methods that could isolate relevant parameter combinations. We have also proposed the pattern-oriented inverse simulation method in another history simulation study of ancient Chinese empires, which uses advanced evolutionary algorithms and high performance computation techniques (Yang et al. 2012). These methods are promising in terms of strengthening the application of our ABM approach to historical studies. The application of these advanced techniques offers considerable challenges to be addressed in our future work.

In conclusion, we believe that the ABS model and results of this study are widely applicable beyond the time frame and region of our investigation. The present study engages with the universal theme of population dynamics that unfolded after the introduction of agrarian culture. Furthermore, this study is the first to apply ABS to this anthropological and archeological issue in Japan. Within Japanese anthropology and archaeology, it is difficult to apply the ABS developed in famous pioneering studies on factors relating to the residential transition of the Anasazi tribe (Dean et al. 2000). For most anthropological and archaeological studies in Japan, the required data, especially paleo-environmental records, are not widely available as for these studies. However, even if there are less data available, as for the current study, ABS is able to compensate for this paucity of data. Therefore, it has the potential to become a powerful tool within Japanese anthropology and archaeology.

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