Journal of Archaeological Science 132 (2021) 105420

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: www.elsevier.com/locate/jas

Population pressure and prehistoric violence in the Yayoi period of Japan

Tomomi Nakagawa [a], Kohei Tamura [b,c], Yuji Yamaguchi [d], Naoko Matsumoto [e], Takehiko Matsugi [f], Hisashi Nakao [a,g,*]

[a] *Anthropological Institute, Nanzan University, Japan*
[b] *Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Japan*
[c] *Center for Northeast Asian Studies, Tohoku University, Japan*
[d] *Archaeological Research Center, Okayama University, Japan*
[e] *Research Institute for the Dynamics of Civilizations, Okayama University, Japan*
[f] *National Museum of Japanese History, The Graduate University for Advanced Studies, Japan*
[g] *Department of Anthropology and Philosophy, Nanzan University, Japan*

ARTICLE INFO

Keywords:
Conflict
Warfare
Japan
Burial jar (*kamekan*)
Yayoi period

ABSTRACT

The causes of prehistoric inter-group violence have been a subject of long-standing debate in archaeology, anthropology, and other disciplines. Although population pressure has been considered as a major factor, due to the lack of available prehistoric data, few studies have directly examined its effect so far. In the present study, we used data on skeletal remains from the middle Yayoi period of the Japanese archipelago, where archaeologists argued that an increase of inter-group violence in this period could be explained by a population-pressure hypothesis. We quantitatively examine the effect of population pressure on the frequency of inter-group violence by compiling an exhaustive data set. We collected demographic information based on burial jars (*kamekan*) and the frequency of violence based on the ratio of injured individuals. The results are consistent with the hypothesis, i.e., high population density can promote inter-group violence.

1. Introduction

The origin of inter-group violence, occasionally referred to as 'warfare', has been a pivotal question in anthropology, archaeology, and other disciplines since the seventeenth century, one often involved in arguments about human nature (Hobbes [1651] 2014; Rousseau [1755] 2009). In addition to a general bioarchaeological interests in violence (e.g., Arkush and Allen 2006; Carman and Harding 1999; Cybulski 1992; LeBlanc 1999; Martin and Harrod 2012; 2015; Redfern 2016), among scholars assuming a warlike predisposition in humans, many have argued the presence of various triggers for inter-group violence, and while not mutually exclusive, a large number of such hypotheses have been proposed: a change in subsistence strategies from hunting and gathering to agriculture (e.g., Guilaine and Zammit 2004; Nolan, 2003), the development of weapons (e.g., Bingham 2000; Otterbein 2004), ecological constraints (e.g., Allen et al., 2016; Ember and Ember 1992; Hsiang et al., 2011; Keeley 1996; Otterbein 2004; Scheffran et al., 2012), phylogeny (e.g., Wrangham and Peterson, 1996; Wrangham and Glowacki 2012; Glowacki et al., 2020), population pressure (e.g., Carneiro 1970; Gat 2008; Nolan 2003; Oka et al., 2017; Turchin and Korotayev 2006), social hierarchy or structure (e.g., Kelly 2000; Flannery and Marcus 2003; Zefferman and Mathew 2015), and so on.

The population pressure hypothesis has received a great deal of attention recently, often in combination with ecological constraints and climatic changes. This posits that a population increase can result in resource scarcity, leading to competition over resources. By analyzing the standard cross-cultural sample by Murdock and White (1969), Nolan (2003) claimed that population pressure can profoundly affect the frequency of warfare in hunter-gatherer and farming societies. Turchin and Korotayev (2006) developed a mathematical model and applied it to several historical data sets, the result of which is consistent with the population pressure hypothesis. Oka et al. (2017) also used various kinds of published anthropological data to argue that population size indirectly caused increases in the conflict casualties. However, for the aim of the present study, i.e., the origin of inter-group violence, few of the relevant studies are quantitatively based on actual archaeological data with some notable exceptions like Allen et al. (2016) and Kohler et al. (2014), which combine bioarchaeological data of skeletal remains with environmental productivity, and political hierarchy or population data to investigate the causes of prehistoric violence in central California

* Corresponding author. Department of Anthropology and Philosophy/Anthropological Institute, Nanzan University, Japan.
E-mail address: hisashinakao@gmail.com (H. Nakao).

https://doi.org/10.1016/j.jas.2021.105420
Received 2 July 2020; Received in revised form 24 May 2021; Accepted 24 May 2021

and prehispanic farmers.

The northern Kyushu region of Japan has received much attention for investigations of inter-group violence in the Japanese archipelago. The subsistence strategy in the Yayoi period (800 cal BC to AD 250 CE), wet rice cultivation, was introduced by immigrants from the Korean peninsula along with weapons such as stone arrowheads and daggers, resulting in enclosed settlements accompanied by warfare or large-scale inter-group violence (e.g., Sahara 1986; Nakahashi 2005; Hashiguchi 2007; Matsugi 2007; Terasawa 2000). As indicated by recent exhaustive surveys of skeletal remains in Japan (Nakao et al., 2016, 2020; Nakagawa et al., 2017), this represents a significant increase in the frequency of violence compared with the population of the preceding Jomon period, pottery makers who followed a complex hunter-gatherer lifestyle and exhibited low levels of mortality due to conflict, in contrast with anthropological and ethnographical studies arguing the ubiquity of inter-group violence among present and prehistoric hunter-gatherers (e.g., Keeley 1996; LeBlanc 2003; Bowles 2009; Frayer and Martin 1997; Allen and Allen 2006; 2014; Allen and Jones 2014; Schwitalla et al., 2014; Lahr et al., 2016). The number of skeletal remains with trauma out of the total samples is 23 out of 2576 for the Jomon period and 100 out of 3298 for the Yayoi period. Chi-squared tests showed statistically significant differences between the two periods, i.e., χ^2 (1, N = 5874) = 32.286, $p < .001$ though the effect size is small (V = 0.074) (Nakagawa et al., 2017). In addition to evidence for intensified violence in the Yayoi period, Nakagawa et al. (2017) reported that injured skeletal remains tended to cluster in the Kinki region (the central area of the Japanese archipelago) and northern Kyushu region (in the southern part of the archipelago) of the Middle Yayoi period (350 cal BC to AD 25 CE).

The northern Kyushu Yayoi data offer further advantages for investigating issues of violence. Some Japanese archaeologists and anthropologists have argued that population pressure may have been an important driver behind increased inter-group violence in the Yayoi period (e.g., Nakahashi 2005; Hashiguchi 2007; Matsugi 2007; Ozawa 2008). The custom prevalent in northern Kyushu of burying individuals in large jar coffins, known as *kamekan*, provides a wealth of relatively well-preserved skeletal remains that are readily dated typologically,

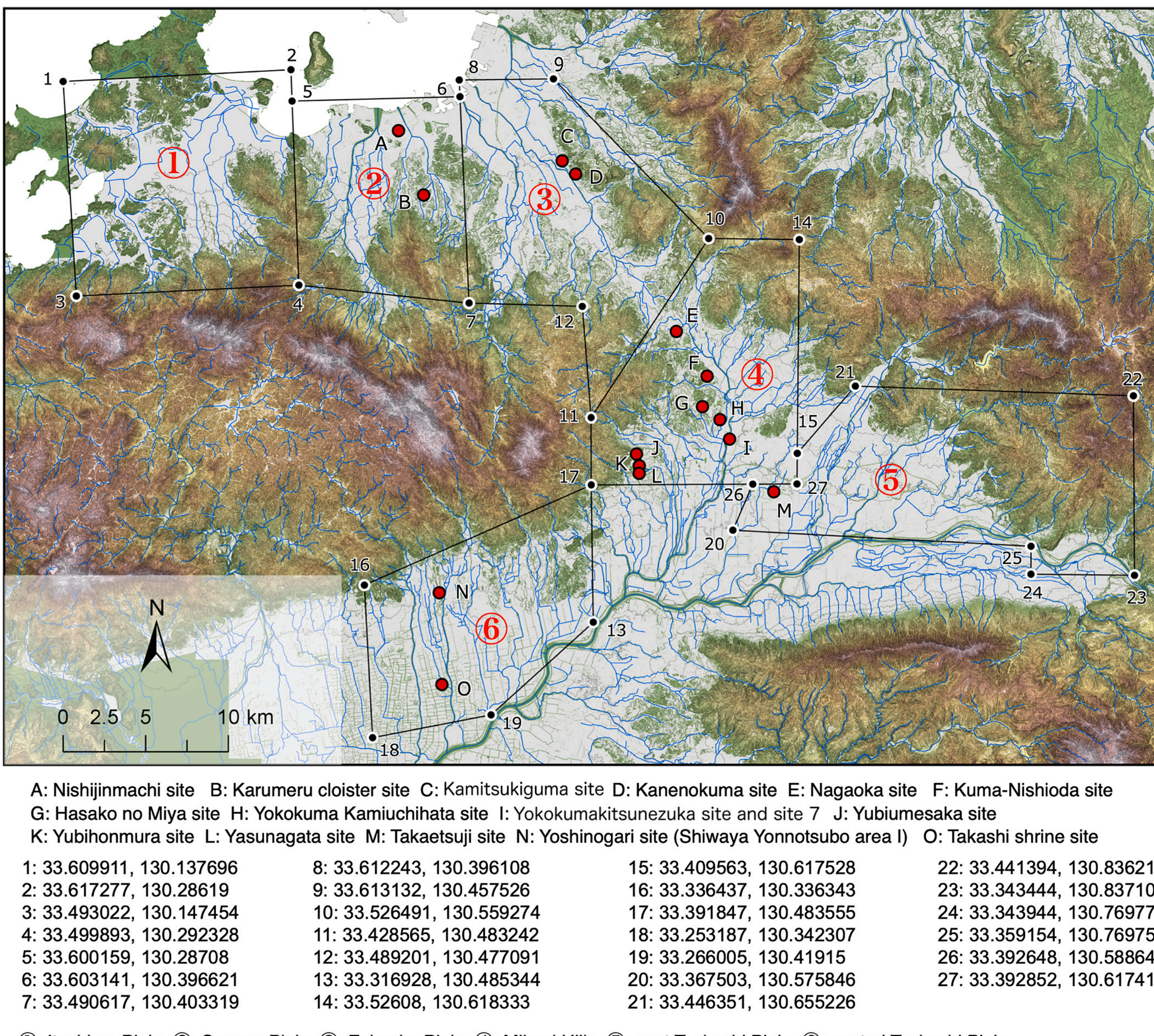


Fig. 1. Detailed map of the six areas. The map is based on the Digital Elevation Model by the Geospatial Information Authority of Japan and created through the ArcGIS Pro 2.3 (https://www.esri.com/arcgis/products/arcgis-pro/overview) (created by YY).

facilitating inferences on demographic trends.

In the present study, we used these data on skeletal remains and jar coffins to examine the origins of violence in northern Kyushu in the Middle Yayoi period because we have the most reliable set of evidence in this period. The jar burial custom was not fully developed in the Early Yayoi period and it quickly disappeared in the Late Yayoi period. We inferred demographic changes, on the one hand, using the numbers of well-dated burial jars as a proxy for population size, and estimated population pressure from the ratio of population to arable land. We also inferred the frequency of violence from the percentages of injured individuals identified within the skeletal population. We then statistically examined the relationship between population pressure and the frequency of violence, finding a positive correlation which suggests that population pressure promoted higher levels of violence.

2. Materials and methods

We focused our data collection on six subregions in northern Kyushu (Fukuoka Plain, Mikuni Hills, Itoshima Plain, Sawara Plain, east Tsukushi Plain, and central Tsukushi Plain, see Fig. 1), where (i) burial jars were commonly used and thus available as a proxy for demographic information, (ii) rescue and academic excavations have been exhaustively conducted, and so the situation at that time is relatively clear and the data is reliable, and (iii) the typology and chronology of the jars have been well developed. These subregions have been regarded as relatively distinctive units both culturally and geographically (e.g., Hashiguchi 2007; Shichida 2017; Terasawa 2000; Ozawa 2002, 2008). It has been often claimed that the northern subregions, such as Itoshima, Fukuoka, and Sawara Plains, constituted a kind of 'chiefdom', and many have argued that the southern subregions had large base sites, such as the

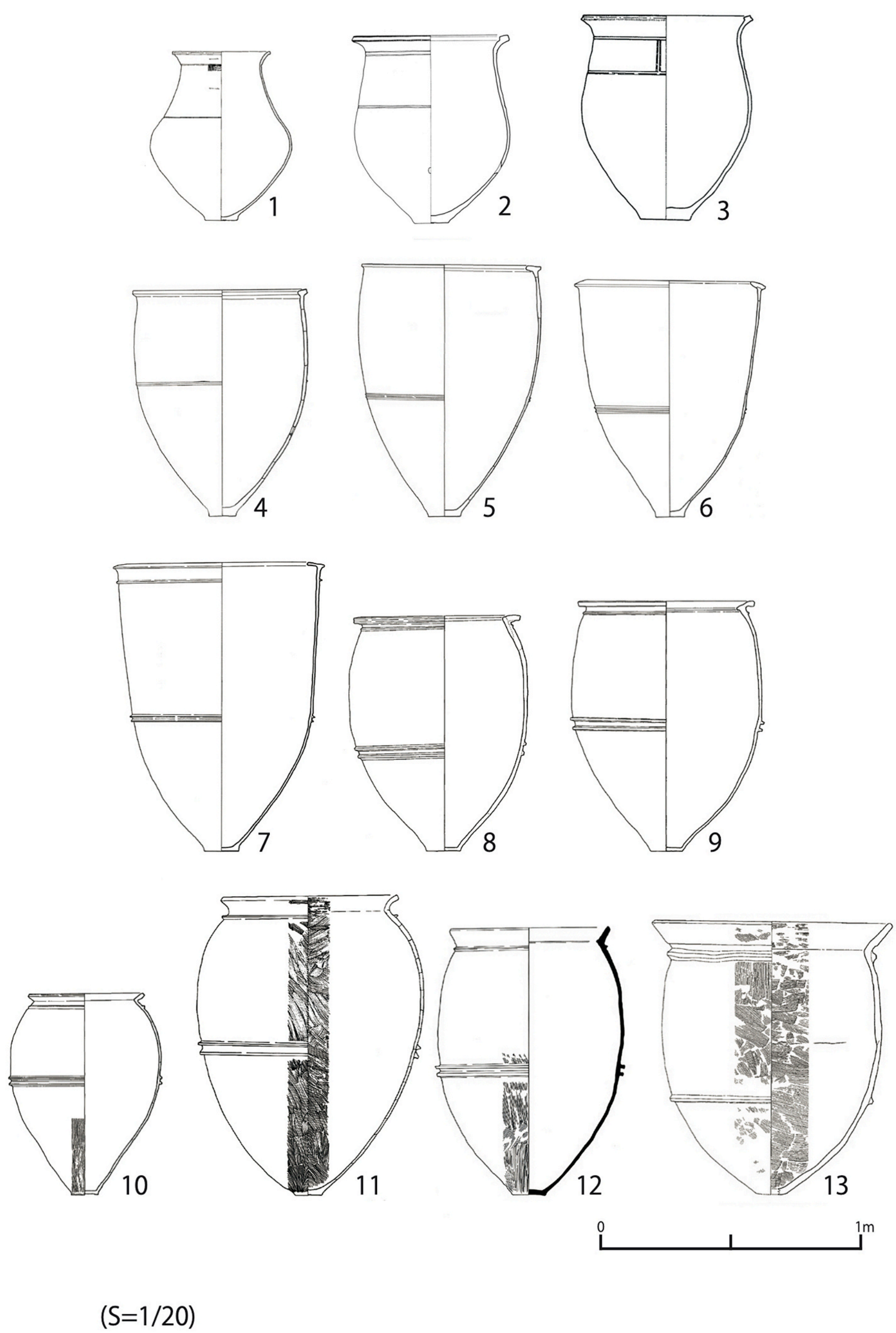


Fig. 2. Types of burial jars (*kamekan*) in the Yayoi period based on typology of Hashiguchi (2005). 1: KIa type at the Shimotsukiguma Tenjinmori site (adapted from Fukuoka City Board of Education 1996: 18), 2: KIb type at the Naka-Terao site (Onojo City Board of Education 1977: 41), 3: KIc type at the Kanenokuma site (Fukuoka City Board of Education, 1985: 22,), 4: KIIa type at the Shobaru site (Fukuoka Prefecture Board of Education 1979: 119), 5: KIIb type at the Hasako no Miya site (Fukuoka Prefecture Board of Education 1979: 99), 6: KIIc type at the Hasako no Miya site (Fukuoka Prefecture Board of Education 1979: 91), 7: KIIIa type at the Hara site (Fukuoka City Board of Education, 1979), 8: KIIIb type at the Dojoyama site (Fukuoka City Board of Education, 1978: 150), 9: KIIIc type at the Dojoyama site (Fukuoka City Board of Education, 1978: 136), 10: KIVa type at the Dojoyama site (Fukuoka City Board of Education, 1978: 157), 11: KIVb type at the Futatsukayama site (Saga Prefecture Board of Education 1979: 189), 12: KIVc type at the Yokokuma Kitsunezuka site (Ogori City Board of Education 1985: 177), 13: KV type at the Sasai site (Fukuoka City Board of Education, 2003: 64).

Higashiodamine or Kuma-Nishioda in the Mikuni Hills, Hiratsuka kawazoe site in the east Tsukushi Plain, and the Yoshinogari site in the central Tsukushi Plain, and that such sites composed relatively distinctive cultural units. Although the borders of the subregions can be defined based on the geographic features and the distribution of archaeological sites, we partially used modern administrative units for delimiting where the borders are not clear.

The jars have been routinely divided into the types shown in Fig. 2, with the typology determined mostly by the shapes of the rims (degree of inclination, whether single or double, etc.) and the bodies (degree of roundness, presence or absence of ridges near the rim, etc.). The chronological order of the types has been established through stratigraphic excavations and observed associations with Chinese artefacts. We adopt the following absolute chronology based on the AMS (Accelerator Mass Spectrometry) radiocarbon dating (Fujio and Imamura 2006), which is consistent with the calendar years estimated from associations with Chinese coins and mirrors (Morioka 1985): Early Yayoi (500–350 cal BC, inclusive of types KIa–KIc); Middle Yayoi, first half (350–200 cal BC, inclusive of KIIa–KIIc); Middle Yayoi, second half (200 cal BC-AD 30, inclusive of KIIIa–KIIIc); Late Yayoi (AD 30–250 CE, inclusive of KIVa–KIVc).

We obtained data on jar types and numbers from Fujio's (1989) dataset which was assembled from published site reports before 1988, and from Nakagawa et al. (2019) for supplemental data on burial jars in two areas (Fukuoka Plain and Mikuni Hills). We collected further data from site reports published after 1989 and confirmed that we had included all relevant items in the Comprehensive Database of Archaeological Site Reports in Japan (Nara National Institute of Cultural Properties, n.d.). The collected data are summarized in Table 1 (see also the supplementary materials for more details).

Restricting our analysis to data for the Middle Yayoi, we estimated the population pressure for each subregion as follows. First, we used the Fundamental Geospatial Data (DEM) 10 m mesh for the Itoshima plain (because the Geospatial Information Authority of Japan (GSI) does not provide 5 m mesh for this area) and 5 m mesh for other areas published by the GSI to calculate the arable land per subregion, assuming that areas less than five degrees in inclination are suitable for cultivation because modern Japanese agriculture usually uses areas less than eight degrees and people in more ancient ages with less effective technologies are anticipated to be able to use only areas less than five degrees (Kaneda et al. 2001). The present study did not depend on the site catchment because paddy fields could be found outside of the site catchment and it is difficult to define the site catchment in different environmental conditions. Second, we utilised assessments for the duration of each type of burial jar (i.e., terms when each type is supposed to have been used) (25 years each for KIIa–KIIb, 100 years for KIIc, 70 years for KIIIa, and 80 years for KIIIb and KIIIc) based on recent AMS datings (Fujio and Imamura 2006; Fujio 2009) and associations with Chinese coins and mirrors (Morioka 1985), and calculated the number of jar burials per year for each type. Next, we inferred the population pressure for each type in each subregion, using the quotient of the number of burials per year divided by the area of arable land as an index (see Table 1).

We also derived the number of skeletal remains with traumas for

Table 1
Summary of the data of the burial jars ('Kamekan') and injured individuals in the six areas (the Fukuoka Plain area, Mikuni Hills area, Itoshima Plain area, Sawara Plain area, central Tsukushi Plain area, and east Tsukushi Plain area) of the middle Yayoi period (350 cal BC to AD 30 CE). For detailed data of injured individuals, see Nakagawa et al. (2017); Nakagawa (2019, 2020), . (1): area (km^2), (2) number of burial jars, (3) density of burial jars (= (2)/(1)), (4) number of injured individuals, (5) number of burial jars per year (= (2)/duration of each type), (6) population pressure (= (5)/(1) × 10), (7) frequency of violence (= (4)/(2)) (compiled by the authors).

Area	Types	KIIa	KIIb	KIIc	KIIIa	KIIIb	KIIIc	Total	(1) Area (km^2)
	Duration of each type (years)	25	25	100	70	80	80		
Fukuoka Plain	(2)	54	284	220	416	484	95	1553	100.062
	(3)	0.540	2.838	2.199	4.157	4.837	0.949	15.520	
	(4)		1			1		2	
	(5)	2.160	11.360	2.200	5.943	6.050	1.188		
	(6)	0.216	1.135	0.220	0.594	0.605	0.119		
	(7)		0.004			0.002			
Mikuni Hill	(2)	465	611	1003	1001	559	543	4182	78.965
	(3)	5.889	7.738	12.702	12.677	7.079	6.876	52.960	
	(4)	1	4	9	15	7	2	38	
	(5)	18.600	24.440	10.030	14.300	6.988	6.788		
	(6)	2.355	3.095	1.270	1.811	0.885	0.860		
	(7)	0.002	0.007	0.009	0.015	0.013	0.004		
Itoshima Plain	(2)	81	49	40	64	53	17	304	83.886
	(3)	0.966	0.584	0.477	0.763	0.632	0.203	3.624	
	(4)							0	
	(5)	3.240	1.960	0.400	0.914	0.663	0.213		
	(6)	0.386	0.234	0.048	0.109	0.079	0.025		
	(7)								
Sawara Plain	(2)	38	122	122	298	187	138	905	58.064
	(3)	0.654	2.101	2.101	5.132	3.221	2.377	15.586	
	(4)				1		1	2	
	(5)	1.520	4.880	1.220	4.257	2.338	1.725		
	(6)	0.262	0.840	0.210	0.733	0.403	0.297		
	(7)				0.003		0.007		
East Tsukushi Plain	(2)	191	76	27	24	116	43	477	94.439
	(3)	2.022	0.805	0.286	0.254	1.228	0.455	5.051	
	(4)		1					1	
	(5)	7.640	3.040	0.270	0.343	1.450	0.538		
	(6)	0.809	0.322	0.029	0.036	0.154	0.057		
	(7)		0.013						
Central Tsukushi Plain	(2)	312	494	808	1011	230	110	2965	100.842
	(3)	3.094	4.899	8.013	10.026	2.281	1.091	29.402	
	(4)				4			4	
	(5)	12.480	19.760	8.080	14.443	2.875	1.375		
	(6)	1.238	1.960	0.801	1.432	0.285	0.136		
	(7)				0.004				

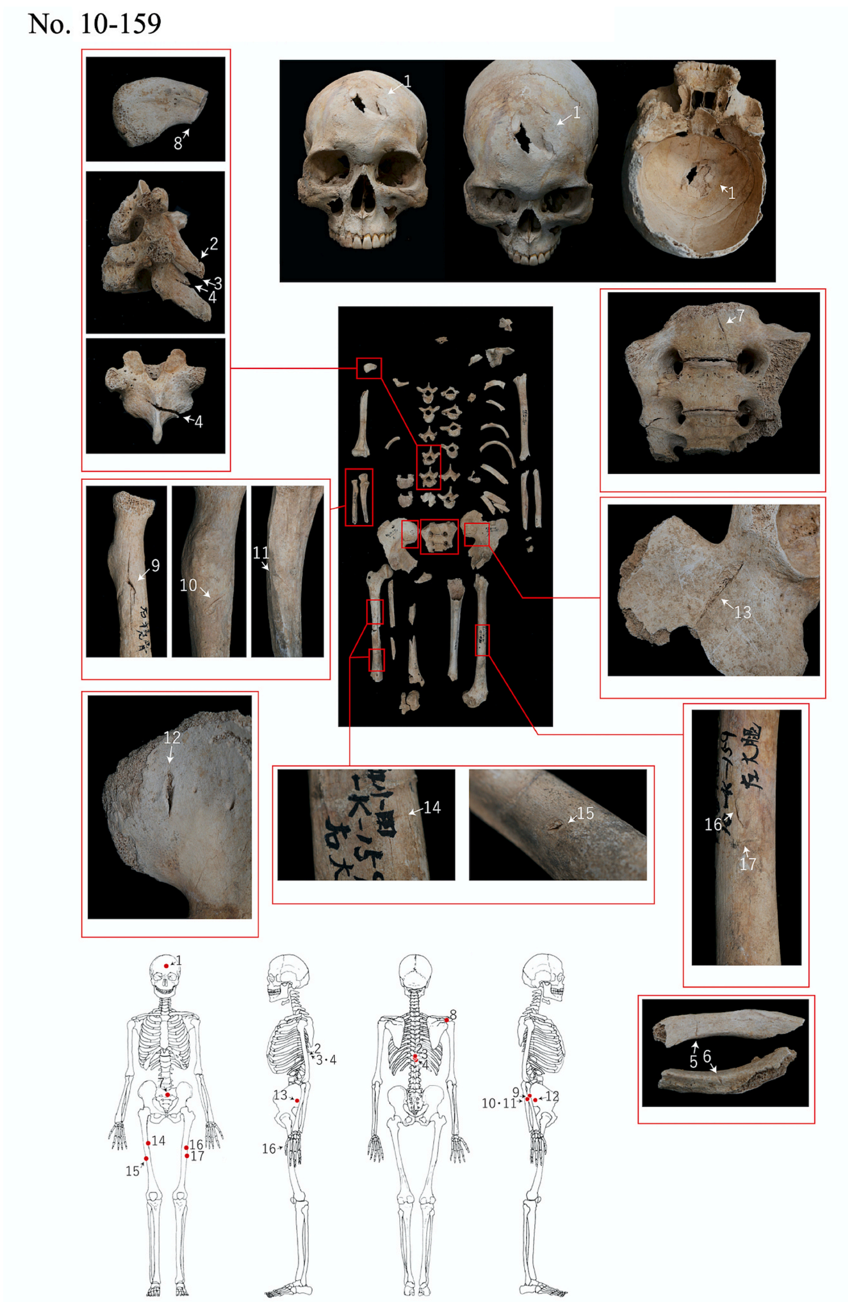
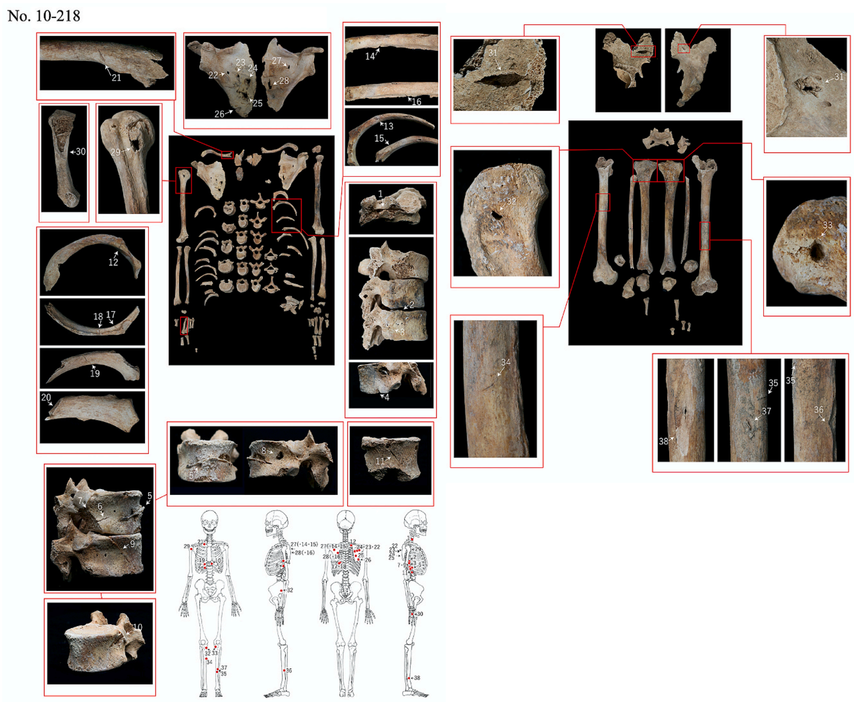


Fig. 3. Traumas found on the skeletal remains No. 10–159 and 10–218 of the Kuma-Nishioda site in the Mikuni Hill subregion as examples. Other cases directly examined are carefully described in Nakagawa (2020). No. 10–159 has seventeen traumas. No.3 and No. 4, and No. 10 and No. 11 were possibly inflicted at the same time, respectively. No. 10–218 has thirty-eight traumas and No. 7 and No. 9 were possibly inflicted at the same time. Because No.14-16 corresponds to No. 27–28 in the anatomical position, they were also possibly inflicted at the same time (photographs by TN).

1. Weapon wound, frontal bone, midline, slot fracture, perimortem
2. Weapon wound, 10th thoracic vertebra (cranial side of spinous process), midline, cut mark, perimortem
3. Weapon wound, 10th thoracic vertebra (caudal side of spinous process), midline, cut mark, perimortem
4. Weapon wound, 11th thoracic vertebra (lamina), from right to midline, cut mark, perimortem
5. Weapon wound, left rib (unknown number), cut mark, possibly perimortem
6. Weapon wound, right rib (unknown number), cut mark, possibly perimortem
7. Weapon wound, pelvic surface, cut mark, midline, possibly perimortem
8. Weapon wound, right acromion, cut mark, possibly perimortem
9. Weapon wound, right radius, proximal and dorsal, point insertion, possibly perimortem
10. Weapon wound, right radius, proximal and ulnar, cut mark, possibly perimortem
11. Weapon wound, right ulna, proximal and radial, cut mark, possibly perimortem
12. Weapon wound, right illium, dorsal, notched defect, perimortem
13. Weapon wound, right illium, dorsal, cut mark, perimortem
14. Weapon wound, shaft of right femur, proximal, cut mark, perimortem
15. Weapon wound, shaft of right femur, distal, notched defect, perimortem
16. Weapon wound, shaft of left femur, midshaft and lateral, cut mark (or notched defect?), perimortem
17. Weapon wound, shaft of left femur, midshaft and lateral, cut mark, perimortem



1. Weapon wound, sixth cervical vertebra, right side, cut mark, perimortem
2-3. Weapon wound, 8th thoracic vertebra (vertebral body), right side, cut mark, perimortem
4. Weapon wound, 7th thoracic vertebra (vertebral body), left side, cut mark, perimortem
5. Weapon wound, 9th thoracic vertebra (vertebral body), midline, embedded stone arrowhead, perimortem
6-7. Weapon wound, 9th thoracic vertebra (vertebral body), right side, cut mark, perimortem
8. Weapon wound, 9th thoracic vertebra (vertebral body), left side, point insertion, perimortem
9-10. Weapon wound, 10th thoracic vertebra (vertebral body), right side, cut mark, perimortem
11. Weapon wound, first lumbar vertebra (vertebral body), right side, cut mark, perimortem
12. Weapon wound, right second rib (around tubercle of rib), cranial and medial, cut mark, perimortem
13. Weapon wound, left third rib, cranial and medial, cut mark, perimortem
14. Weapon wound, left third rib, caudal, cut mark, perimortem
15. Weapon wound, left fourth rib, cranial and medial, cut mark, perimortem
16. Weapon wound, left fourth rib, caudal, cut mark, perimortem
17-18. Weapon wound, right 9th rib, caudal, cut mark, perimortem
19. Weapon wound, right 10th rib, ventral, cut mark, perimortem
20. Weapon wound, right 11th rib, ventral, cut mark, perimortem
21. Weapon wound, right collar bone, caudal and medial, cut mark, perimortem
22-25. Weapon wound, right shoulder blade, point insertion or notched defect, perimortem
26. Weapon wound, right shoulder blade, medial, cut mark, perimortem
27-28. Weapon wound, left shoulder blade, notched defect, perimortem
29. Weapon wound, right humerus, proximal, point insertion, possibly perimortem
30. Weapon wound, right metacarpal bones, proximal, cut mark, possibly perimortem
31. Weapon wound, left pelvic bone (ilium), medial, notched defect, perimortem (the trauma continued from ventral side to dorsal side)
32. Weapon wound, right tibia, proximal and medial, point insertion, possibly perimortem
33. Weapon wound, left tibia, proximal and medial, notched defect, possibly perimortem
34. Weapon wound, right femur, midshaft and medial, cut mark, possibly perimortem
35. Weapon wound, left femur, midshaft and lateral, cut mark, possibly perimortem
36. Weapon wound, left femur, midshaft and posterior, cut mark, possibly perimortem
37. Weapon wound, left femur, midshaft and anterior, notched defect, possibly perimortem
38. Weapon wound, left femur, midshaft and medial, cut mark (?), possibly perimortem (because the posterior edge of the trauma is more shape than the anterior edge, it was possible that he was stabbed from the back and the edge of the trauma was broken when someone withdrew the weapon)

Fig. 3. (*continued*).

burial jar types in our study area from an exhaustive set of skeletal data for the Yayoi period (Nakagawa et al., 2017; Nakagawa 2019) and calculated the ratio of injured persons to total jar burials for each type as an index of the frequency of violence. The numbers are summarized in Table 1. The total number of the skeletal remains with trauma is 47, and the number of the archaeological sites with skeletal remains in the northern Kyushu area of the middle Yayoi period is 79, and the number of the sites with the burial jars is 51 in the Itoshima Plain, 46 in the Sawara Plain, 72 in the Fukuoka Plain, 42 in the Mikuni Hills, 37 in the east Tsukushi Plain, and 50 in the central Tsukushi Plain (see also supplementary files). We have also examined all of the accessible skeletal remains with traumas. Detailed information is summarized in supplementary materials and some examples in Fig. 3 (see Nakagawa 2020 for more details of the other cases).

Although it is often argued that antemortem traumas (i.e., non-lethal injuries) are not due to inter-group violence, the present study includes such traumas if we cannot exclude the possibility that an antemortem trauma was made (1) for a defence against a blow or (2) by a weapon. We included the case where a weapon was located so close to the skeletal remains that the weapon is supposed to have been embedded in soft tissue rather than the skeleton and not to be a grave good.

Finally, we performed a logistic regression analysis taking population pressure as the explanatory variable and the frequency of violence for each area at each phase as the response variable. We used R v.3.6.1 for the analysis (R Core Team 2019).

3. Results

The data used for assessing population pressure and the frequency of violence by subregion and jar burial type are summarized in Table 1 and details of traumas in all suspicious cases are described in supplementary materials and Fig. 3. A half of traumas ($24/47 = 51.1\%$) are perimortem, consistent with the previous claim that a cluster of skeletal remains with traumas in the focal areas and period (Nakagawa et al., 2019; Nakagawa 2020) was likely to be attributable to inter-group violence rather than interpersonal.

The values of the population pressure and the frequency of violence are plotted in Fig. 4. The highest number of injured individuals, along

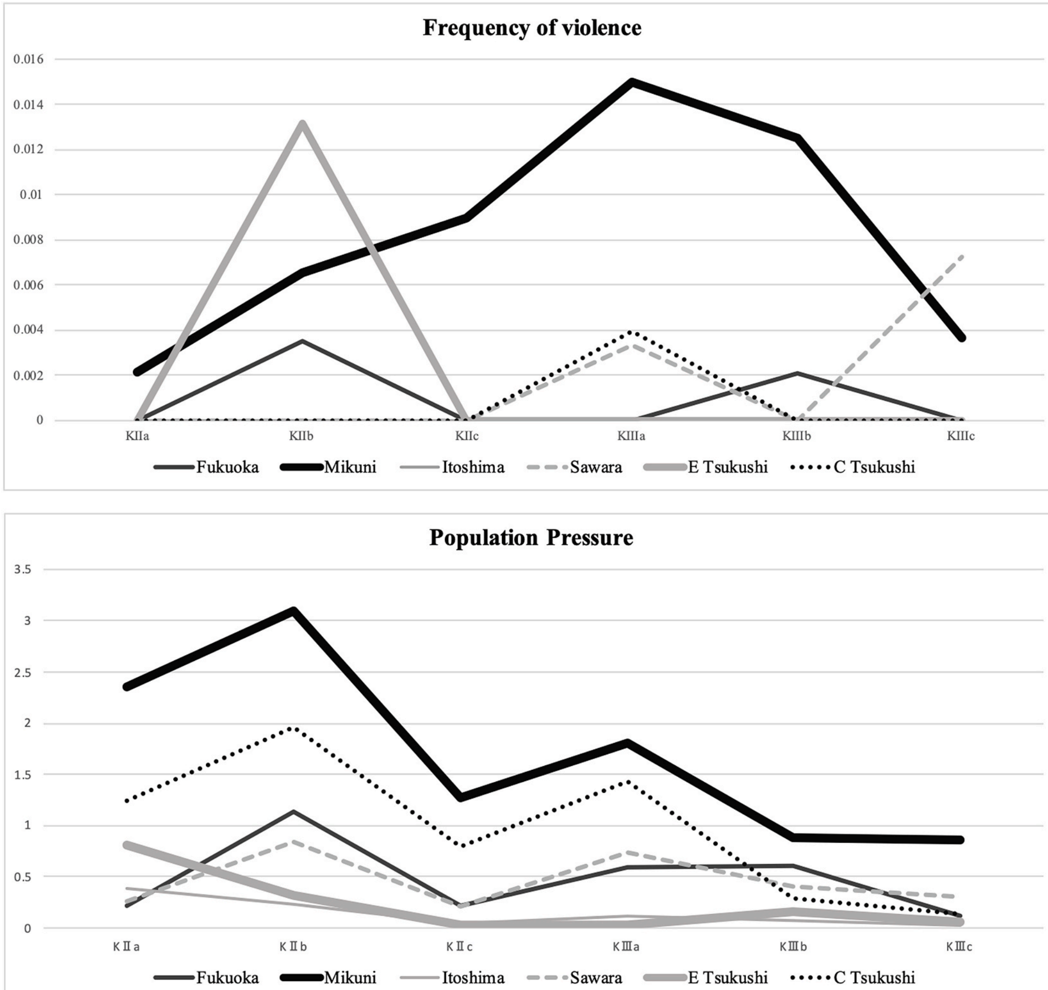


Fig. 4. Temporal changes of the frequency of violence and population pressure in the targeted six areas of the middle Yayoi period (drawn by the TN and HN).

with the highest frequency-of-violence value, was found for type KIIIa in the Mikuni Hills, followed by type KIIIb in the same subregion. Relatively high frequency-of-violence values were also found in the east Tsukushi Plain for type KIIb and the Sawara Plain for type KIIIc, although there was only a single injured individual in each case. The highest overall values for population pressure were also seen in the Mikuni Hills subregion, followed by those of the central Tsukushi Plain.

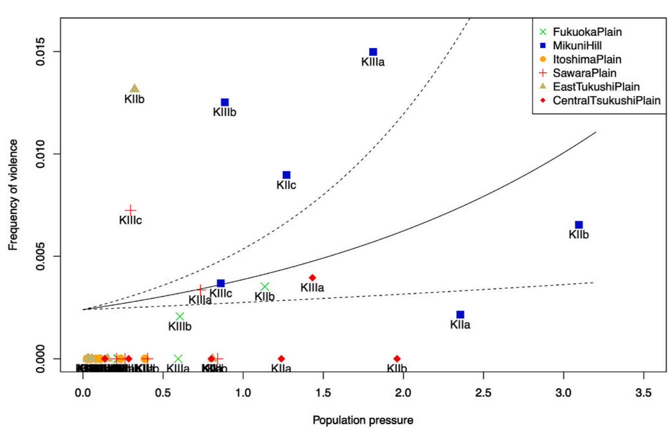


Fig. 5. Scatter plot of the relationship between population pressure and frequency of violence in each area of each period. Solid and dashed lines represent the model prediction and the 95% CI (drawn by TK).

In both areas, population pressure rose from the time of type KIIa at the start of the Middle Yayoi to a peak with type KIIb, followed by a decrease in the subsequent phase of type KIIc before increasing to a secondary peak at the time of type KIIIa.

Statistical analysis found a positive correlation (odds ratio: 1.616; 95% CI = 1.146, 2.243; $p = .005$; see also Fig. 5), suggesting that the population pressure affected the frequency of violence. Our data set includes data points with different time lengths (25, 70, 80, and 100 years), i.e., the levels of aggregation of events can be different depending on subphases. Possible biases include a different dependency on population pressure and a larger variation compared with a data set without the aggregation. We discussed two approaches to adjust these biases in section 3 of the supplementary information. We also considered several complex statistical models, including the generalized linear mixed model and zero-inflated Poisson model in section 4 of the supplementary material. In some of these analyses, the effects of population pressure were not statistically significant. A possible reason is that the high proportion of injured individuals and large population pressure are concentrated in the Mikuni hills subregion. Many of these models, however, suggest that the effects of population pressure affect the proportion of injured individuals, particularly by adjusting the above-mentioned biases.

4. Discussion

In the present study, we collected data for inferring population density and the frequency of violence in northern Kyushu during the

Middle Yayoi period in order to explore the causes of inter-group violence. Our results are consistent with the population pressure hypothesis of previous studies (Carneiro 1970; Gat 2008; Nolan 2003; Turchin and Korotayev 2006).

While other studies of this region for the Middle Yayoi period have considered population pressure as the main driver of inter-group violence (Nakahashi 2005; Hashiguchi 2007; Matsugi 2007; Ozawa 2008), and although we took the effect of population density on the frequency of inter-group violence as the sole focus of our analysis, we do not claim population pressure as the lone cause of inter-group violence. In fact, although population density and frequency of violence tended to correlate (Fig. 5), their peaks do not correspond (Fig. 4): the high levels of population pressure for the Mikuni Hills KIIa and KIIb phases (2.355 and 3.095) and for central Tsukushi Plain KIIb (1.960) were attended by low frequency-of-violence values (0.002, 0.007, and 0, respectively), whereas the opposite pattern was seen of relatively low population pressure scores for the east Tsukushi Plain KIIb (0.322) and Sawara Plain KIIIc phases (0.297) together with higher frequency-of-violence levels (0.013 and 0.007, respectively), even though the two latter values were products of single injured individuals as already mentioned. These discrepancies suggest that the cause of frequent violence has not been fully explained. The effects of other, including social, factors should be investigated in future studies.

It is possible that nutritional and environmental factors were responsible for the frequency of warfare. First, we have examined the age and sex specific mortality, which are summarized in Table 2. The results suggest that mortality of children and the sex ratio in the area where relatively higher frequency of warfare was found, such as the Mikuni Hills area, were not significantly different from other areas. Second, we investigated stress markers, such as enamel hypoplasia, on the skeletal remains at the sites where injured individuals were found. We found only two of 159 cases. Although the precise nature of stress markers including enamel hypoplasia is debated (e.g., Edinborough and Rando 2020), both results are not consistent with the possibility that nutritional and environmental factors were major driving forces in the frequency of warfare and consistent with the claim that the cases of enamel hypoplasia are relatively few in the northern Kyushu area of the middle Yayoi period compared to other areas (Koga 2003).

The frequency of violence might be influenced by the development of social hierarchy or political organization (e.g., Oka et al., 2018), presumed to be reflected in highly stratified burial systems in which certain members of the ruling elite, conventionally referred to as ‘kings’ in Japanese archaeology, have tombs with large quantities of prestige goods such as bronzes (weapons and mirrors), followed by a class of ‘warriors’ interred with lesser amounts of bronze or iron weapons, while ‘commoners’ were buried in communal cemeteries with few grave goods. Typical cases are found at the type KIc phase site of Yoshitake-Takagi in the Sawara Plain, and at the type KIIIc phase sites of Mikumo-Minamishoji in the Itoshima Plain and Sugu-Okamoto in the Fukuoka Plain (Kasuga City Board of Education 1994; Fukuoka city Museum of History, 1986). It is worth noting that the frequency-of-violence values for all three subregions are remarkably low throughout the Middle Yayoi, except for the final rise (to 0.007) seen in the type KIIIc phase for the Sawara Plain. On the other hand, such kingly tombs are not found in the Mikuni Hills and the central and east Tsukushi Plains, suggesting the lack of such a powerful elite. And while Middle Yayoi frequency-of-violence values are also low throughout for the central Tsukushi Plain, the Mikuni Hills and east Tsukushi Plain areas show the three highest individual sub-period levels (0.015 and 0.013 at Mikuni Hills, and 0.013 at east Tsukushi) for the entire northern Kyushu region. This suggests that powerful elites in more stratified societies may generally have a role in repressing the frequency of violence.

It has also been proposed that warfare was not the result, but a cause of social stratification as local leaders increased their power and status through military conflict (Hashiguchi 2007: 91–137). However, a recent study indicates that the social status of injured individuals was relatively low in the Mikuni Hills and Tsukushi Plains where there is greater evidence of violence (Nakagawa 2020). In a society where achievements by military leaders earned them social status, participation in conflicts would be positively evaluated and we might assume the injured would be more favourably treated at the time of burial. But the Mikuni Hills and Tsukushi Plains show neither any gain in status for the injured, nor signs of stratification comparable to areas such as the Fukuoka Plain where the ratio of injuries was much lower. We have thus identified no evidence so far to support a model in which violence promotes social stratification. Considering that the degrees and actual conditions of social stratification varied depending on subregion and sub-period, future research is needed to clarify in greater detail the relationship between frequency of violence and the degree of social stratification over time.

In addition, the development of weapons also might be relevant. It is often pointed out that the introduction of weapons and their evolution into more lethal forms were related to the frequency of violence in the Yayoi period (e.g., Matsugi 2007; Kobayashi and Sahara 1964). However, we do not think advancements in weaponry directly promoted inter-group violence in the northern Kyushu region. This is because sophisticated weapons concentrate in the Sawara, Fukuoka, and Itoshima Plains, where kingly tombs indicate greater social stratification but the frequency of violence was lower than less advanced areas such as the Mikuni Hills. It thus appears likely that the degree of weapon development was not a direct factor in the increase of violence.

We used the logistic regression to examine the effect of population pressure on the occurrence of violence. However, our statistical analysis has several limitations. First, although the unit of our analysis is subregion due to, for example, difficulties in calculating site-level population pressure, site could be more appropriate as the actual level of inter-group violence. Second, the present study did not control for statistical non-independence, i. e, historical relationships between subregions or sites. A number of methods have been proposed to control for it based on a certain measure representing the historical relationship. In Japanese archaeology, similarities in pottery have been routinely used as proxy. Because pottery used in this region was relatively homogeneous, a quantitative approach warrants further research. Third, there could be a time-lag between population pressure and the occurrence of violence as proposed in a previous study (Turchin and Korotayev 2006). However, because our data set includes different time intervals, it is unclear how to incorporate time-lag into statistical analyses. A theoretical investigation

Table 2
The age-at-death and sex of the skeletal remains investigated in the present study. See Nakagawa (2019) for more details.

Area	Adults			Children (<15)	Unknown	Total
	Females	Males	Unknown			
E Tsukushi	17	28	11	6	5	67
Mikuni	234	383	112	125		854
Fukuoka	85	106	24	46		261
Sawara	13	26	6	5		50
Itoshima	1	4		2		7
C Tsukushi	64	94	7	15		180
Total	414	641	160	199	5	1419

could be a future work to investigate how different levels of time aggregation can affect the patterns of time-lag in a data set.

In sum, while finding results consistent with the population pressure hypothesis, we do not reject other possible causes of inter-group violence. Levels of prehistoric inter-group violence were the products of multiple factors, involving specific ecological, social, and cultural backgrounds. Such complex conditions should be explored in each case.

5. Conclusion

The present study examined the population pressure hypothesis for the occurrence of prehistoric inter-group violence using data for the northern Kyushu region during the Middle Yayoi period. The statistical results of correlating population pressure, as inferred from burial jar data, with frequency-of-violence levels, indicated by the ratio of injured individuals, supported the hypothesis as higher frequencies of violence were found in areas with greater population pressure. Although other possible causes (e.g., social hierarchy, development of weapons and so on) might influence the frequency of violence, we argue that in many cases such influence was likely indirect.

Author contributions

TN and HN designed research and gathered the data. TN examined the skeletal remains with traumas, KT conducted statistical analysis, and YY calculated the areas investigated. NM and TM contributed archaeological aspects of research including dating chronology of the jar burials. TN, HN, and KT wrote the paper with discussion and contributions by YY, NM, and TM

Acknowledgements

This work was supported by the Japan Society for Promotion of Science (JSPS, No. 19J30001, No. 20K00019, No. 17K03226, No. 19H05738, No. 18K01064, No. 19H05733, No. 19H05734, No. 19H04520), and Nanzan University Pache Research Subsidy I-A-1 for the 2020 academic year. We are really grateful to anonymous reviewers for their highly helpful and important comments, which significantly improved our manuscript. We also thank the Saga Prefecture Board of Education for the useful information on the Yoshinogari site and the Chikushino city Board of Education for the permission of the use of photos from the Kuma-Nishioda site.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2021.105420.

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