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RESEARCH PAPER

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Regional patterns of pastoralist migrations under the push of reduced precipitation in imperial China

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Abstract

Aim: As a response of pastoralists to climate change, nomadic migration deeply shaped Chinese history during the imperial era. Existing research on climate-driven nomadic migration is conducted mainly on a national–continental scale. To advance the current work, we aim to resolve migratory movements at a provincial–regional scale using a large and long-term historical dataset as a first attempt. The spatio-temporal features of nomadic migration under climatic effects, specifically precipitation, are analysed in the theoretical context of behavioural ecology.

Location: China.

Time: Imperial era (220 BC–1910 AD).

Study subject: Nomadic pastoralist minorities in imperial China.

Methods: We frame the analysis using an ideal free distribution model. A total of 1,842 historical location records of pastoralist immigration are empirically examined. Precipitation anomalies and nomadic migration are statistically assessed with nonparametric and Poisson regression methods, and temporal interdependencies among provincial–regional migratory movements are explored with a vector autoregressive model.

Results: We divide imperial China into six regions according to statistical results and geographic factors. Overall, decreased precipitation and drought provoked pastoralist migrations in a north-to-south direction. Northern nomads, with an apparent preference for central China as a major destination, triggered the most conflicts with resident agriculturalists. Nomads originating from the Tibetan minority regions moved north-eastward into Qinghai Province as their main destination.

Main conclusions: Long-term regional patterns of pastoralist migration are closely associated with drought-induced ecological change in imperial China. Climate-driven dynamics assessed with long-term historical data facilitate the understanding of climate–ecology–society interactions in behavioural ecology and macroecology. Moreover, findings from imperial China may imply that cultural acceptance and communications could avoid conflicts between immigrants and original residents when facing mass migration, an issue of growing contemporary urgency in many parts of the world.

KEYWORDS
Chinese history, climate change, decreased rainfall, ideal free distribution, redistribution, spatio-temporal pattern

1 | INTRODUCTION

In studies of imperial China, the term 'nomads' refers to pastoralists who traditionally resided in the northern or western regions (Bai & Kung, 2011). Pastoralist relocation threatened territorial security and farming livelihoods in imperial China; thus, nomadic migrations were carefully recorded in historical documents (Ge, Wu, & Cao, 1997). Existing studies, only focused on China as a whole, find that these incursions are affected by climate and more closely associated with precipitation compared with temperature (Bai & Kung, 2011; Fang & Liu, 1992; Pei & Zhang, 2014; Pei, Zhang, & Lee, 2016; Zhang et al., 2015). To better understand nomadic migrations, a provincial–regional scale is adopted in the present work. In particular, downscaling spatial analysis is highlighted in a social–ecological investigation (Codding & Bird, 2015; Keith et al., 2012; Moritz, Hamilton, Chen, & Scholte, 2014).

Nomadic pastoralist societies depend on natural pasture conditions, and migration is central in their adaptive responses to climate change (Hinkel & Bisaro, 2015). In the semiarid zones of Asia, drought can reduce bioproductivity by 40%–90%, with serious effects on grazing stock (Huq et al., 2004). Therefore, the linkage between precipitation change and nomadic migration is constructed and justified. High population density is a key factor in migration (Codding & Jones, 2013). However, the traditional northern nomadic regions of imperial China typically had low population densities; thus, precipitation is considered a major factor of their migration (Büntgen & Di Cosmo, 2016; Fang & Liu, 1992; Hu, 1983; Pei & Zhang, 2014; Pei et al., 2016; Zhang et al., 2015). Because precipitation generally increases from north to south in China, the south suffers less from decreased rainfall than the north even under widespread drought (Zhang & Liang, 2010).

While analysis of nomadic migration may provide information on past social responses to ecological change, these events also deeply influence Chinese history and geopolitical conditions. From 221 BC onwards, nomadic tribes in the country's northern marginal areas launched periodic large-scale incursions southward into its agricultural heartland. These events, such as the Uprising of the Five Barbarians (300–350 AD), the Mongolian Conquest (1200–1270 AD) and the Manchurian Invasion (1644 AD), repeatedly interfered with agriculturalist regimes in China. These events demarcate the subsequent periods known as the Sixteen Kingdoms to the northern and southern dynasties (300–590 AD), Yuan dynasty (1270–1368 AD) and Qing dynasty (1644–1911 AD). These three periods are also called the *Yin* periods (Ledyard, 1983; Zhang et al., 2015) (details in Supporting Information Appendix Section 1.1).

Previous studies of nomadic migration in imperial China are conducted at the national–continental scale, causing difficulties in resolving provincial–regional variations in (a) the main directions; (b) preferred destinations; and (c) the interaction among nomadic migration streams across different provinces. In this work, our objective is to build on previous studies by examining pastoralist migration under climate change at the provincial–regional scale and generalize our findings. Therefore, our analysis is framed in terms of the ideal free distribution (IFD) within the generalizing framework of behavioural ecology (Fretwell & Lucas, 1969). Under the IFD, movement among habitats is assumed to be without cost ('free'). However, in our case, the relocation of pastoralists is not free and caused historically recorded regular conflicts with resident agriculturalists.

In summary, the present application charts the following paths through these assumptions and variations. The study targets knowledge and theory gaps. First, a long-term nexus between precipitation change and nomadic migration at the provincial scale (using current provincial divisions with slight changes, as shown in Supporting Information Figure S1) is analysed, particularly from the statistical perspective. Second, the IFD model is reviewed under the context of imperial China. The hypothesis assumes that pastoralists are induced by an IFD-like quest for improved pasturage through redistribution to high-precipitation regions. We find that this is broadly the case, with exceptions that merit attention.

2 | MATERIALS AND METHODS

2.1 | Theoretical model underpinning this study

The IFD model addresses questions of migration and population distribution over habitats differentiated by basic suitability. Visual representations of the model and details of its assumptions, the conceptual structure, and predictions are found in Sutherland (1996), Winterhalder, Kennett, Grote, and Bartruff (2010) and Codding and Bird (2015). Simplified IFD assumes that individuals move from one habitat to another that offers any advantages in suitability. In theory, the original model assesses suitability by using the Darwinian measure of reproductive fitness. In practice, biologists and anthropologists usually adopt proxy measures, such as availability of subsistence resources.

This basic IFD allows to modify its assumptions. If any assumption is changed, we will have a corresponding predictions. For instance, habitat suitability may rise or fall for density-independent reasons, such as changing climate. For low population densities, habitat suitability may increase rather than decrease with population growth, a positive density dependence known as the 'Allee effect'. Economies of scale in provision of subsistence infrastructure or related collaborative endeavours that enhance suitability are examples. In the despotic or ideal despotic distribution (IDD) variant individuals or perhaps groups of individuals are not affected equally by suitability changes. Several 'despots' are assumed to be able to defend shares better than others, with predictable effects on migration and population distribution (Bell & Winterhalder, 2014; Kennett, Winterhalder, Bartruff, & Erlandson, 2015; Prufer et al., 2017; Summers, 2005).

Nomadic pastoralists are societies with wide networks of information on environmental conditions (see Discussion); they are also pre-adapted to migratory mobility in the quest for quality pasturage for their herds. Consequently, we focus on IFD migrations provoked by climate change and its effects on geographic distributions of habitats experiencing depressed or elevated grassland productivity. In our analysis, Allee effects are not evident in historical materials and thus are not considered. Similarly, we exclude dynamics that surely arose from inequality and unequal consequences of climate change within our focal populations (nomadic pastoralists and residential agriculturalists).

2.2 | Source of response variable and covariates

Our data on nomadic migration are derived and compiled from the most recent and fine-grained archive (Ge et al., 1997). The data constitute 1,842 records, reflecting nomadic migrations at the provincial level during the period 220 BC–1910 AD (Supporting Information Appendix Section 1.1). These records are usually written by government officials or royal historians and can be coded by time period and location to generate a data series (Figure 1).

We adopt the nationwide precipitation data assembled by Pei and Zhang (2014) to match research scale, as shown in Figure 1. It is an anomaly record, not an assessment of absolute precipitation amounts (Supporting Information Appendix Section 1.2). In Supporting Information Appendix Section 1.2, we report an analysis indicating that compared with temperature, precipitation is a better predictor of nomadic migration. In this study, drought mainly indicates that precipitation reached a nadir (bottom phase) and periods in which precipitation consistently declined from a peak point.

Precipitation reconstruction in China at the provincial scale over the last 2,000 years is limited. However, we verify the conformity of the national precipitation record of Pei et al. (2014) with at least

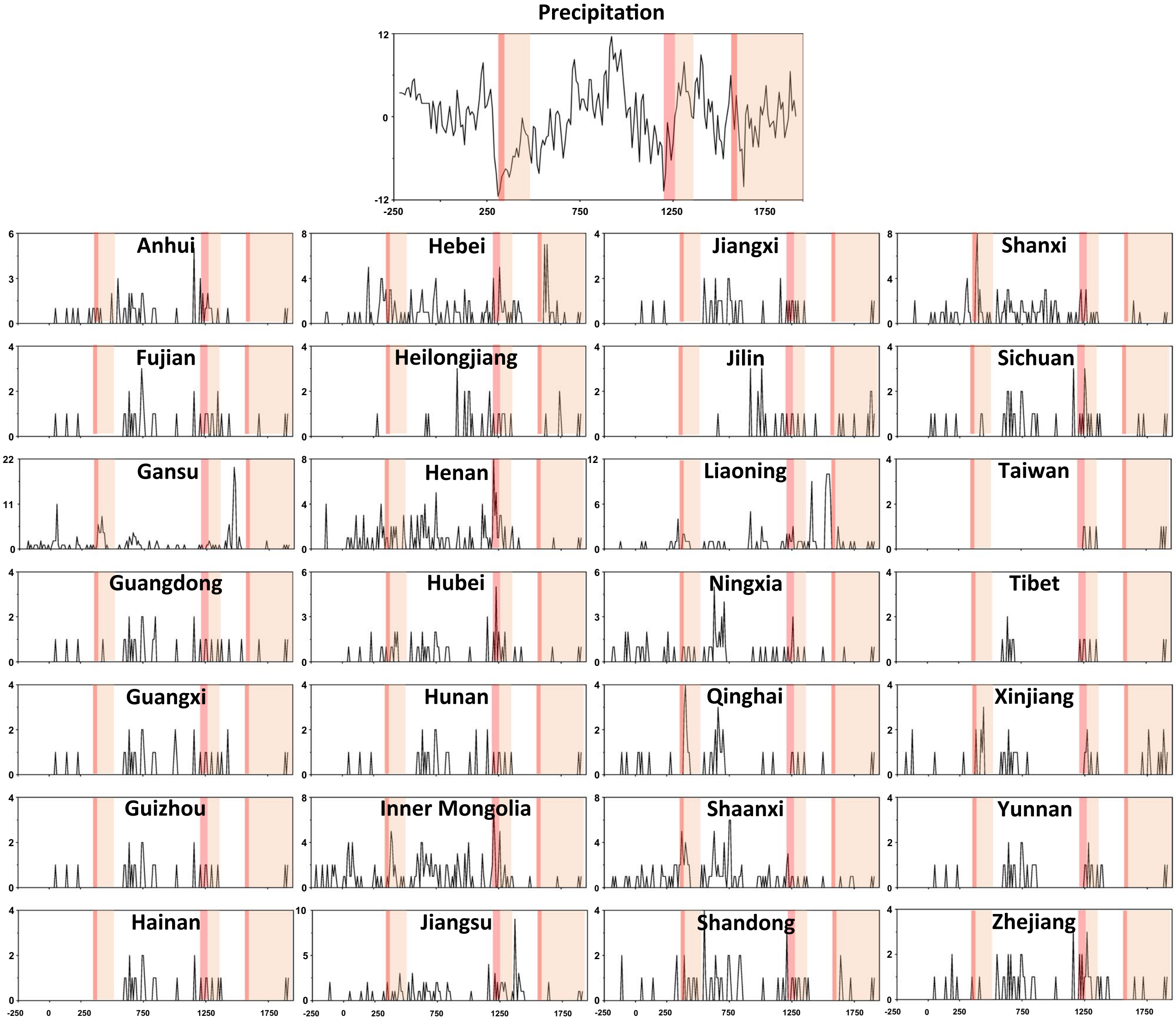

FIGURE 1 Precipitation data series from Pei and Zhang (2014) and migration records in each province. The precipitation *y* axis is in mm, based on anomaly reconstruction. The *y* axis unit of each province is the *number of events*. The *x* axis shows the calendar year. The dark red shading indicates periods of the Uprising of the Five Barbarians (300–350 AD), the Mongolian Conquest (1200–1270 AD) and the Manchurian Invasion (1644 AD). The light red shading indicates periods of the Sixteen Kingdoms to the northern and southern dynasties (300–590 AD), Yuan Dynasty (1270–1368 AD) and Qing Dynasty (1644–1911 AD). For additional details on the history of these periods, please refer to Supporting Information Appendix Section 1.1

1,500-year-long reconstructions that exist at the provincial scale, including Jilin Province by Zhang, Xia, Zhang, and Liu (2012), Xinjiang by Feng, Zhang, Zhu, Tang, and Gao (2005), Sichuan Province by Li et al. (2006), Gansu Province by Tan, Cai, and An (2010), Guizhou Province by Dykoski et al. (2005), Shaanxi Province by Cai et al. (2010) and Tibet by Conroy et al. (2017). All these provincial-scale records are reconstructed from natural proxies. The application of these natural proxies-based reconstruction could provide further tests on the document-based reconstruction of Pei and Zhang (2014) (see verification in Supporting Information Appendix Section 2.1).

Nomadic pastoralist movement into the agricultural regions of imperial China caused conflicts (Pei, Lee, Zhang, & Fei, 2018). The spatial and time-coded records of these battles (n = 2,737) are also derived from the latest and most fine-grained archive (Editorial-Committee-of-Chinese-Military-History, 2003; Zhang et al., 2015).

2.3 | Nonparametric analysis

Among different nonparametric methods, Kendall correlation analysis is selected as a common and robust method for measuring the strength of dependence between two variables (Huber & Ronchetti, 2009; Supporting Information Appendix Section 1.4. This analysis works especially well when normality and linearity cannot be assumed (Kang & Sen, 2008). Thus, the association between precipitation change and nomadic migration is first examined via Kendall correlation analysis.

2.4 | Poisson analysis

The migration records are recorded in the form of count data. Consequently, we adopt Poisson regression instead of ordinary least squares regression (Cameron & Trivedi, 1998) in a logarithm model format (Brouhns, Denuit, & Vermunt, 2002) to further analyse the association between precipitation change and nomadic migration (Supporting Information Appendix Section 1.5).

2.5 | Vector autoregressive model

To detect interactions among nomadic migrations across provinces, we implement vector autoregressive analysis (VAR; Supporting Information Appendix Section 1.6). This model determines whether migration into one province is associated with the subsequent appearance of nomadic minorities in adjacent provinces. VAR is an econometric model that captures the interdependencies among multiple time series and generalizes the univariate autoregressive model by allowing more than one evolving variable. Compared with structural models with simultaneous equations, VAR does not require as much knowledge about the forces influencing a variable. The only prior knowledge required is a list of variables that can be hypothesized to affect each other intertemporally. Akaike's information criterion determines the appropriate lag length (Akaike, 1974). VAR is conducted to analyse the linkages of nomadic migration among provinces.

For additional information on adopted variables and methods, please refer to Supporting Information Appendix Sections 1.1–1.3.

3 | RESULTS

Migration peaks usually occur during periods of reduced precipitation (Figure 1). Gansu, Hebei, Henan, Inner Mongolia, Jiangsu, Liaoning and Shaanxi Provinces are examples. The results of the statistical tests of this descriptive observation are shown in Tables 1 and 2 to test this descriptive observation.

In Table 1, significant and negative Kendall and Poisson precipitation coefficients indicate that migration into a region is associated with decreased rainfall; the reverse relationship also holds. Lack of significance indicates that precipitation has no effect on nomadic migration.

As an example of our VAR results, we refer to the result of Inner Mongolia in Table 2. The significant VAR results for Inner Mongolia relative to Heilongjiang and Shaanxi Provinces indicate that the appearance of nomadic minorities in Inner Mongolia follows their appearance in Heilongjiang and Shaanxi Provinces. In other words, the nomads in Inner Mongolia likely come from the Heilongjiang and Shaanxi Provinces. VAR results that are not statistically significant indicate that a province, such as the Heilongjiang and Hebei Provinces, is the original dwelling place or is continuously occupied by nomads. VAR provides insights into the geo-temporal sequences of migration-associated events and facilitates the reconstruction of migratory pathways.

Using the criteria presented in Table 3, we aggregate 28 provinces into six multi-province regions, as shown in Figure 2. Finally, the spatial pattern of nomadic migration among provinces is indicated by Figure 3, which also depicts latitudinal information on nomad–farmer conflicts.

Generally, the migration trend of pastoralist minorities experiencing drought stress over this 2,000-year period is mainly north to south (Figure 2). Nomadic minority migrations pushed by rainfall deficits consistently orient from drought-affected Regions A and B to Regions C and D, where precipitation levels are higher and therefore have more water resources. Moving further, migrants would reach Region F. Thus, migratory movements unrelated to precipitation usually occur in Region F, which experiences an even higher level of precipitation (Zhang & Liang, 2010).

3.1 | Region A

Region A covers the north-western and north-eastern regions of China. North-western China is extremely arid and dry, whereas north-eastern China is severely dry and cold, being surrounded by mountains to the west, north and east. These areas have never been major agricultural zones (Di Cosmo, 1994). Region A is the

TABLE 1 Results of Kendall correlation and Poisson analysis on precipitation and nomadic migration in each province

Region	Province name	Kendall correlation	Poisson analysis	
		Precipitation	Constant	Precipitation
A	Heilongjiang	0.008	−1.996***	0.060
	Inner Mongolia	−0.028	−0.335***	−0.024
	Jilin	−0.003	−2.008***	0.070
	Liaoning	−0.084	−0.502***	0.020
	Xinjiang	−0.044	−1.682***	−0.021
B	Sichuan	−0.024	−1.587***	−0.023
	Tibet	−0.047	−2.811***	−0.031
C	Gansu	−0.091	−0.197**	−0.080***
	Hebei	−0.058	−0.368***	−0.051***
	Shandong	−0.085	−1.345***	−0.063**
	Shanxi	−0.045	−0.619***	−0.049**
D	Anhui	−0.100*	−1.396***	−0.075**
	Henan	−0.166***	−0.568***	−0.098***
	Hubei	−0.097*	−1.420***	−0.066**
	Shaanxi	−0.147***	−0.558***	−0.079***
	Qinghai	−0.135**	−1.722***	−0.110***
E	Yunnan	0.096*	−1.991***	0.082*
F	Fujian	0.053	−1.799***	0.045
	Guangdong	0.008	−1.842***	0.016
	Guangxi	0.016	−1.842***	0.017
	Guizhou	0.006	−2.035***	0.012
	Hunan	−0.013	−1.967***	−0.012
	Jiangsu	−0.003	−0.881***	0.020
	Jiangxi	−0.003	−1.782***	0.002
	Ningxia	−0.071	−1.176***	0.001
	Zhejiang	0.005	−1.397***	−0.011

Note: Beijing and Tianjin are combined with Hebei Province. Shanghai forms part of Jiangsu Province. Hong Kong and Macau are included in Guangdong Province. Chongqing is merged into Sichuan Province. For more detailed information, please refer to the Supporting Information.
***Significant at the .01 level for all provinces; **Significant at the .05 level for all provinces; *Significant at the .1 level for all provinces.

original dwelling place of pastoralists; thus, their appearance or movement in this region is generally not associated with precipitation. Independent of high or low precipitation, pastoralists live and move within Region A. Therefore, results of the Kendall correlation and Poisson analyses are not statistically significant. Region A is considered the northern nomadic minority (NNM) region.

3.2 | Region B

The western part of Sichuan Province consists of expansive mountain ranges that form the easternmost part of the Qinghai–Tibet Plateau, which has no monsoon to cause extensive rainfall and a low temperature due to the high altitude. The Tibet and Sichuan Provinces are the homeland of the Tibetan people. The border region between these two provinces is Khams, and the region inside Tibet is Ü-Tsang. Tibet and Sichuan combine as Region B, which is considered the Tibetan minority (TM) region.

Regions A and B can be grouped into one nomadic pastoralist region. However, we distinguish them due to their ethnically distinct resident nomadic minorities. Regions A and B did not receive nomads from the adjacent Regions C and D. Only Shaanxi Province connected Regions A and B in accordance with our VAR results (Table 2), which are discussed in the next section.

3.3 | Region C

The statistical results draw attention to two features of this region: (a) according to the Poisson analysis, nomadic people opted

TABLE 2 VAR results on nomadic migration in each province

Region	Province name	VAR results	
		VAR significance	Connection with adjacent province(s)
A	Heilongjiang	.873	–
	Inner Mongolia	.040**	Heilongjiang, Shaanxi
	Jilin	.996	–
	Liaoning	.005***	–
	Xinjiang	.001***	–
B	Sichuan	.000***	Shaanxi
	Tibet	.000***	Qinghai, Sichuan
C	Gansu	.011**	–
	Hebei	1.000	–
	Shandong	.052	–
	Shanxi	.527	–
D	Anhui	.000***	Henan, Jiangsu
	Henan	.000***	Anhui
	Hubei	.000***	Henan, Jiangxi, Shaanxi
	Shaanxi	.000***	Inner Mongolia
	Qinghai	.000***	Tibet
E	Yunnan	.000***	Sichuan, Tibet
F	Fujian	.000***	Jiangxi
	Guangdong	.000***	Fujian, Jiangxi
	Guangxi	.000***	Yunnan
	Guizhou	.000***	Sichuan, Yunnan
	Hunan	.000***	Hubei, Jiangxi, Sichuan,
	Jiangsu	.000***	Anhui
	Jiangxi	.000***	Anhui, Fujian, Hubei
	Ningxia	.000***	Inner Mongolia
	Zhejiang	.000***	Anhui, Fujian, Jiangxi

Abbreviation: VAR = vector autoregressive analysis.
***Significant at the .01 level for all provinces **Significant at the .05 level for all provinces.

to move into Region C, which provided sources of water and grass and thus an escape from the reduced precipitation; and (b) similar to Regions A and B, Region C was nearly always invaded or occupied by nomadic minorities. These findings are similarly supported by the VAR results, which are not statistically significant. Just like the region of *Sixteen Prefectures* (Supporting Information Appendix Section 1.1) in the Five Dynasties, Yuan, and Ming dynasties, this region was more or less regularly invaded or occupied by nomads.

3.4 | Region D

Qinghai Province has always been considered a pastoral land (Pei et al., 2016; Zhang et al., 2015) unlike other provinces in this region. Qinghai Province is closely connected with Tibet and known as Amdo. Together with Khams and Ü-Tsang, Qinghai Province is one of the three major settlement areas for Tibetan people. Despite this fact, we group Qinghai Province into Region D for consistency with the statistical results in Tables 1 and 2. According to the Poisson and Kendall analyses, nomadic migration into this region increases only during reduced precipitation. In addition, significant VAR results in Table 2 indicate that Region D was not routinely or nearly always invaded or occupied by nomads, thus differentiating it from Region C.

3.5 | Region E

Yunnan Province has a generally mild climate, influenced by its south-facing mountain slopes and the Pacific and Indian Oceans. Although the growing period is long, the rugged terrain provides little arable

TABLE 3 Criteria of regional division of nomadic migration in imperial China

Region	Included provinces	Impacts of climate change indicated by: Kendall correlation analysis	Impacts of climate change indicated by: Poisson analysis	Nomadic immigration from adjacent region (A–F) as indicated by VAR
A	Heilongjiang, Inner Mongolia, Jilin, Liaoning and Xinjiang	Not statistically significant	Not statistically significant	Region C
B	Sichuan and Tibet	Not statistically significant	Not statistically significant	Region C
C	Gansu, Hebei, Shandong and Shanxi	Not statistically significant	Significant and negative	Nil
D	Anhui, Henan, Hubei, Shaanxi and Qinghai	Significant and negative	Significant and negative	Regions A and B
E	Yunnan	Significant and positive	Significant and positive	Region B
F	Fujian, Guangdong, Guangxi, Guizhou, Hunan, Jiangsu, Jiangxi, Ningxia and Zhejiang	Not statistically significant	Not statistically significant	Regions A, B, C, D and E

Abbreviation: VAR = vector autoregressive analysis.

FIGURE 2 Migratory regionalization of China's provinces. The yellow arrows show that nomadic migration associates statistically with dry climatic effects. The thin orange arrows show nomadic migration associated with reasons other than pressure due to reduced precipitation. The thick arrows in orange show nomadic migration during wet climatic periods, which we hypothesize to be based on the trade of commodities that depend on moisture or rainfall

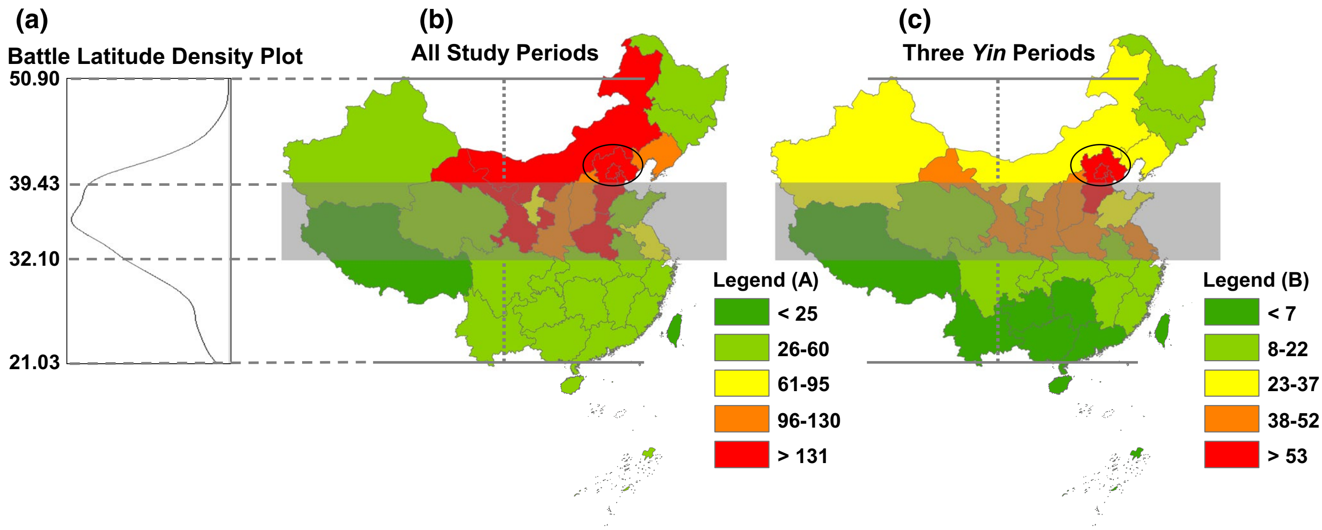

FIGURE 3 Migration events by province and density distribution of pastoralist–agriculturalist conflicts by latitude. (a) Battle latitude density plot; (b) distribution of nomadic migration events in each province during the entire imperial period; and (c) distribution of nomadic migration events in each province during three *Yin* periods, including the Sixteen Kingdoms of the northern and southern dynasties (300–590 AD), Yuan Dynasty (1270–1368 AD) and Qing Dynasty (1644–1911 AD). The grey region of the boxplot shows the latitudinal band representing the densest region of conflict between nomadic minorities and agriculturalists. The battle latitudes range from 21.03°–50.90° N; the interquartile boxplot range is 32.10°–39.43° N. The black ovals indicate the region of the *Sixteen Prefectures*

or pastoral lands. In Chinese history, Yunnan Province has been occupied by minorities whose economy relied on trade in commercial products (Yang, 2004). Region E is therefore non-agricultural, similar to Regions A and B. The significant and positive coefficient of precipitation via Poisson analysis indicates more nomadic migration into Yunnan Province under *increased* rainfall. Significant VAR results show that migration into Region E mainly originates from the Tibetan area (Tibet and Sichuan Provinces).

3.6 | Region F

Except for Ningxia Province, Region F is a traditional region for agriculturalists. A monsoon-influenced area characterized by warmth and humidity (Zhang et al., 2008), landforms in this region are relatively flatter than those of north and west China. Ningxia Province is the only province in north China grouped into Region F. This province is located in the *Hetao* Region on the upper reach of the Yellow River and has abundant water and grass. This environmental factor overall differentiates Region F from Regions A and B, despite similar results for the Kendall correlation and Poisson analyses in these three regions.

In Figure 3, we compare the provincial distribution of nomadic migration events with a latitudinal range of 2,737 battle events between pastoralists and agriculturalists. Figure 3a is the density plot of battle latitude; Figure 3b shows the distribution of nomadic migration events in each province during the entire imperial period; and Figure 3c presents the distribution of nomadic migration events in each province during the historically recognized *Yin* Periods, when nomads occupied the heartland of imperial China (Zhang et al., 2015). Figure 3b,c again demonstrate that Regions C and D are the primary destinations of northern nomadic minorities, which overlap with major regions of pastoralist–agriculturalist conflicts, as indicated by the grey region of the boxplot in Figure 3. Specifically, as a key part of the *Sixteen Prefectures*, Hebei Province (see map, Figure 2) shows the largest number of nomadic migration events, consistent with its historically known routine invasion and occupancy by nomads. Under conditions of reduced precipitation, nomadic minorities move to Regions C and D to escape from climatic stress, leading to the emergence of conflicts with farming-based societies.

4 | DISCUSSION

The above results reflect the long-term nexus between precipitation change and nomadic migration at the provincial scale. Six regions are divided in accordance with the provincial–regional results. The research reaches its targets to uncover spatio-temporal patterns of pastoralist migrations under the push of reduced precipitation in imperial China. We now turn to the theoretical, methodological and practical implications of our analysis for long-term migratory patterns under climate change.

4.1 | Climate-induced migration

Our empirical findings are based on precipitation anomaly data, historical records and quantitative analysis. The pastoralist minorities of China, migrating under the duress of reduced precipitation in search of better pastures, had to overcome the resistance of the residential agriculturalists who already occupied the most attractive destinations. The hostilities faced by migrants moving into southern regions certainly impeded their movement; conflicts over control presumably led to unequal access to resources (Jazwa, Kennett, & Winterhalder, 2016; Prufer et al., 2017). However, resistance by the agrarian population was also negatively affected by reduced precipitation. The shortage of rainfall for crop production diminished political defensive capacity (Pei et al., 2018). Thus, agricultural regions and political centres may have been the least able to resist nomadic incursions at the same point when nomads were motivated to migrate. Migration was not 'free' but apparently motivated by net advantage.

The NNM from Region A and the TM from Region B had different preferences for migratory destinations to escape decreased precipitation. As shown in Figure 2, the NNM from Region A preferred to migrate into Regions C and D (excluding Qinghai Province), which were the main agrarian areas for wheat and millet. However, the TM from Region B mainly sought relocation to Qinghai Province.

4.2 | Interactions among non-agricultural regions

Provincial–regional analysis demonstrates that Inner Mongolia in Region A and Sichuan Province in Region B experienced nomadic migration from Shaanxi Province (Table 2). This finding implies that the NNM in Region A and the TM in Region B had opportunities to interact through Shaanxi Province. In Chinese history, the NNM in Region A and the TM in Region B had frequent communication. Archaeological research also indicates that prehistoric peoples migrated into the TM region from the adjacent Shaanxi Loess Plateau in the early Holocene (Chen et al., 2015).

The interactions between the non-agricultural Regions B and E indicate another pattern that is not anticipated by our hypothesis. Yunnan Province in Region E is anomalous in that it experienced migration from the TM region when precipitation was higher than usual. We believe this exception occurs because Yunnan Province has been a major trade corridor within the TM region since the 8th century. This trading area is recorded as the *Ancient Road of Tea and Horses* (Yang, 2004) and *Tibetan–Yi Corridor* (Yao et al., 2017), and commercial activities are dominated by trade in tea and horses. The production of these commodities depends on favourable climate conditions (Yang, 2004).

Yunnan Province was the traditional region occupied by minorities, such as the Yi, rather than by agriculturalists. Peoples of the TM region believe themselves to be descendants of *Tibeto–Burmans*, who are likewise identified as the ancestors of several minorities in Yunnan Province (Wang et al., 2011). Thus, compared with surrounding agrarian regions, Yunnan Province was unique in its interactions with Region B due to trade and ethnic affinities.

Pastoralist interactions seem to lead to fewer conflicts compared with their contact with agriculturalists, as shown in Figure 3. In particular, the NNM's migration into agrarian regions led to more conflicts compared with the TM's migration into Yunnan. This finding may be explained from two aspects. First, minorities in Yunnan and pastoralists in Tibet believe they have cultural and religious bonds. However, in the past, agriculturalists had totally different culture and religions from pastoralists. Second, minorities in Yunnan and pastoralists in Tibet possibly had commercial connections that facilitated maintenance of peaceful relationships. But, at that time, commercial communications between farmers and pastoralists were rare. The Great Wall can be considered one of the examples that blocked communications.

Empirical studies on imperial China may also have implications that could help address migration-related issues of current society. For example, climate change is implicated in mass migration and social unrest in present-day Syria (Kelley, Mohtadi, Cane, Seager, & Kushnir, 2017). In this regard, cultural acceptance and communications could serve as the key to prevent conflicts between immigrants and original residents. In Syria, businesses have been mobilized to tackle the issue of mass migration, which could benefit both immigrants and original residents (Kelley, Mohtadi, Cane, Seager, & Kushnir, 2015).

4.3 | Ideal free and despotic models

IFD and IDD models have been adapted to diverse scales, including small islands (Winterhalder et al., 2010), a state such as California (Yaworsky & Codding, 2018), and occupation of the Pacific and its subregions (O'Connell & Allen, 2012). These examples cover hunter–gatherer, pastoralist, and agricultural production systems. IFD success in imperial China and in other cases show that the independent but concurrent adaptive decisions of individuals or small groups can result in orderly and seemingly coordinated processes at considerably larger scales. We hope to highlight the potential of the approach to organize and facilitate the testing of alternative variables, hypotheses, and more detailed scales of analysis (Moritz, Hamilton, Scholte, & Chen, 2014) compared with those presented here.

In the present analysis, we have violated some assumptions of the basic model in applying the IFD to the case of historical China. First, basic IFD assumes that relocation is unconstrained (Tremayne & Winterhalder, 2017; Winterhalder et al., 2010), but the migration of nomadic minorities in imperial China nearly always caused conflicts with agriculturalists who already occupied the regions to which they were attracted (Fang & Liu, 1992; Pei & Zhang, 2014; Pei et al., 2016). Second, the basic IFD focuses on density-dependent changes in habitat suitability due to population growth and decline. However, the model can easily accommodate density-independent changes. In our analysis, precipitation changes presumably affect habitat suitability on a long-term scale, either by diminishing the suitability of an occupied region or enhancing that of a region that might become occupied, or both. Although 'suitability' could include diverse factors beyond climate (Fretwell & Lucas, 1969; Jazwa et al., 2016; Moritz et al., 2014), pastoralists in imperial China were compelled by drought to move for survival. Finally, neither previous studies of nomadic migration in imperial China nor existing IFD applications so far have considered interactions among migration streams. Analysis using VAR methods expands options for linking ecological, social and historical elements of migration and resettlement, adding analytical capacity that better recognizes causal complexity.

Dynamic processes increase the complexity of a social–ecological system compared with those of IFD models in behavioural ecology. The effects of climate change on societies are clear in studies over long time periods and large spatial scales (Zhang et al., 2015). Similar to this study on pastoral migration in imperial China, such study coverage could enable the inclusion of climate change effects to examine the dynamic processes in social–ecological systems empirically. In this regard, much attention should be paid to combining climate-driven, scale, and dynamic perspectives together in the future.

5 | CONCLUSIONS

As a first attempt, this study empirically examines the association between precipitation change and nomadic migration at a provincial–regional scale throughout the entire imperial history of China. Long-term regional patterns of nomadic pastoralist movements are closely associated with climate fluctuations, especially drought. The findings are drawn mainly through statistical methods and quantitative evidence. Furthermore, we emphasize the potential of incorporating density-independent changes (climate change) in habitat suitability into IFD modelling and augment the analysis of migration pathways with VAR of interactions among temporal sequences of migratory events. Historical records on pastoralist migration in imperial China are used. Future work is necessary to explore further evidence on nomadic migrations and their causes and effects, which could be comparable to research on the effects of volcanic eruptions on social upheaval and conflict in ancient Egypt [see Manning et al. (2017)]. We look forward to an improved quality of data on nomadic migration and precipitation, which should be prioritized in the future.

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DATA ACCESSIBILITY

All data on nomadic migration are given in the Supporting Information.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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